ELECTRICAL SWITCHING IN A DIAKOPTICS BASED TRAM TRACTION SIMULATION TOOL AND ITS IMPLEMENTATION IN A SCADA ENVIRONMENT

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Master of Science

Electronic Systems and Engineering Management

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Thesis submitted to the Faculty of Engineering, Computer and Mathematical Sciences in total to fulfilment of the requirements for the degree of

Doctor of Philosophy

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-September 2020-

Abstract

Safe electrical switching is a pre-requisite for secure and reliable operation and maintenance in any electrical utility and traction network. Electrical system safety regulatory bodies and corporate electrical regulations provide protocols including 'no inadvertent system switching' and are very strict regarding system safety policies and practices. An electrical High Voltage system ensures coded, legal and safe operational practices to achieve the required system safety, meeting, for instance, 'on-time-every-time' operational requirements. Every electrical entity needs to report their safe work practices in proper system safety documentation and effective coded demonstrations, and ensure safety through training-refresher programs to be accredited by technical commission and regulators.

Electrical industries usually track real-time system parameters by remote monitoring, higher-level visual foot patrols, local-drone-online camera monitoring and preventative maintenance plans over the lifetime of the network system-switchgear maintenance regime. They undertake required maintenance and corrective progressive work with a systematically safe approach and in a documented manner. Safe electrical system isolation-restoration programs and effective workgroup safety is guaranteed by job specific risk assessment and job safety procedures.

This thesis proposes an automated isolation-restoration switching method to be applied in the traction industry with special emphasis on system safety switching practices. It elaborates on how diakoptics, a mathematical method of tearing, stands out as one of the best methods to simulate and analyze a large-scale tram traction network. Examples based on traction systems in Adelaide, South Australia are used in this thesis as case studies on safe and effective isolation-restoration switching practices. The diakoptics algorithm splits a complex traction network into smaller pieces which are solved separately, and gets the optimized simulation of the whole electrical network in real time. Solutions of electrical subsections are combined to produce the

correct representation of the entire network's de-energized or energized switchgear state at a given time.

The diakoptics - based 'model tram traction simulator' has been developed to cope with the system safety network switchgear orientation and system operational switching requirements. The model focuses on achieving electrical section-wise bottom to up topological power isolation, operational power restoration and entire network instantaneous electrical isolation-restoration in planned, unplanned and absolute emergency situations. A competent electrical operator, by working with the mimic of the traction simulator overhead and substation switchgear, can make an informed decision to progress. The on-duty electrical control officer updates the simulator to a system operational status. As the simulator switchgear connection-orientation mimics the real-time system switchgear operational state, the crew virtually makes a real-time patrol of the work location and the isolation limits, being able to plan safe maintenance work or prepare for a system upgrade.

The system switching demonstrations, formally approved switching templates, related catenary system and detailed substation switchgear mimics which the maintainer requires are also included in the simulation tool. An automated isolation-restoration switching program to undertake any planned, unplanned and emergency maintenance work has been extensively tested and verified. The simulator has been upgraded to accommodate any future extensions and bypasses of the network. 'One click' immediate remote de-energization of the entire traction system has been included in the tool. Asset management, system safety management options, and system remote switching have been addressed. The tool is also capable of accommodating for future legislative changes to remote locking & tagging requirements.

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Statement of originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree. I acknowledge that copyright of published works contained within this thesis resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

10/09/2020

Md Abul Hasnat Date

List of publications

Conference paper:

M. A. Hasnat, R. Zivanovic and S. F. Al-Sarawi, "Electrical traction system implementation in a SCADA environment," *2019 29th Australasian Universities Power Engineering Conference (AUPEC)*, Nadi, Fiji, 2019, pp. 1-6, doi: 10.1109/AUPEC48547.2019.211881.

Journal paper:

M. A. Hasnat, R. Zivanovic and S. F. Al-Sarawi, "Diakopics based tram traction tool implementation in a SCADA environment," (in press) *Australian Journal of Electrical and Electronics Engineering*, 2020

Statement of Authorship

Title of Paper	Electrical traction system implementation in a SCADA environment
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	M. A. Hasnat, R. Zivanovic and S. F. Al-Sarawi, "Electrical traction system implementation in a SCADA environment," *2019 29th Australasian Universities Power Engineering Conference (AUPEC)*, Nadi, Fiji, 2019, pp. 1-6, doi: 10.1109/AUPEC48547.2019.211881.

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Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	18/06/2020

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Contribution to the Paper	Contributing to the research and discussion to address the research question, write and edit of the submitted paper.		
Signature		Date	8/7/2020

Please cut and paste additional co-author panels here as required.

Statement of Authorship

Title of Paper	Diakopics based tram traction tool implementation in a SCADA environment	
Publication Status	☐ Published ☑ Submitted for Publication	☐ Accepted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Australian Journal of Electrical and Electronics Engineering	

Principal Author

Name of Principal Author (Candidate)	Md Abul Hasnat		
Contribution to the Paper	Principal and corresponding author Initial drafting of the journal paper and submit to the supervisors for their review. Accommodating feedbacks from the reviewers' prior to its final submission.		
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Acknowledgements

My sincere thanks goes to many people who played a role in this tram traction tool development process, study and thesis work.

I would like to convey my earnest gratitude and appreciation to the following

People and organizations:

- Dr Rastko Zivanovic, my supervisor, and Dr Said FK Al Sarawi, my co-supervisor, for being cooperative and directed to the point throughout the journey.

- Rail Infrastructure Management, Government of South Australia, for their very encouraging and logistic support of operational tram traction system including Electrical Control Centre systems.

- Finally, I would like to thank Schneider Electric for making the CitectSCADA development and runtime tools available for free. Also their excellent and freely available user manuals and tutorials made this thesis possible.

List of abbreviations

AC- Alternating Current

AMPRN - Adelaide Metropolitan Passenger Rail Network

API – Application Program Interface

ARS – Adelaide Railway Station

BS – Bypass Switch

CB - Circuit Breaker

DC – Direct Current

EA- Engineers Australia

ECC – Electrical Control Centre

ECO – Electrical Control Officer

EOL – End Of Line

ES- Earth Switch

EMU – Electric Multiple Unit

HSCB- High Speed Circuit Breaker

HV – High Voltage

IED – Intelligent Electronic Device

JSA – Job Safety Advice

KS – Knife Switch

kV – Kilo Volt

L&D – Learning and Development

LV – Low Voltage

MTM – Metro Train Melbourne

NCC – Network Control Centre

OCC – Operational Control Centre OHW – Overhead Wire

O&M- Operation and Maintenance

POI – Point of Isolation

PTA – Public Transport Authority

RTU – Remote Terminal Unit

RIM- Rail Infrastructure Management

SAPN – South Australian Power Network

SCADA – Supervisory Control and Data Acquisition

SI- Section Insulator

TFS – Transfer Switch

TT – Tap to Trolley

UFC – Underground Feeder Cable

Chapter 1

INTRODUCTION

1.1 Background

A tram traction network is usually equipped with several incoming substations, where incoming AC (Alternating Current) is controlled, protected and rectified to the outgoing OHW DC (Overhead Wire Direct Current) operated catenary systems. The catenary system consists of an 'up and down direction' locomotive travelling on an overhead contact wire, a mast-registration arrangement, air break knife switches and parallel UFC (Underground Feeder Cable) systems. In operational condition, the incoming supply is controlled and protected via an inline CB (Circuit Breaker)-Isolator-Earth switch busbar arrangement. The up & down OHW and UFC systems are partitioned into sections by the placement of a required number of intermittent section isolators, KS-TT (Knife Switch-Tap to Trolley) switches, to facilitate the effective system operation & maintenance of an independent electrical section. All outgoing operational feeder CBs, isolators, TTs and KSs to the OHW and parallel UFC systems are kept closed and locked in normal operation. All incoming-outgoing feeder CBs are operated, controlled, protected and monitored via an inline IED (Intelligent Electronic Devices) as well as via a remote SCADA (Supervisory Control and Data Acquisition) system. The related system earth switches, section bypass switches and incoming power supply busbar coupling switches are intentionally kept 'open & manually padlocked' to safely ensure the traction system's continuous operation, monitoring and maintenance.

Electrical system switching, i.e. isolation and restoration, is part of the work involved in any corrective or maintenance-related activity in an operational electrical network. To optimize a switching procedure, the preparation of a switching schedule is required for a safe time-critical approach in an electrical network and the completion of associated system work. Electrical system switching is usually carried out with both local and remote switching methods. In either case, a competent and authorized switching team execute real-time switching steps [1]. The work crew must formulate a collective approach and time & target oriented sequential switching steps to facilitate a specific operational-maintenance outcome. On the other hand, switching schedules are based on a procedurally driven system-controlled approach and maintenance-focused systematic work requirements [2]. When patrolling the worksite, writing sequential isolation-restoration steps, verifying the switching execution steps and approving the switching program for a given task are all critical procedures. If any new work has to be done or a new switching step has to be implemented within a given switching section, a revisit of the whole electrical switching plan and a re-verification process must be undertaken to secure the operational system and the safety of the maintenance crew [3].

There are several system modelling and visualization tools [4] available that explain electrical system fundamentals and parameter trending. Electrical system switching is strictly based on the related system safety policies and documented procedures [5]. In a traction system, the crew members have to finish their work within a time constrained window and in an optimized manner [6-7]. Otherwise, the situation across the network will be chaotic and that will subsequently affect passenger timetables. For instance, to optimize the efficiency of a traction network and accelerate system maintenance, Tokaido Shinkansen Japan introduced robot-supported system maintenance [8], Deutche Bahn is equipping with future-oriented digital tracks [9] and MTM (Metro Trains Melbourne) has commissioned remote overhead de-energization and remote earthing systems to reduce system switching window, enhance maintenance time and maximize workgroup efficiency on track [10].

In this research, we investigate a diakoptics-based tram traction simulation tool that mimics a real time system switchgear operation in normal, abnormal and emergency conditions and executes associated system switching sequential steps. A diakoptics technique has been implemented to visualize the model network and tear it. It is a mathematically-based concept for quickly splitting electrical sections into subsections, solving each subsection individually, and then recreating the network as a whole [11]. After extensive pilot runs (in MATLAB, JAVA) and progressive functional tests in CitectCADA, the diakoptical method [12] to model the tram traction system has been implemented.

AMPRN (Adelaide Metropolitan Passenger Rail Network) has been utilized as a pilot study of tramline traction tools and associated system switching practices. The AMPRN tramline system is composed of 42 km up & down OHW sections, which are being fed from eight adjacent substations. Those substations receive 11 kV (kilo Volt) of AC (Alternating Current) power from the SAPN distribution system [13]. The incoming AC voltage is rectified to 600 V DC and fed to the tram locomotives as shown in the tram route in the Fig. 1.

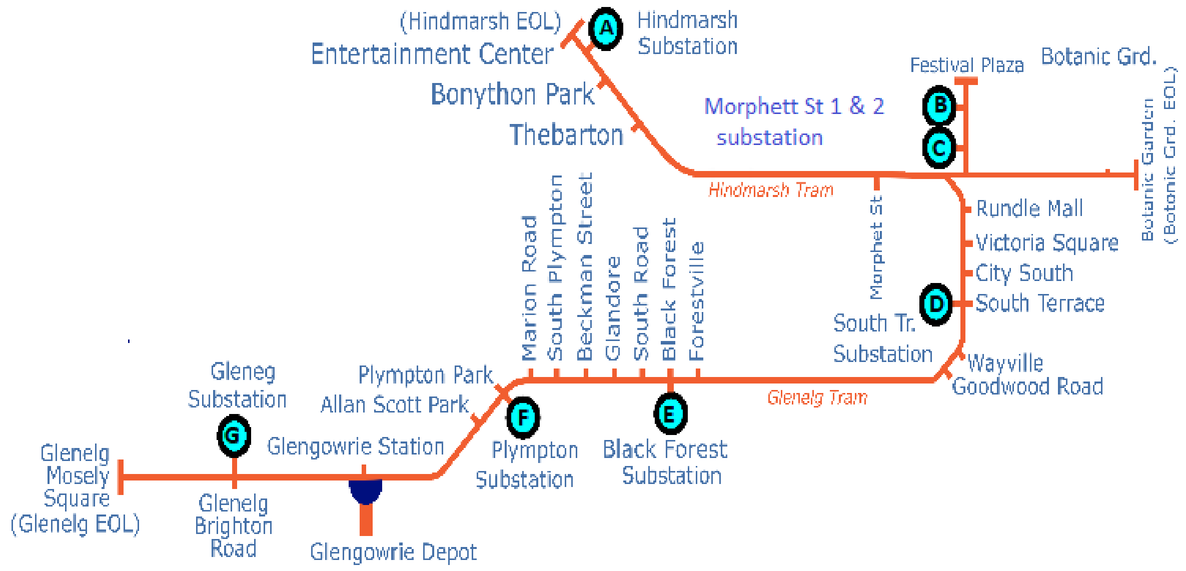


Fig. 1. Adelaide Metropolitan Passenger Rail Network (tramline route)

1.2 Motivation and scope of the thesis

SCADA consolidates and streamlines control for an increasing range of input variables (runtime voltage, current, system parameters trend, and trip log), which electrical controllers, field crew and maintenance engineers rely on, but not the overall switchgear state of the traction system. There are diverse custom developed solutions i.e. Siemens VICOS [14] and Citect simulator [15] commercially available but those are not fit for the purpose of generating automated system switching isolation-restoration programs. To be proposed is an offline and real-time system switching simulation tool for the traction system aimed towards accelerating work and meeting 'easy to operate' system switching requirements.

The main scope of work in this thesis is outlined as follows:

1. Checking compliance with the required legislative objectives, implementing the mimic of an AMPRN tramline traction system including associated overhead wire-substation switchgear interlocking arrangements.
2. Exploring the tool implementation platform requirements, formulate end-user expectations, and decide solutions.
3. Making a fit-for-the-purpose solution to develop a diakoptics based algorithm and implementing in a user friendly simulation tool.
4. Implementing all possible AMPRN practical switching cases, extensively testing the diakoptics-based algorithm in the traction power simulation tool.

5. Reviewing end user feedback, and comparing and validating the simulation outcome of the real time traction power switching programs.
6. Exploring any unwanted or emergency practical cases of electrical isolation-restoration situation and accommodating effectively into a diakoptics algorithm; integrating into the simulation tool.
7. Developing a benchmark safety framework for a real-time and regular switching generation tool for the electrical engineering O&M (Operation & Maintenance) crew.
8. Examining the scope of addition or extension or bypass of the electrical traction network and integrating related visuals in the tramline simulation tool.
9. Evaluating the commercial value of the model simulator.
10. Exploring upcoming legislative protocol incorporation and the readiness of the tool for the future.

By following above, this research meets an extensive switching system procedure upgrade contribution to the related safety protocols, establishes a niche for automated (chronological switchgear operational safety verified and ready to commence work) isolation restoration system switching at any given operational & maintenance system requirement activities.

1.3 Explanation of system switching

Traditionally, traction utilities follow a handwritten switching program 'writing-checking-approval' method to execute both planned and unplanned switching programs. For instance, in the Adelaide tramline traction system, a switcher writes required switching program steps to isolate and restore a section of OHW, substation switchgear or UFC. Then, the draft isolation-restoration schedule is forwarded to a checker who reviews and, if necessary, accommodates all missing or required orders. Once the program is thoroughly checked and reviewed, it is forwarded to a toolbox meeting for final authorization and approval. If the limits of isolation-restoration or the work location is changed, and if that sudden change needs to be accommodated within the switching program, then again a crew has to iterate the whole writing-review process prior to their toolbox authorization and approval.

This type of ongoing switching approach not only requires a huge effort and long work-hours, but also deserves a very costly and inefficient process. There are strict legislative requirements in the industry to exercise a safe isolation-restoration protocol as well as coded practices.

Electrical system safety for workgroups & switching proceedings is guaranteed by the use of a very strict switching schedule verification and safe work practices.

1.4 Existing simulation tool availability

There are many plug and play tools found in the market to understand, visualize and analyze the system switchgear performance [16], electro-magnetic compatibility [17], vehicle performance [18], electrical system, network simulation, and power system earthing-grounding-electromagnetic interference [19]. But very few tools are available to understand and optimize the safety of isolation-restoration switching practices and monitor their compliance with the required safe work requirements and regulations.

RIM (Rail Infrastructure Management) is looking for a complete system safe work practice model in one package, as their existing commercial simulator allows for system alarms and remote operations only. It gives to the operator a quick system health-check, overview and control over the remote operational CB system. But it doesn’t produce any automated switching program sequence for planned or unplanned emergency works. This functional switching plan requirement drives the required safe work practices in an automated safe sequential format. The system-switching approach must be based on real time switching models and subsequent network electrified & non-electrified state modelling, which is related to safe work practices, employees switching methodology and system safety demonstrations.

1.5 Simulation evaluation techniques

Through a thorough analysis of available software options and the current system switching understanding, a general user-friendly simulation tool is developed. Preferably, a pilot will be made in Java, functionally tested in MATLAB and technically implemented in citectSCADA, and finally launched to assess existing employees’ level of ease and satisfaction.

A system-viable option has been looked into to visualize the model network and tear the network to the least. After extensive research into system interlocking based network formation [20], optimum load flow technique [21], network tearing [22] and network component state-simulating, complete mimic representation including switching state display techniques is considered. After a successful pilot run, the diakoptical method [23] is selected to develop the general tram traction simulation tool.

1.6 Major Contributions

An outline and a target oriented task plan has been developed based on the current understanding of existing AMPRN electrical switching safe work practices and following numerous rigorous and progressive team discussions. The main points are below:

- The tram traction simulation tool is implemented in an employee friendly CitectSCADA environment. This demonstrates how implementing diakoptics algorithms improves the simulation and optimizes the electrical isolation-restoration process. It helps to understand the workgroup's work-limit, isolation limits, switching requirements and the generation of sequential safe switching chronological step statements.

- The simulation tool explains the switchgear operational status of the traction system to the user. It helps the user to understand the 'isolation-restoration' concept with easy-to-execute switching demonstrations. The user becomes familiar with the departmental template requirements and will be able to follow the requirements to meet the work limit and POIs for a given maintenance task.

- The ability of the tram traction simulation tool's diakoptics algorithm to accommodate future substation and overhead system extensions has been tested and verified.

- The simulation tool is equipped with a 'Deadman switch' philosophy. It is ensured that an employees with non-electrical backgrounds can still maintain the safety of the entire system in a 'single click' during an emergency in the case that the electrical operator is unavailable, such as for medical reasons.

- Several new legislative work approaches, including remote locking & tagging, remote trackside switch electrical switching, are equipped with diakoptics-based algorithms.

1.7 Thesis Organization

This thesis' chapters have been written for a target audience familiar with similar fields of electrical network operational switching, focusing on industry safe work methods, electrical work readiness and electrical network switchgear safe work isolation-restoration activities. The thesis completion chart is attached in the appendix A.

The thesis is organized into nine chapters following this introductory section:

- **Chapter 2:** We present a background of the traction simulation tool that includes all related system switchgears. We discuss our motivation to develop this simulation tool. We concentrate on the objectives of this research and how the CitectSCADA software has met those goals and requirements. The simulation algorithm concept has been discussed. How the load flow analysis and the voltage of every node is calculated in the simulation has been explained.

- **Chapter 3:** Implementation of diakoptics into the related torn network has been discussed. We develop subsections to present a general diakoptics simulation tool for substations, underground and overhead systems. The overall diakoptics process, including objective functions, are programmed in Cicode. Graphical components (substation and switchgear mimic display) of CitectSCADA have been discussed. An overall diakoptics representation of the AMPRN tram traction network has been presented in this chapter.

- **Chapter 4:** We discuss the tramline simulation tool in subsection networks and develop individual switching states of the system switchgear. Specifically, how the algorithm connects respective sub-sections together and searches for energized and de-energized switchgears within the limits of isolated work locations in sub-sections. For efficient and timely work management, automated switching sequential steps such as 'isolation and restoration process' generation has been developed.

- **Chapter 5:** We discuss any required extensions of the generic tram traction simulation tool for any future extension of the real network. We have added two more dual rectifier substations named 'Semaphore & Woodville' and associated 10km OHWs, UFCs, and overhead catenary systems. The complete diakoptics implementation, and associated switching state and isolation-restoration functionalities, has been verified and tested.

- **Chapter 6:** Overall System control and safety integration monitoring is the main discussion of this chapter. We discuss and integrate the 'Deadman Switch' philosophy into the tram traction simulation tool. This incorporates a hardware- software interface switch by which the operator or any authorized non-electrical attendant in the OCC can disable the total OHW feeding power from all substations by a single click or lever pull.

On its execution, the entire traction network OHW will be de-energized instantaneously by opening all outgoing feeder load CBs from all incoming substations. This is a warranted response when the regular operator faints, encounters a medical issue or is otherwise unable to operate in an extreme emergency, when all incoming power sources must be opened with minimal effort and expertise.

- **Chapter 7:** This section presents a report of the final operational and functional traction simulation tool after fine-tuning for end-user satisfaction. In addition, we have obtained an overall operational review from the ECC and maintenance personnel with recommendations to be included in the tool. The document handed over to the engineering team has been explained in this chapter.
- **Chapter 8:** We discuss the idea of commercialized general traction simulation tools which may be prototyped for mining, distributed generations, etc. The RIM is also actively looking to develop their offline train simulator and enhance their existing asset management systems and remote overhead sectioning systems. How the traction simulation tool can be generalized for object coding and tagging has been assessed.
- **Chapter 9:** We discuss how the simulation tool may provide opportunity for assisting EA's awareness programs regarding legislative changes in electrical system remote locking & tagging and trackside switching. How the simulator can play a satisfactory role in training employees on remote locking & tagging has been explained.
- **Chapter 10:** We discuss the general conclusions of this thesis, propose possible improvements and directions for any future work. The user-reference guide and API functions have been discussed.

Chapter 2

PROJECT BACKGROUND

2.1 Introduction

The traction simulation tool includes all relevant substation switchgear such as the incoming 11 kV CBs-disconnector-earth switch, step down (11/.45 kV) transformer 600 V DC CB-disconnector-earth switch, rectifier, transfer switch, overhead traction lines, up & down section arrangements, parallel UFCs and TT switch feeding arrangement. A section of OHW and UFC system of adjacent converter stations is shown in the Fig. 2.

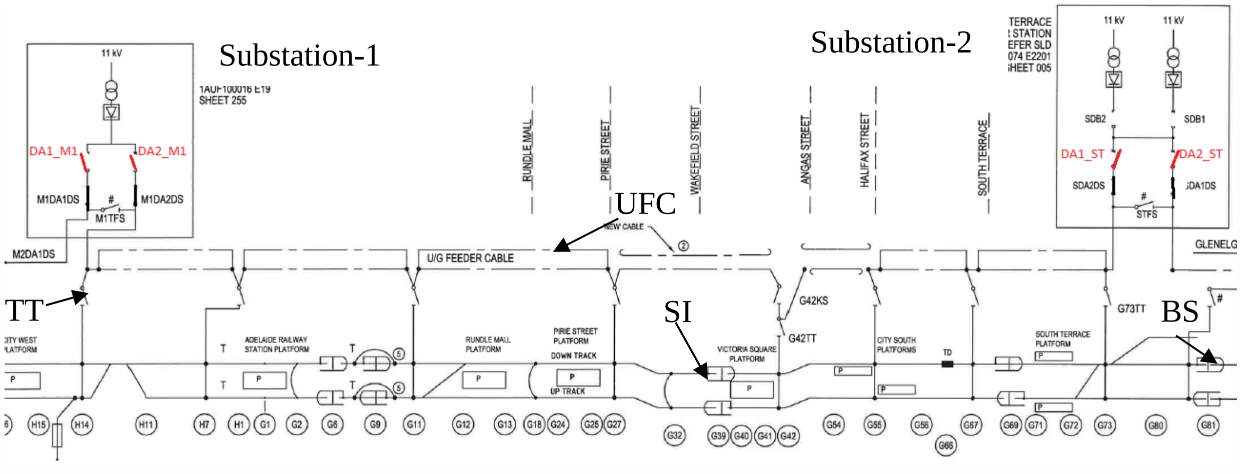


Fig. 2. A section of overhead wires and underground feeder stations

In the Fig. 2, the incoming of 11 kV dual supply is fed from the adjacent SAPN distribution substation and then stepped down to 452 V AC by a stepdown transformer. The twelve pulse rectifier system rectifies 452 AC to 600 V DC which is then fed to the related tram overhead section. A parallel UFC system shares the EMU load, balances the inter-substation traction load current and minimizes the section voltage drop.

The individual substation switchgear stays to its true representation of station operational interlocking arrangement of isolator-earth switch-CB-OPEN-CLOSE, TFS-CB-OPEN-CLOSE verification and continuous system operation.

2.2 Simulator concept

The electrical engineering team is looking at options for a real-time simulation tool for the Adelaide tram traction system. So that their maintenance & operational staff and electrical engineers are able to use the required simulation tool and determine when it is safe to work on a particular part or section of the traction system at any given time. The simulation tool ideally incorporates all relevant switchgear of the converter stations, overhead lines and underground systems [24] in graphics. The operator clicks on the related switchgear to understand the required remote or local opening or closing operation of the switchgear. The simulation tool recalculates the traction system, determining which, if any, circuit element or line section has been isolated. Isolated system switchgear elements displays as de-energized in ‘grey’ and the rest of the network elements still LIVE in ‘red. The simulation has been enhanced for advanced features like switchgear electro-mechanical interlocking and related chronological sequence of system load flow operations [25]. The simulation generates a sequential isolation and restoration steps, facilitates the required safe and controlled electrical section isolation, such as step by step traction switching activities.

RIM (Rail Infrastructure Maintenance) has to consider every corrective or maintenance work as unique in nature; even if they are exactly similar or repeated task. As of their legal requirements and coded safe work practices [26], they need to make a prior worksite visit, isolation plan, switching program preparation and obey the approval process with no exception. The simulator has to guide its user in a sequence so that the user can verify how many network switchgear need to be isolated or restored to secure a worksite prior to generate a switching program. The user has to make an informed decision prior to selecting a POI (Point of Isolation), probable earthing points and produce the required sequential isolation-restoration switching steps to secure the worksite.

The simulator may be utilized to train new employees or refresh on the correct switching procedure for mock isolation-restoration switching activities. The simulation allows verification for any switching procedure when needed. It has to be a readily available tool to enhance system safety of the maintenance personnel and switching verification for upcoming operation and maintenance activities.

The simulation tool has to be equipped with any upcoming future substation-overhead extension, bypass and modification. The tool addresses absolute emergency scenarios. For instance, if the on-duty electrical operator had a heart attack or is unavailable or unable to operate from the operational SCADA system or when there is a dewirement or natural disaster, a non-electrical operator operates the whole system to maintain the utmost safety for the public and maintenance personnel.

2.3 Software preference

We are focusing on an easy to operate and minimal training required simulation tool for the electrical controllers, employees and engineers. It has been decided to choose the

CitectSCADA package [27] as of the best system fit due to its modularity, graphical user interface and free online tutorials. The software is also flexible to model existing traction system switchgear diversity and requirements.

CitectSCADA is a software package which enables the user to control and monitor the entire traction system by exchanging data into the remote servers from the site IEDs via RTUs [28]. The simulation tool is built on the CitectSCADA platform. It is a free software available for download on the Schneider Electric [27] website. The free version can only be used in the offline mode. We will be using this software as a simulator platform and not interfacing it with any field RTUs as of the tool development requirements. It has been established that the on-duty electrical controller will update the simulator switchgear status prior to any switching step scenario run. As a result, the simulator tool switching state represents the real-time system operational mimic prior to any system switching isolation-restoration generation.

Citect provides a graphical user interface that shows the status of each element in the system. CitectSCADA is an obvious choice because of its excellent graphics builder, modularity and familiarity among electrical engineering and maintenance employees as of their existing tram traction operational SCADA server. It allows designing of the traction network in a precise manner. The most significant feature is object tagging in different switchgear components of the traction network. The programming package is called Cicode which allows users to structure the ever changing states of the electrical switching operations.

AMPRN tramline ECC (Electrical Control Centre) operators use CitectSCADA with 5000 Input-Output (IO) points, which suggests that this traction simulation tool features can be linked with the site switchgear IEDs in the online/offline version when needed. The simulation tool may be used in the SCADA mobile version (in tablet or iPad) when it is interfaced with the existing offline operational simulator server.

2.4 System Simulation Modelling

Modeling of the whole traction network in a functional mimic is a substantial and complex task. Fortunately, application of graph theory in electrical networks play an important and useful role in electrical network analysis [29]. An electrical network, either alternating or direct current, consists of system switchgear components, that are connected electrically. Electrical components are an accumulation of physical electrical devices and electrical subsystems to maintain the overall network energy flow [30].

A load flow program [31] is used in steady-state analysis of power systems. In load flow analysis information about admittances of all lines are stored in a Y-bus matrix. Using this system matrix and with knowledge of some fixed values in the system (e.g. voltages, active and reactive powers at some buses), the voltage of every node (simulation area) can be calculated [32]. An iterative strategy is required to solve a load flow problem. Values of the system switching states can be obtained using the load flow method.

The system current node matrix, voltage node matrix, bus admittance matrix are based on Kirchoff's current law. We can take the example of IEEE 4 bus system and derive the general equation for n-bus network $[I_{bus}] = [Y_{bus}]*[V]$ based on Kirchoff's current law. Where [I] is the n bus current node matrix, [Y] is the n bus admittance matrix and [V] is the n bus voltage matrix. The details of electrical network mathematical analysis and related system load flow mathematical calculations are out of scope of this thesis.

In this simulator development algorithm, a similar computation process is taken into consideration. It uses the node voltage to establish the network switching state. Each switching system model consists of two kinds of matrices: connection matrix and state matrix. These matrix-based methods work on a binary principal and matrices only have two kinds of elements zero and one. Zero in the connection matrix means two parts are not physically connected, which means either the switch or the circuit breaker between the two areas are open. While, one means the switch or CB is closed. The state matrix (initial matrix) is a binary vector which shows the active state of each line. The length of the vector is equal to the dimension of the connection vector. An internal matrix called the solution matrix is obtained by multiplying the connection matrix and state matrix. Unfortunately, the MATLAB implementation demonstrates this procedure requires a substantial numbers of iterations.

The switchgear is operated in the simulation by the user. Opening or closing a switch states to change the connection matrix of the changing part and recalculates the system. The new connection matrix is multiplied with the last state matrix and after several iteration, the whole system is reached its true state. This is shown in a case-study that includes operator input (open

& close i.e. toggling switches) and then determines the values in the connections matrix as of the algorithm shown in appendix B.

2.5 Simulation challenges

Implementation of the tram traction network switchgear system interlocking, circuitry, parallel UFC, associated documented requirements including system safe work practices into the simulator, involve a huge laborious work. We have met with the network engineers in each and every development stage, undertaken progressive bidirectional discussions on:

- Step by step work processes such as system patrol, planning, and sequential isolation-restoration considerations,
- Legal expectation for the overall simulation outcome,
- System load flow and chronological work steps,
- Ease of operation and end-user satisfaction,
- Clear messaging and fit-for-the-purpose electrical switching steps execution.
- Overall system safety check as of the ECC operational procedure (liaison between the ECO and the OCC operators).
- Simulator stepwise safety compliance protocols (interlocking and sequential operation), expectations, challenges, standards, risks & procedures.
- Continuous feedback and operational functional verification of the simulator.

2.6 Summary

We have discussed required simulator development background information and requirements of the user-friendly traction simulator tool in this chapter. As the electrical engineering unit staff, controllers are familiar with the existing operational CitectSCADA, it has been unanimously decided to be the simulator development platform to proceed. The basic traction system configuration, motivation to develop a user-friendly traction simulation tool, electrical engineering expectation in the simulation tool, procedural requirements, software development requirements and simulation algorithm concept have been outlined.

Chapter 3

DIAKOPTICS IMPLEMENTATION

3.1 Introduction:

Adelaide tram traction network is equipped with converter stations, overhead systems and UFC systems. The simulator platform must mimic and simulate the open-close state of all traction CBs, isolators, earth switches, TT switches, bypass switches and related substation switchgears.

The optimization of the electrical system is a common issue and covered by a wide range of literatures due to the nonlinear and multi objective nature of the systems. A suitable integrated optimization method and algorithms for system problems [30] have been thoroughly analyzed. Computational method for large sparse system analysis [31] such as large scale load flow and optimal power flow issues [32] have been looked at. Any electrical network consist with isolators, earth switches and CBs can be considered as a tree or graph where nodes represent the state of power line and lines present the electrical system switches (either energized or de-energized state). To optimize the internode communication and determine the switching state of the traction system, graph theory based Depth First Search [33] and Breadth First Search [34] algorithms have been investigated. Due to the traction substation switchgear orientation, switchgear interlocking and duel feeder energy flow, OHW and UFS switchgear energy flow layered requirements, the overall network switching state determination outcome has become very slow. Hence we have to focus on tearing the traction network, the network formation [35] and network load flow studies [36-37] demonstration that dramatically simplified and accelerated required simulation arithmetic computations.

We couldn’t meet our expectations after a considerable research on a switching staged functionality, pilot switching state implementation in MATLAB, java, visual basic, and C++. After formulating the demo algorithm, the size of the matrix grew exponentially for the simulation area. Very poor performance has been observed in the simulation, even though the algorithm did not iterate over the whole connection matrix. It has been realized that we have to rely on a tearing and recombining network formation technique [38]. Therefore, we introduced the tearing and recombining diakoptics technique that has played a very effective role in similar tasks. The process has facilitated the whole network tear to the least, solve independently and reconfigure the solved network states as a whole [39].

Diakoptics is a technique accredited to Gabriel Kron, developed in the 1950's. Kron formulated a piecewise method for solving electrical power flow problems and its analysis. The method allows the complicated dc electrical railway network problems to be illustrated in a detailed and orderly manner [22]. The idea is to split a large network into smaller pieces in which sequentially maintains its identity and then in smaller pieces simulations are done individually and recombined to the true representation of the whole network [22-23]. In general, diakoptics was developed to be used to break a system with linear and non-linear relationships into two systems [40]. This allows the sub-systems to be solved separately and then combined to form a complete solution for the simulation. As a result of this, the technique decreases the amount of computation needed to solve the systems. This is one of the key aspects for using the diakoptics method for the tram traction simulation tool development algorithm as shown in the Fig. 3.

The diakoptics method has been used to solve the traction network system, is quite straight forward as it basically tears the network into small subsystems, solve them individually and then putting the subsystems together to recreate the solution of the entire system switching representation. The algorithm not only simplifies the network but also accelerates the related arithmetic computations.

In AMPRN, there are two types of substations: single and double rectifier substations as shown in the Fig. 4 and Fig. 5. Each substation is interconnected via a double UFC connection to maintain the system voltage and share electrical loads along with the OHW sectioned systems.

Each substation is separated into subsystems that have similar switch configuration and UFC to OHW arrangement that allows for repetition in CitectSCADA. The subsystem types are listed in Fig. 4 & Fig. 5 with labelling 'subsystem 1' to 'subsystem 5'. These subsystems are represented by a n×n matrix, called the "connections matrix", where n is the number of nodes in the subsystem, with each node representing a line and nodes can be separated by a switch. An 'energisation matrix' is also involved with the diakoptics method, which is a n×1 matrix. This matrix represents what nodes are in CLOSE and which ones are in OPEN state, where a '1' represents a CLOSE node and '0' represents an OPEN node. These two matrices are multiplied together, resulting in a number of arithmetic procedures in the order of n^2. Hence a smaller matrix dramatically reduces the amount of computations required to generate a solution. The multiplication process is repeated until the energization matrix values remain in a steady state.

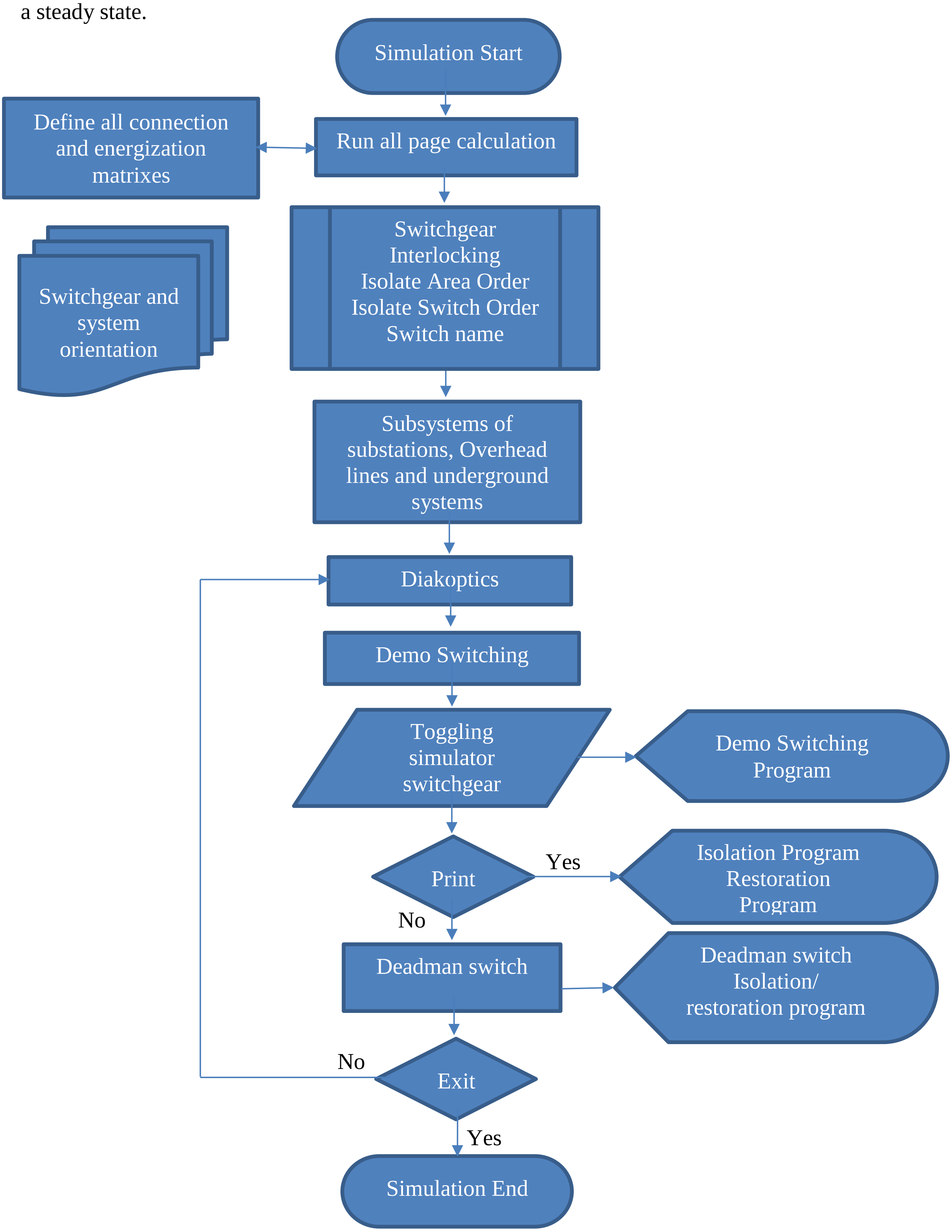


Fig. 3. Simulator algorithm flowchart

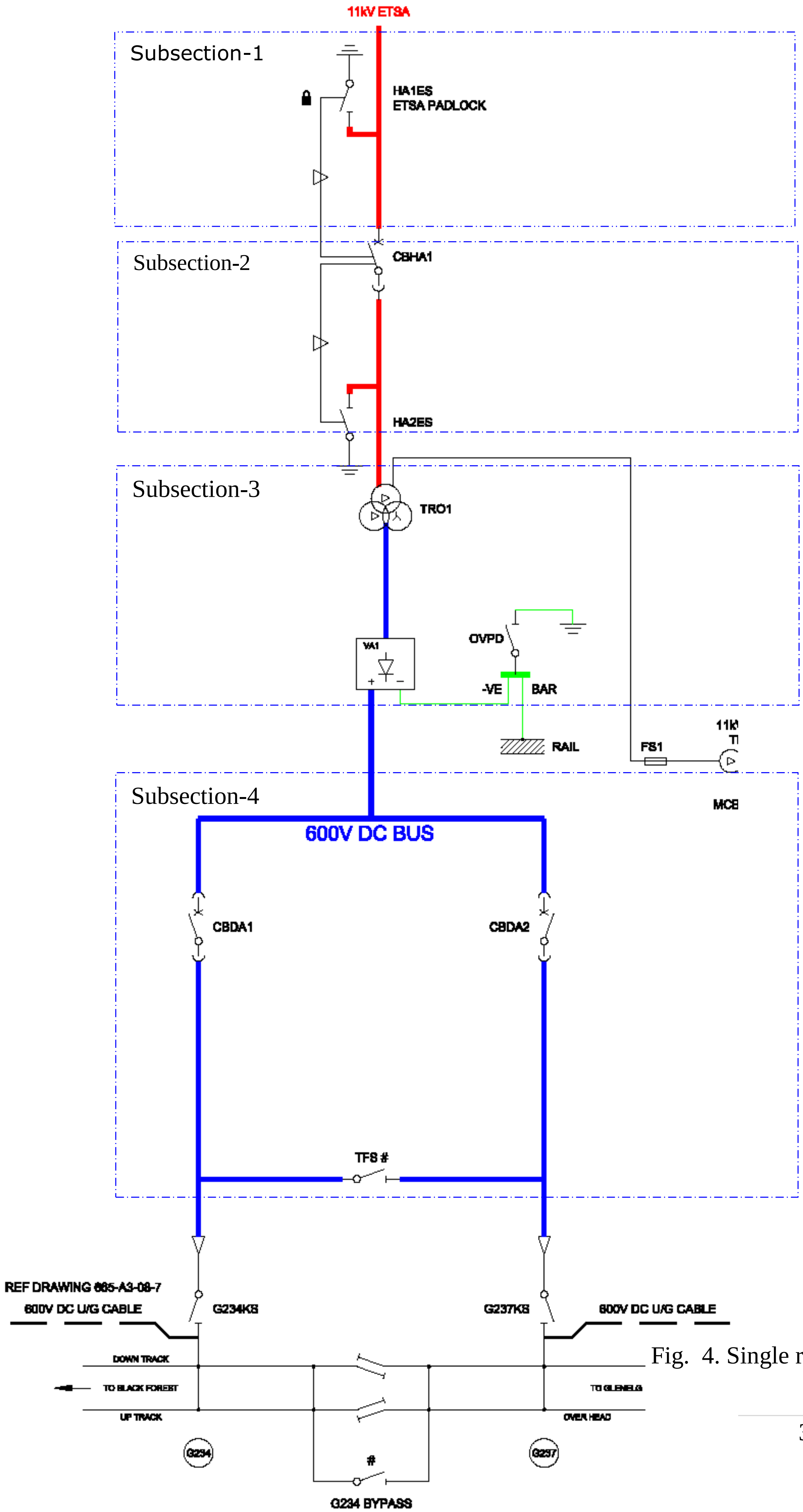


Fig. 4. Single rectifier substation

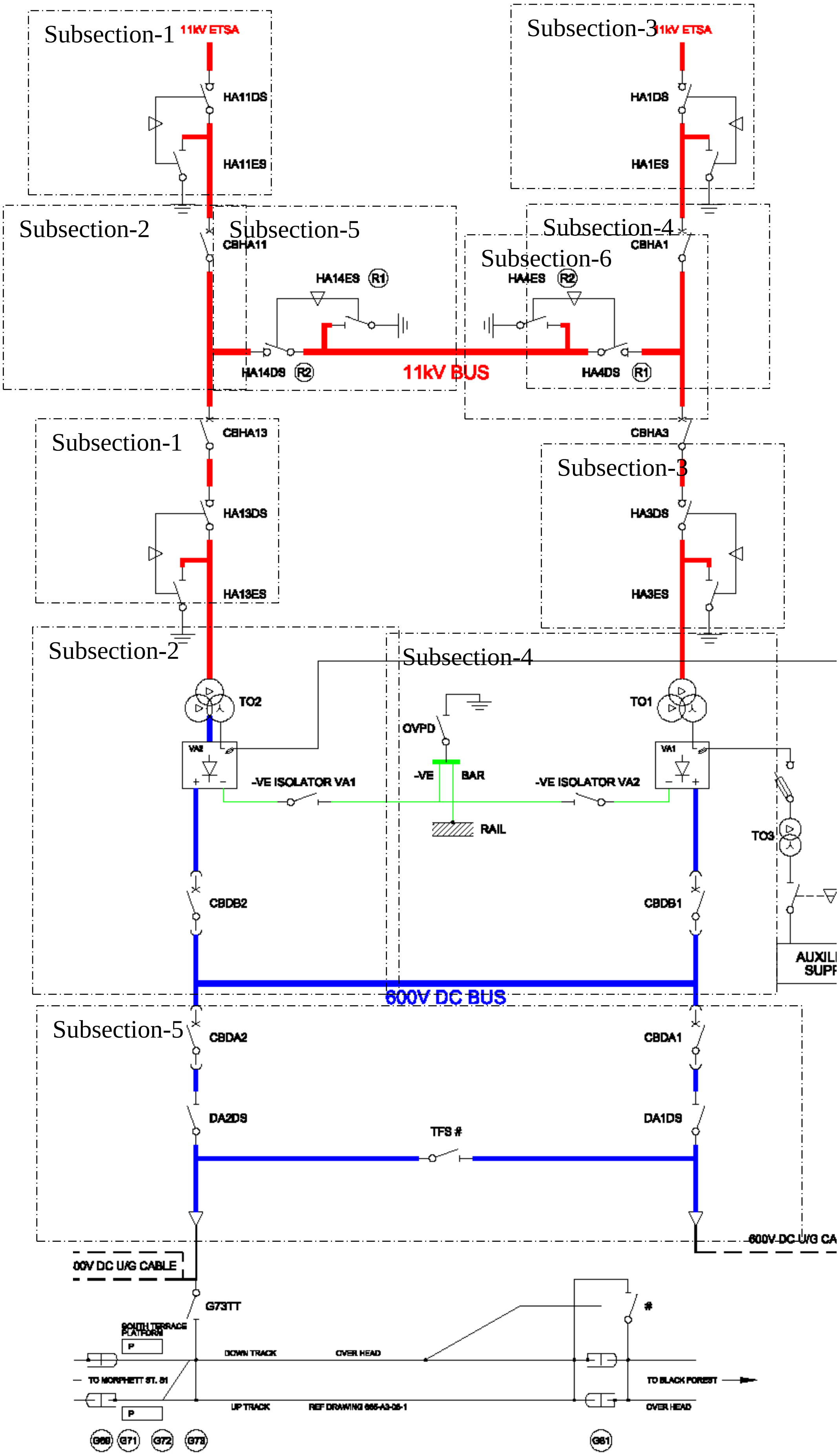


Fig. 5. Double rectifier substation

3.2 Subsystems definition

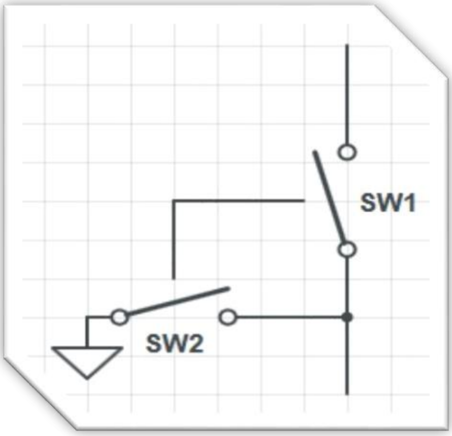
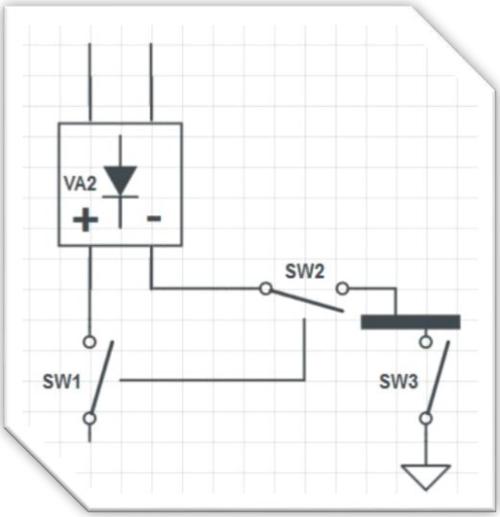
We have defined the subsystems to implement the diakoptics solution. After looking over the schematics of the OHW and substations; five reoccurring combinations of switches such as CB, Isolator, Earth Switch, TFS and Tap to TT were considered as of the following single and double rectifier feeder station of Fig. 4 and Fig. 5. The subsystem formation allows to split the whole traction network into different pages.

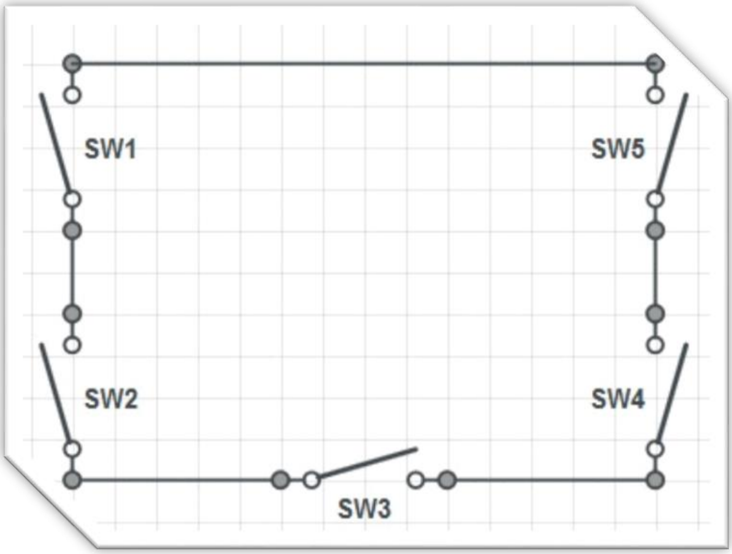
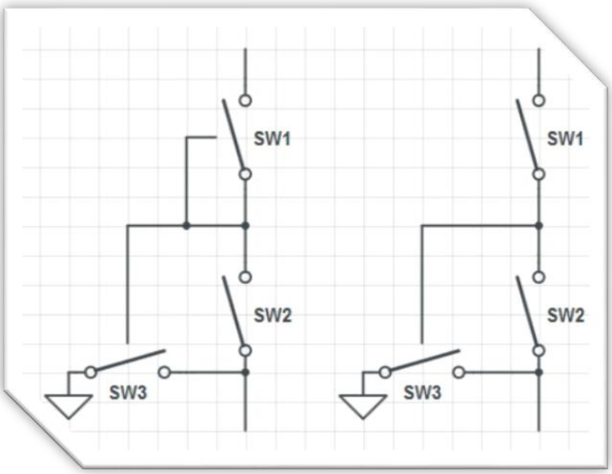
Those reoccurring combinations of switches can be seen along with the connection matrices for each subsystem. The connection matrix is written, so that it can be applied generically to any substation's subsystem. The point of the connection matrix is to provide the functions with a picture of 'how the subsystem is individually connected'. Then the connections matrix is multiplied with the energization matrix. The initial energization matrix only shows the 11kV input power supply energized from the distributor. Multiplication of connections and energization matrix continues until a steady state matrix solution is reached. This matrix will show the current energy state of each section of the system.

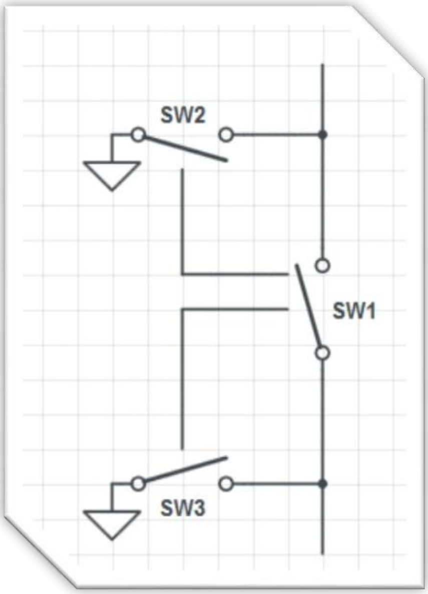
Each substation is separated into subsystems that have similar line and switch configurations that allows for repetition in the code. The subsystem types are listed in the following with labelling 'subsystem 1' to 'subsystem 5'. How subsystem connection matrix and its switching states (*Sw* variables) in diakoptics implementation works is found in the appendix C.

Combinations of system switches are seen in Table 1 along with the connection matrices for each subsystem. The subsystem is a part of the whole system which is broken into smaller parts, and can be solved individually without any external interference. The purpose of the total system tearing into subsystems, is to solve them individually and then putting the subsystems back together to recreate the solution of true switching representation of the entire traction system.

Table 1. Subsystems and Connection Matrices

Subsystem 1	**subSys1 (Sw1,Sw2)**
	$\begin{bmatrix} 1 & Sw1 & 0 & 0 & 0 \\ Sw1 & 1 & \overline{Sw1} & Sw2 & 0 \\ 0 & \overline{Sw1} & 1 & \overline{Sw2} & 0 \\ 0 & Sw2 & \overline{Sw2} & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix}$
Subsystem 2	**subSys2(Sw1,Sw2,Sw3)**
	$\begin{bmatrix} 1 & Sw1 & 0 & Sw2 & 0 \\ Sw1 & 1 & \overline{Sw1} & 0 & 0 \\ 0 & \overline{Sw1} & 1 & 0 & 0 \\ Sw2 & 0 & 0 & 1 & Sw3 \\ 0 & 0 & 0 & Sw3 & 1 \end{bmatrix}$

Subsystem 3	**subSys3(Sw1,Sw2,Sw3,Sw4,Sw5)**
	$\begin{bmatrix} 1 & Sw1 & 0 & 0 & Sw5 \\ Sw1 & 1 & Sw2 & 0 & 0 \\ 0 & Sw2 & 1 & Sw3 & 0 \\ 0 & 0 & Sw3 & 1 & Sw4 \\ Sw5 & 0 & 0 & Sw4 & 1 \end{bmatrix}$
Subsystem 4	**subSys4(Sw1,Sw2,Sw3,logical_type)**
	logical_type=1 $\begin{bmatrix} 1 & 0 & Sw1 & 0 & 0 \\ Sw1 & 1 & Sw2 & \overline{Sw2} & Sw3 \\ 1 & Sw2 & 1 & Sw1 & 0 \\ 0 & \overline{Sw2} & \overline{Sw1} & 1 & \overline{Sw3} \\ 0 & Sw3 & 0 & \overline{Sw3} & 1 \end{bmatrix}$ logical_type=0 $\begin{bmatrix} 1 & 0 & Sw1 & 0 & 0 \\ Sw1 & 1 & Sw2 & \overline{Sw2} & Sw3 \\ 0 & Sw2 & 1 & 0 & 0 \\ 0 & \overline{Sw2} & 0 & 1 & \overline{Sw3} \\ 0 & Sw3 & 0 & \overline{Sw3} & 1 \end{bmatrix}$

Subsystem 5	**subSys5(Sw1,Sw2,Sw3)**
	$\begin{bmatrix} 1 & Sw1 & \overline{Sw1} & \overline{Sw1} & Sw2 \\ Sw1 & 1 & 0 & 0 & Sw3 \\ \overline{Sw1} & 0 & 1 & \overline{Sw1} & \overline{Sw3} \\ \overline{Sw1} & 0 & \overline{Sw1} & 1 & \overline{Sw2} \\ Sw2 & Sw3 & \overline{Sw3} & \overline{Sw2} & 1 \end{bmatrix}$

Combining these subsystems together in different combinations both single and double rectifier feeder substations in the tramline traction tool can be modelled as in Fig. 6. In this figure, it shows how subsystems construct both type of traction substations.

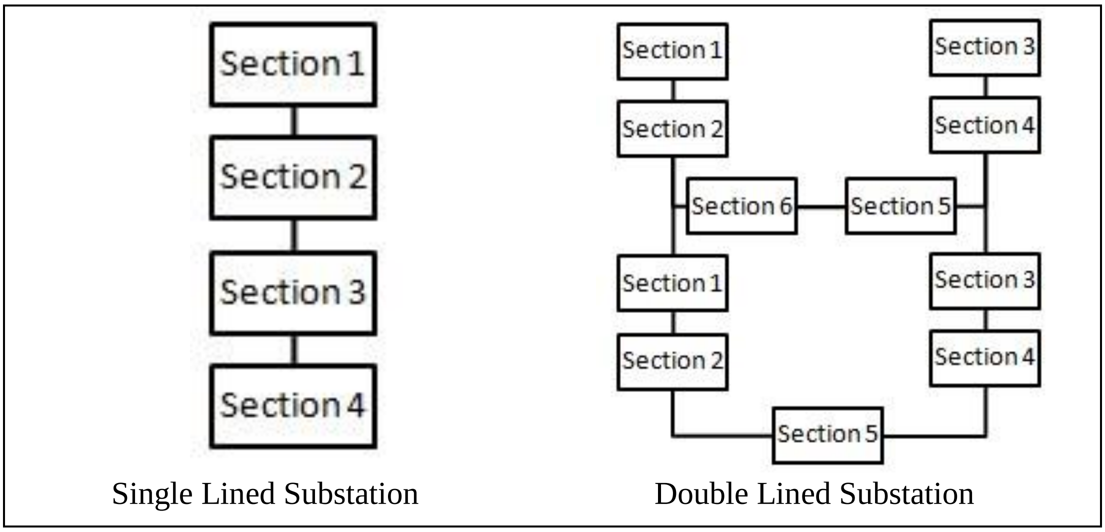


Fig. 6. Single and double rectifier substation of subsystems

This allowed the subsystem functions to be applied into all substations. A similar process may be applied to the parallel substation. However, as there are a number of sections in the parallel substation, the function is applied twice to the substation, using the results of the first function to determine the initial conditions of the second function. This allowed a generic function to be applied to any parallel substation in the tramline system simulation development.

As there are significantly less switches on OHW and UFC system (compare to the substation), there are no generic functions required for the subsystems of OHW and UFC systems. Required codes for each specific OHW and UFC section lines have been defined. The whole system is divided into 55 subsystems. Then the connection matrix is multiplied with the energization vector. The initial energization vector only shows the 11kV input power supply is energized via the incoming SAPN distribution feeder. The multiplication continues (the connections and energization matrix) until a steady state matrix is reached. This matrix has showed the current switching state of each section i.e. all subsystems of the entire traction system.

3.3 CitectSCADA Coding (Cicode and Graphics)

The process including all objective functions are programmed in Cicode. It is the vital part of the system which is used in edit commands, implement actions and new functions for a switching network. Usually, three parts are involved in a CitectSCADA project. These are:

- Cicode

One of the main issues with translating the code is the restrictions that Cicode puts on the uses of matrices in functions. Citect doesn't allow inputs or outputs of functions to be large matrices and has a maximum array size of 42x42. Those functions are recreated and therefore adapted to accommodate the restrictions of Cicode. Those functions are linked together by the graphical pages and genies in CitectSCADA Explorer.

- Graphics

Graphics are the visual operation component of CitectSCADA, which shows the status of all switching devices of the tram traction simulation tool. Furthermore, the simulation process may be operated by the graphics command unless this device is locked. Morphett St to South Tce OHW section and Hindmarsh substation graphics are shown in Fig. 7 and Fig. 8.

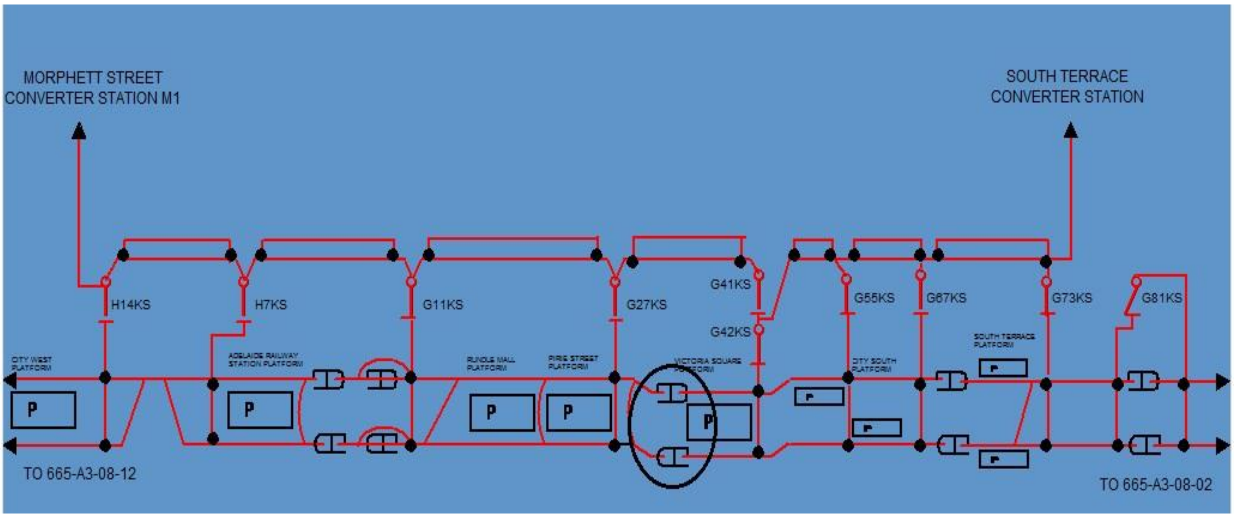


Fig. 7. Graphics of Morphett St -1 to South Tce converter stations

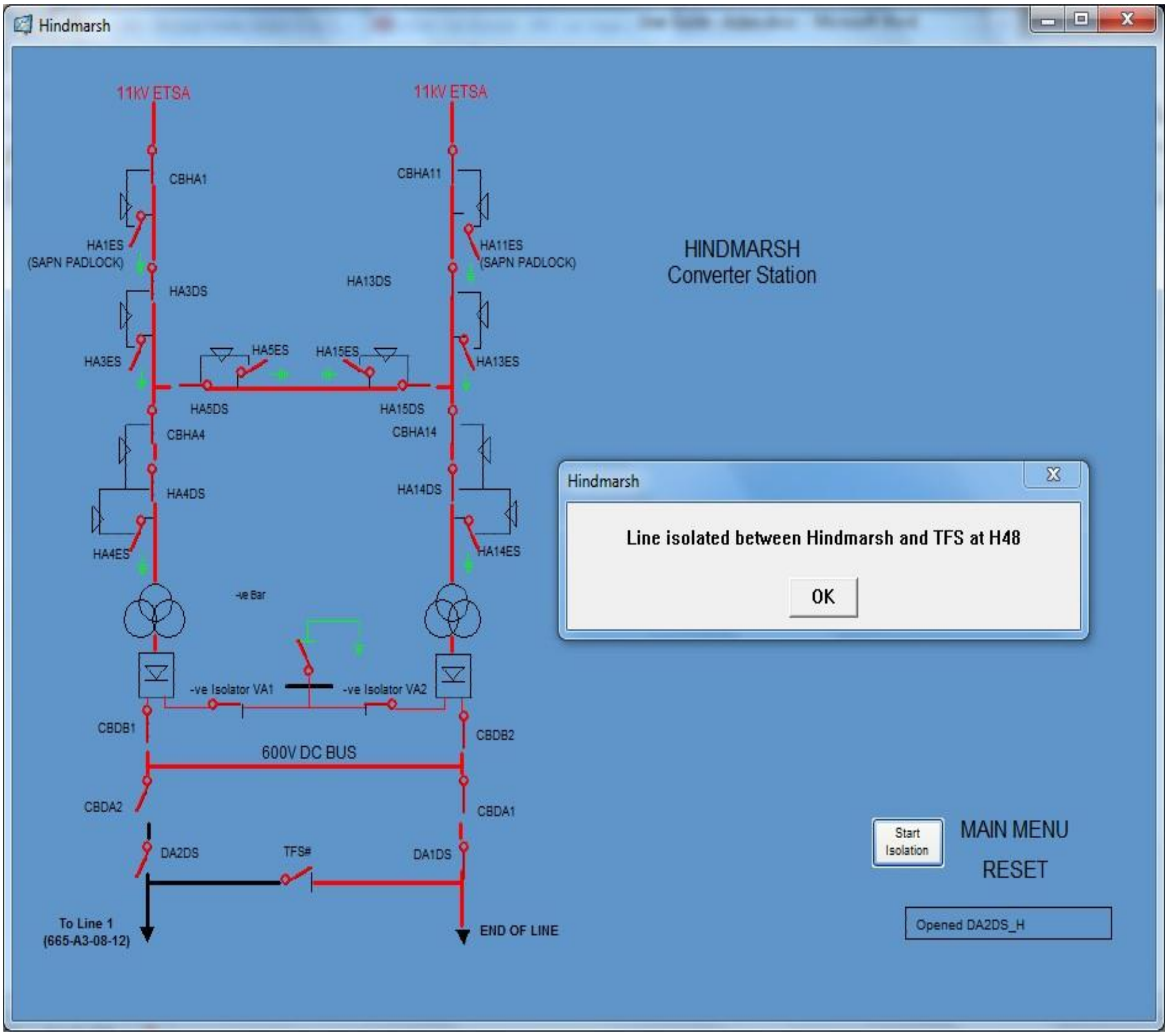


Fig. 8. Graphics of Hindmarsh dual rectifier converter station

□ Databases

The database is a storage unit which stores all configuration information. A database links devices status with Graphics which realizes the real time monitoring and controlling.

3.4 Overall Traction Network diakoptics representation

A summary of the Adelaide tram traction network is shown in Fig. 9.

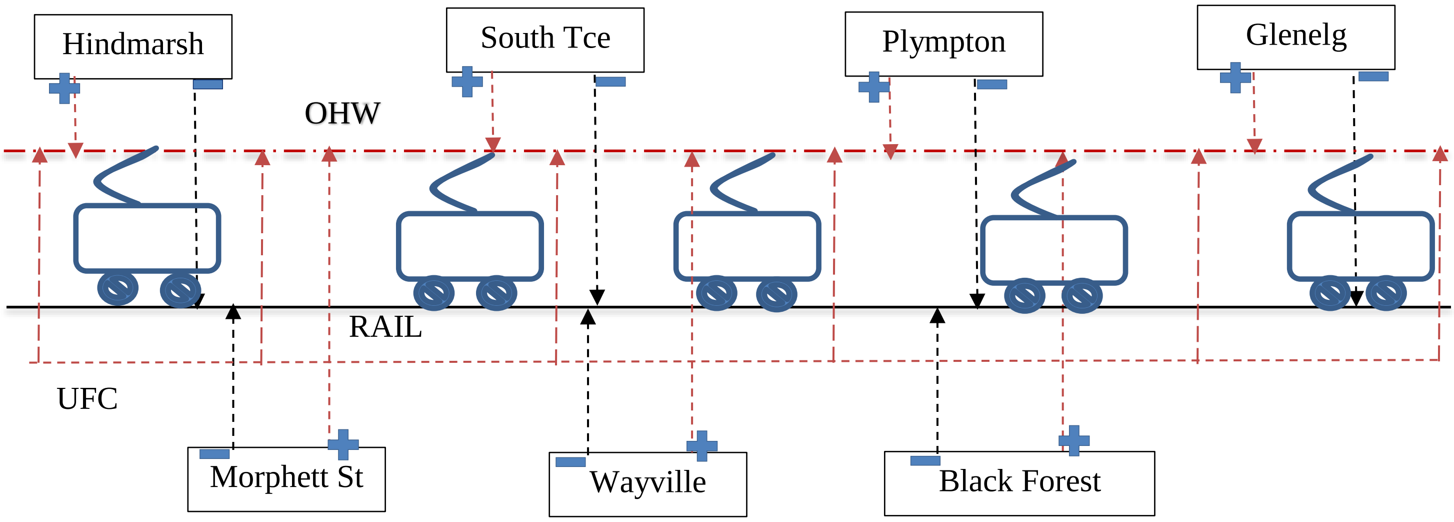


Fig. 9. Adelaide Tram Traction Network

The diakoptical representation of the entire traction system, is seen in Fig. 10. Each shaded area in the Fig. 10 represents a substation which connects to the OHW and parallel UFC section in the traction system. These are:

Subsystems 1-11 represent a dual rectifier substation (Hindmarsh).

Subsystems 13-16, 18-20 represent single rectifier substation (Morphett-St 1 & 2).

Subsystems 23-33 represent a dual rectifier substation (South Tce).

Subsystems 35-37 represents a single rectifier substation (Black Forest).

Subsystems 39-41 represents a single rectifier substation (Plympton).

Subsystems 44-54 represent a dual rectifier substation (Glenelg).

Subsystems 12,17,21,22,34,38,42,43 and 55 represent OHW and UFC system from the Entertainment Centre, Hindmarsh EOL to Moseley Square, Glenelg EOL.

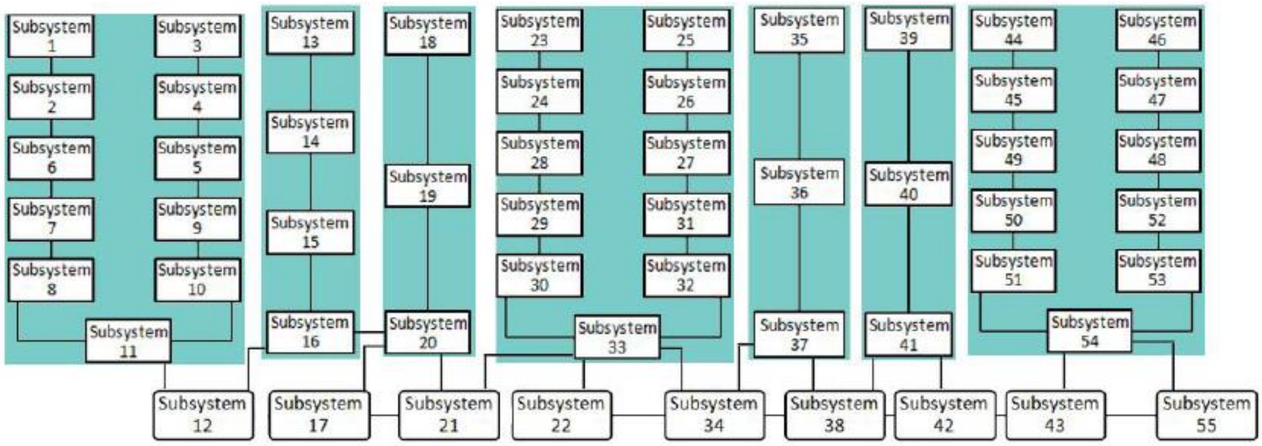


Fig. 10. Summary of torn network (diakoptics subsections) of the traction system

In the Cicode program, code for all seven substations; OHW, parallel UFCs, system switching states, variable definitions, system-switchgear interlocking, etc. have been explained.

3.5 Challenge to implement diakoptics algorithm in Citect

The functional diakoptics codes have been confirmed to work in MatLab initially and then translated the code into Cicode. Due to the number of issues, the efficiency of having generic functions are lost for a bit. One of the main issues with translating the code is the restrictions that Cicode puts on the uses of matrices in functions. Cicode doesn't allow inputs or outputs of functions to be matrices. So, the MatLab functions are developed for respective diakoptical subsystems that couldn't able to be written as they are in MatLab. The MatLab functions therefore are adapted to accommodate the restrictions of Cicode

3.6 Summary

The general tram traction systems switchgear and their translation to the diakoptical algorithm have been discussed in this chapter. The subsystems definition and representing the entire tram network into diakoptics subsystems are explained. The limitations, restrictions, and overcoming those programming restrictions into citectSCADA including relationship between Cicode, graphics and database are mentioned.

Chapter 4

THE NETWORK SWITCHING STATE IMPLEMENTATION

4.1 Introduction

The isolation and restoration process i.e. the electrical switching program is used in a day to day scheduling in any electrical utility. Those programs must be effective for a safe controlled system operation, limited-maintenance-time window oriented efficient work management, safe system maintenance and operational system restoration safety. A switching program tells the switcher exactly which switches have to be open and in what order for a given corrective or maintenance task. A switcher and checker have to go through a safe isolation process and issue a 'permit to work' to the workgroup prior to any normal or emergency maintenance work. So, having 'a ready to work' system generated isolation and restoration switching program, carry an added advantage and efficient workhour-management to the workgroup. Diakoptics based subsystems algorithm does this system switching state determination, subsequent mapping and switching steps (isolation-restoration) generation efficiently, easy to execute and in a professional way.

4.2 Mapping of the isolation procedure

The isolation function considers two switches as inputs and determine the path of isolation between them. It initiates this by looking up the switches in the database and determining which subsystem they are connected in. A path-way between the two subsystems is then worked out as of example in the Fig. 11.

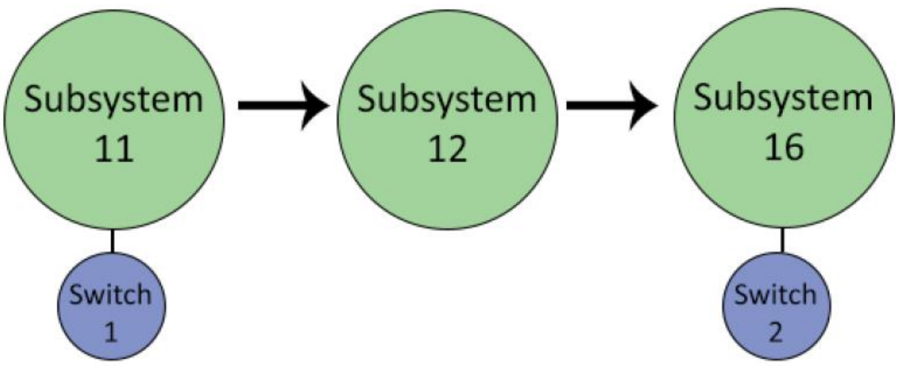


Fig. 11. Mapping of the isolation procedure

In this example, if the given limits of isolation is defined between switch-1 and switch-2, the simulation already found in what subsystem the switches are built in. The software algorithm would have returned subsystem-11 and subsystem-16. A pathway between these two subsystems is looked up and stored in the array. This process is similar to the concept of a linked list [41]. Each substation is considered as a node in the system and has its connections mapped accordingly. The subsystems are numbered such that a series of conditions can provide the function with a clear path to navigate through the system. Once the order of the subsystem has been obtained, the switches that need to be open are scanned from a database and stored in switch array of the built functions.

In the above example, the function connects in two areas and works out what switches are between two areas. It stores the list of areas in the matrix. The matrix is then re-arranged, so that the substation areas are listed first, then adjacent line areas. The state matrix will return the matrix size and which area it belongs to. Following on from each element of area will be input into the database lookup function to what switches needed to isolate. The function returns the arrays, switch, switch name and area name. Switch array contains switch numbers in the sequential order that need to be isolated. Switch name array contains the name of the switches and the area name array contains the name of the substation or OHW or UFC systems.

There are a number of key safe operation switchgear interlocking to be followed as mapped in as-built electrical & mechanical interlocking of the switchgear. All these logics have been mapped in functions followed regarding the order of the switch and switchgear sequential safe operation. Those interlocking and safety principles have been verified in citectSCADA graphics prior to its chronological open or close operation as of the related isolator, bypass switch and substation switchgear.

4.3 Switching Sequence (isolation-restoration process) generation

Diakoptics integration is the fundamental technique for the traction simulation tool, which is responsible for simplifying the simulation process of isolation-restoration program. The automatic generation of isolation-restoration switching program has been integrated into the simulation during the development of this project. In any given planned or unplanned task in substations or UFCs or OHWs, minimum two isolation and work limit switches have to be chosen as POIs. Only then the simulation generates required safe switching steps to carry out an isolation- restoration switching steps for a safe work accomplishment, as shown in the Fig. 12 work methodology. The isolation-restoration work methods certainly needs to meet the required maintenance expectations including safe work completion and safe system restoration. For instance, when a 600 V DC CB or a 11 kV AC CB needs to be replaced in a substation, a details procedural-functional assessment for the task, any consumable MDS (maintenance data sheets) has to be thoroughly risk assessed (Fig. 13) as of the related standards. On the other hand, when a TT (Tap to Trolley) switch needs to be serviced on an OHW systems, related tensioned infrastructure (pole registration, arms, contact, guy wires) system safety and workgroup JSA (Job Safety Advice) have to be properly adhered and followed. The crew must treat any work as unique & isolated in nature, even though they usually undertake repetitive work including system isolation-restoration frequently. The details of a complete isolation-maintenance work done-system restoration cycle is explained below.

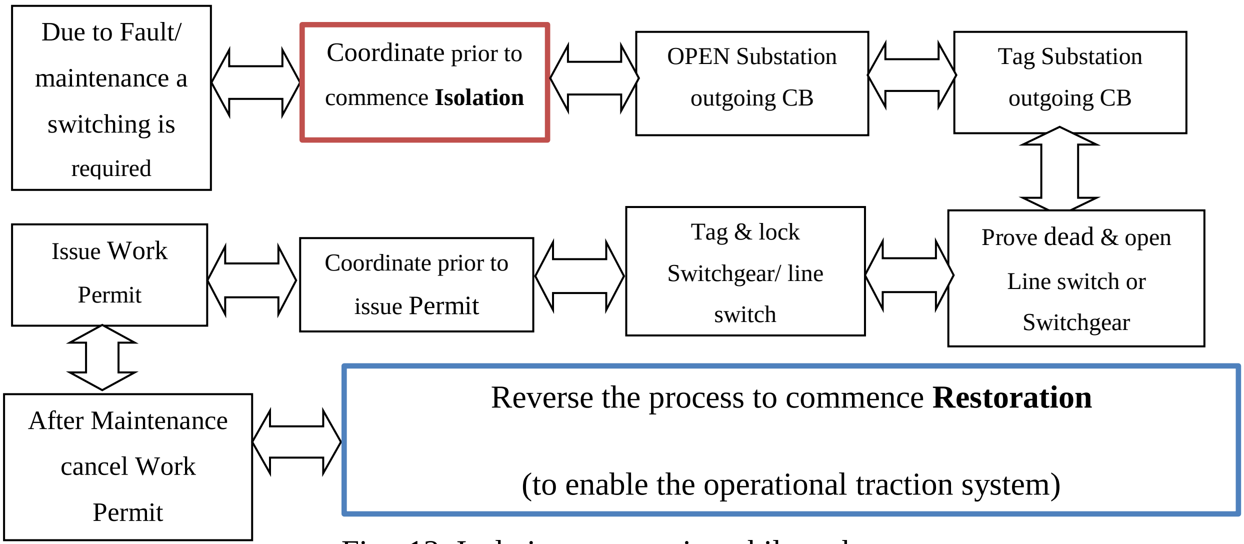


Fig. 12. Isolation- restoration philosophy

A risk assessment matrix with a value of 8 would be considered moderate while a value of 20 would be catastrophic and would require drastic risk management plans as shown in the Fig. 13 for a given task. The crew must work with the related job specific standards to eliminate or control the associated risk for their maintenance work requirements.

		Consequences				
		Insignificant (1) No injuries / minimal financial loss	**Minor (2)** First aid treatment / medium financial loss	**Moderate (3)** Medical treatment / high financial loss	**Major (4)** Hospitable / large financial loss	**Catastrophic (5)** Death / massive financial loss
Likelihood	**Almost Certain (5)** Often occurs / once a week	Moderate (5)	High (10)	High (15)	Catastrophic (20)	Catastrophic (25)
	Likely (4) Could easily happen / once a month	Moderate (4)	Moderate (8)	High (12)	Catastrophic (16)	Catastrophic (20)
	Possible (3) Could happen or known it to happen / once a year	Low (3)	Moderate (6)	Moderate (9)	High (12)	High (15)
	Unlikely (2) Hasn't happened yet but could / once every 10 years	Low (2)	Moderate (4)	Moderate (6)	Moderate (8)	High (10)
	Rare (1) Conceivable but only on extreme circumstances / once in 100 years	Low (1)	Low (2)	Low (3)	Moderate (4)	Moderate (5)

Fig. 13. Value risk matrix (As of Australian OHS standard)

The subsystem implementation is discussed in previous chapters, along with how the connection matrix and energization matrix have worked. As the simulation user deals with the POIs (Point Of Isolation), in practice and in diakoptics, it requires the use of subsystems need to be a way to translate what switch belongs to in which subsystem. When the two switches or isolation limits are selected for the POIs, the switches are passed to a function that translate what the switch numbers of the two switches are. Those switches match the two subsystems from the section as of the chapter three subsystem arrangement that each switch belongs to. Once the POIs have been selected and the switches subsystems have been determined, the other function as stated in section 4.2 determines the interconnecting subsystems between the two subsystems to be isolated. As the order of the subsystems are known, the function finds the switches in each subsystem and finds the order of switches that need to be opened in the individual subsystems. The function prints out each subsystem switching order obeying special interlocking conditions into the sequential isolation steps as shown in the Fig. 14. In this figure, Morphett St Converter Station Isolator (DA2DS_M1) and South Tce Converter Station CB (CBDB1_ST) switching points are selected as the switching POIs.

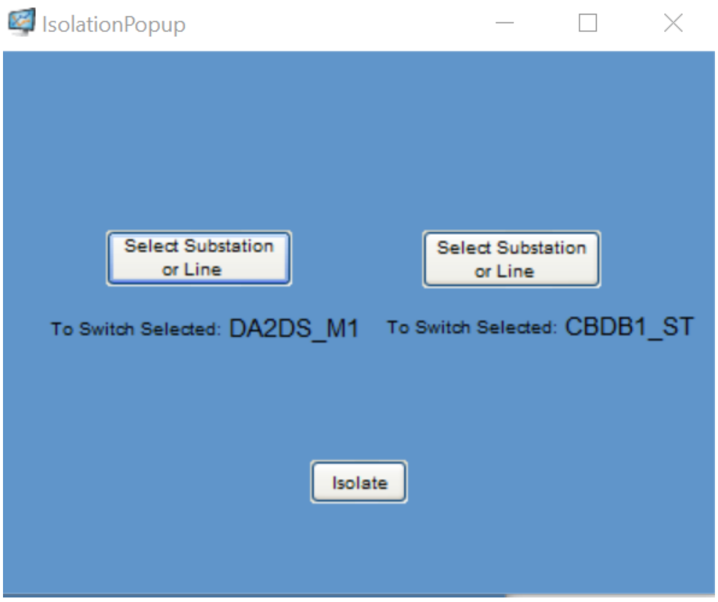


Fig. 14. POI from DA2DS_M1 and CBDB1_ST

Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Line2, open, lock and tag G41KS
2	Confirm the tram line is clear of trams	19	At Line2, open, lock and tag G27KS
3	Advise tram control of switching commencement	20	At Line2, open, lock and tag G11KS
4	At Morphett_M1, open, lock and tag CBDA1_M1		
5	At Morphett_M1, open, lock and tag DA1DS_M1		
6	At Morphett_M1, open, lock and tag CBDA2_M1		
7	At Morphett_M1, open, lock and tag DA2DS_M1		
8	At Morphett_M1 check TFS_M1 is open and lock & tag		
9	At South_Terrace, open, lock and tag CBDA2_ST		
10	At South_Terrace, open, lock and tag DA2DS_ST		
11	At South_Terrace, open, lock and tag CBDA1_ST		
12	At South_Terrace, open, lock and tag DA1DS_ST		
13	At South_Terrace check TFS_ST is open and lock & tag		
14	At South_Terrace, open, lock and tag CBDB1_ST		
15	At Line2, open, lock and tag G67KS		
16	At Line2, open, lock and tag G55KS		
17	At Line2, open, lock and tag G42KS		

Restore

Fig. 15. Isolation schedule for POIs

When the simulator user clicks the isolate button as shown in the Fig. 14, the simulator generates an isolation schedule program for the given POIs, as shown in Fig. 15. It shows all sequential steps for a safe isolation program between two POIs. It is a simplified and ‘ready to work commence’ switching program as of the standard formal isolation schedule provided by the qualified personnel during a hand-written switching program. The details of the POIs selection and ‘ready to be approved’ isolation-restoration switching program generation process is shown in the Simulator User Procedure (appendix D).

As of the engineering requirements, the simulator user has to click on the system schematics of lines and converter stations to select the correct POIs. In a real work scenario, during the work-isolation-restoration planning process, the switcher-checker team have to visit the worksite, get them familiar with the work location and probable designated earthing points prior to their scheduled isolation planning. So, after an operational status check and clicking on the required network schematic, the user can make an informed decision about the work limit and required POIs to achieve a safe isolation-restoration switching program for that given work execution.

Generally; this simulator switching programs should give a clear idea/ cross check of the steps required to perform an isolation-restoration at any given time. The simulation shows the system operational mimics as shown in the Fig. 16. between defined POIs. The user will click on the required network schematic TT switches, open or close those switches, go to the adjacent substations and open both feeding CBs. This gives the user the following system de-energized status and an easy way to select the POIs to generate the required isolation-restoration programs in a ‘single click’. In an on-site switching program execution, all remote CBs may be open by the ECOs from the remote ECC unless specified otherwise.

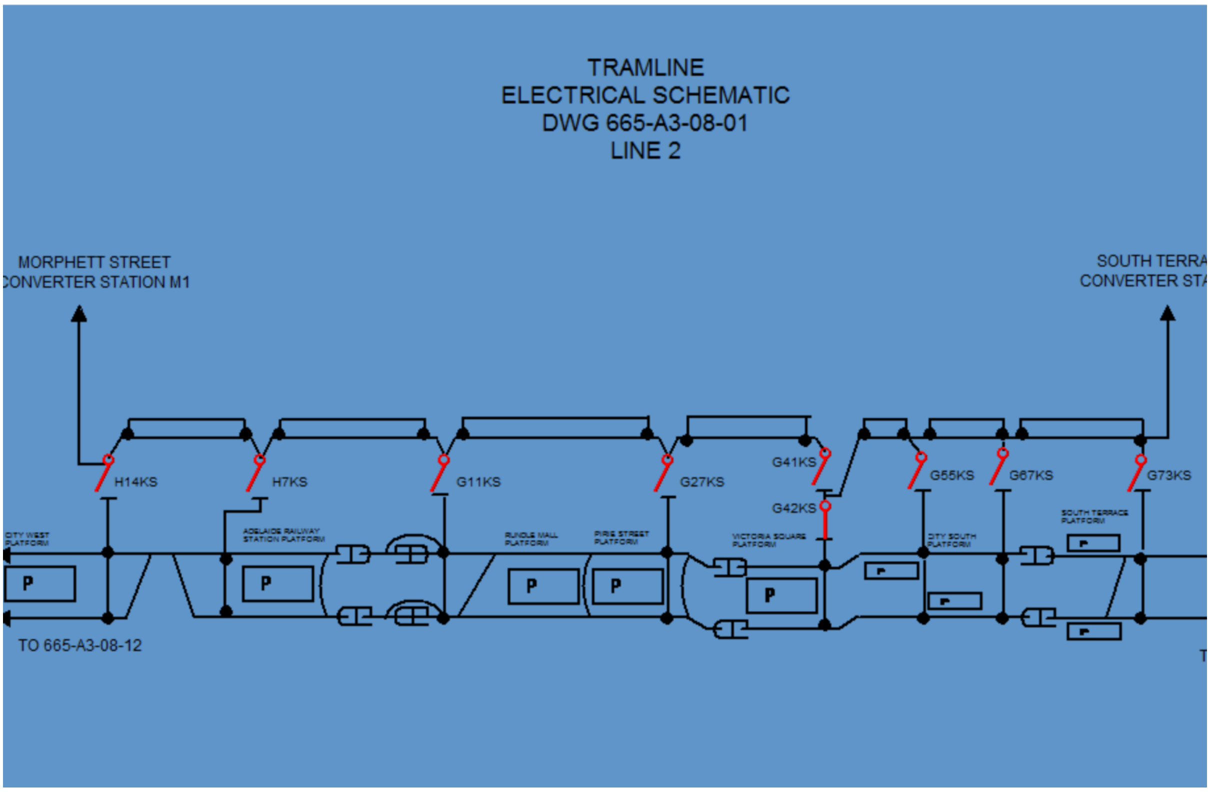


Fig. 16. Isolation mimic display for a POIs

The system restoration schedule describes the safe restoration of the system in the opposite order of isolation. It explains exactly how the system is restored in a safe ‘bottom to up restoration manner’ without any damage to the switchgear and ensures workgroup safety. The restoration schedule is generated by clicking an interface button ‘restore’ for said POIs in the mimic at the end of the isolation schedule. It generates a restoration schedule in an opposite manner of the isolation sequential steps. It prints all restoration steps including the system restored mimic display as shown in the Fig. 17. In the following restoration steps, the restoration schedule has been generated between Morphett St Converter Station Isolator

(DA2DS_M1) and South Tce converter station CB (CBDB1_ST) switching POIs. The tool displays the restored substation and OHW catenary systems as shown in Fig. 18.

Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Morphett_M1, remove tag, unlock and close CBDA2_M1
2	Remove all Earths	19	At Morphett_M1, remove tag, unlock and close DA1DS_M1
3	Advise tram control of switching commencement	20	At Morphett_M1, remove tag, unlock and close CBDA1_M1
4	At Line2, remove tag, unlock and close G11KS		
5	At Line2, remove tag, unlock and close G27KS		
6	At Line2, remove tag, unlock and close G41KS		
7	At Line2, remove tag, unlock and close G42KS		
8	At Line2, remove tag, unlock and close G55KS		
9	At Line2, remove tag, unlock and close G67KS		
10	At South_Terrace, remove tag, unlock and close CBDB1_ST		
11	At South_Terrace check TFS_ST is open and remove tag & unlock		
12	At South_Terrace, remove tag, unlock and close DA1DS_ST		
13	At South_Terrace, remove tag, unlock and close CBDA1_ST		
14	At South_Terrace, remove tag, unlock and close DA2DS_ST		
15	At South_Terrace, remove tag, unlock and close CBDA2_ST		
16	At Morphett_M1 check TFS_M1 is open and remove tag & unlock		
17	At Morphett_M1, remove tag, unlock and close DA2DS_M1		

Isolate

Fig. 17. Restoration schedule

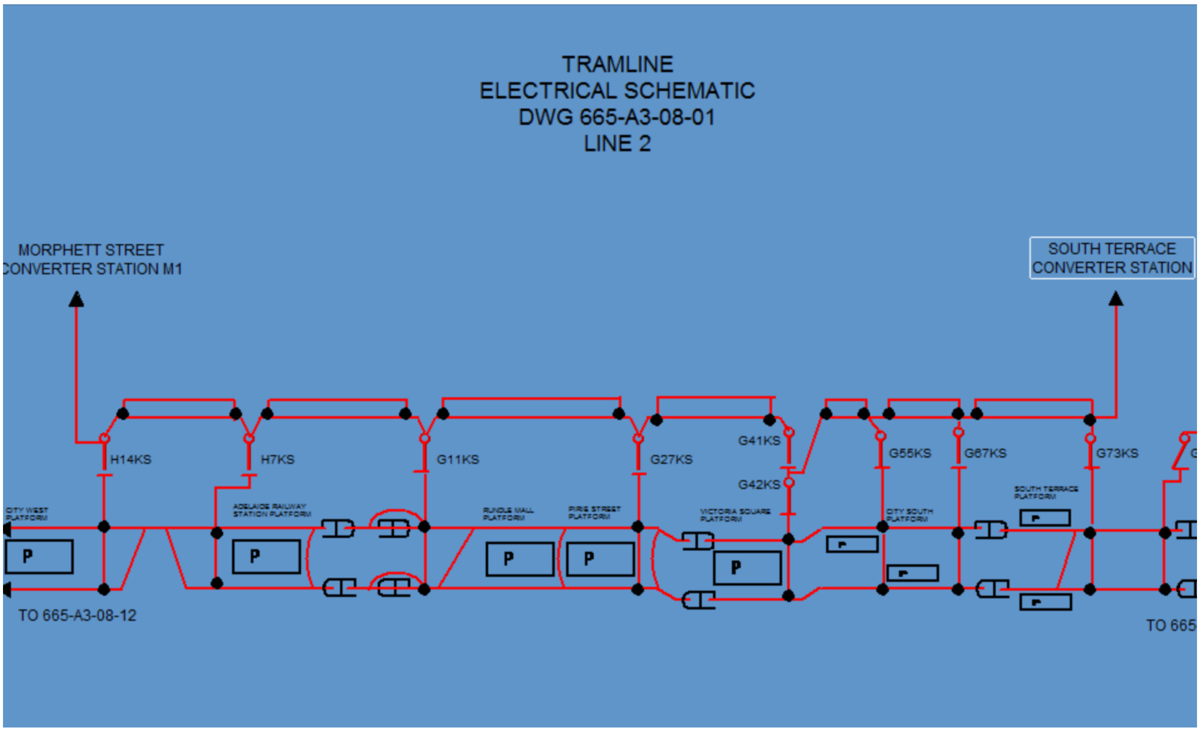


Fig. 18. Restoration mimic display

4.4 Pros and cons of the proposed technique and comparison with the traditional approach

The simulator generated switching approach is certainly quicker than a traditional manual handwritten one. But there is a huge fatigued mindset approach from the existing working group to execute their hard-worked hand-written isolation plan output from the readily available automated tool. The group initially thought that their daily network patrol switching assessment activities have been slashed and consumed from the automated output. After panel presentation and discussion with the team, this fear has been dissolved as the crew has to physically lock & tag all POIs, regardless of the automated switching program preparation and ready to work commencement on site. The switching crew has appreciated the simulator generated automated switching approach as that made switching program preparation simple and readily available to commence their maintenance work on site.

4.5 Summary

We have outlined the specific switchgear subsystems switching status and how to map between two POIs in this chapter. The switching philosophy with several isolation-restoration examples have been discussed. How the user uses an informed POIs and generate required switching program is a critical step to learn. The end-user requirements, system switching demonstrations, engineering system switching template and 'ready to be approved' type automated system switching program generations are shown in the simulation user procedure (appendix D).

Chapter 5

NETWORK EXPANSION

5.1 Introduction

In a traction network, future network extension, existing network upgrade, temporary overhauling or permanent or long term lines or substation bypass, is a common practice. The model tram traction simulation tool is obliged to be future proof. Any OHW, UFC and substation switchgear addition have to be added and bypassed in an easy and user friendly process. The modularity of the diakoptics based tool has been tested by adding two new dual rectifier substations and around 10km underground and overhead traction systems. Overall system switching state, required isolation-restoration including system interlocking functionalities have been verified and tested.

5.2 New substations and Catenary Systems

Two substations are going to be built in two suburbs named Semaphore and Woodville to extend the existing tram traction route towards Port Adelaide as shown in the Fig. 19. The construction distance from the existing Hindmarsh substation to Woodville substation is around four kilometers and the length from Woodville to semaphore is around five kilometers. South Australian State Government has a development plan to include five more trams in their future fleet system. To support the additional tram load, the new substations need to be a dual rectifier power supply. Thus, a double lines supply substation switching configuration is designed as of the related diakoptics sub-systems. The Woodville and Semaphore dual rectifier substations mimics are shown in the Fig. 20. Both converter stations are fed from the nearest SAPN distribution networks.

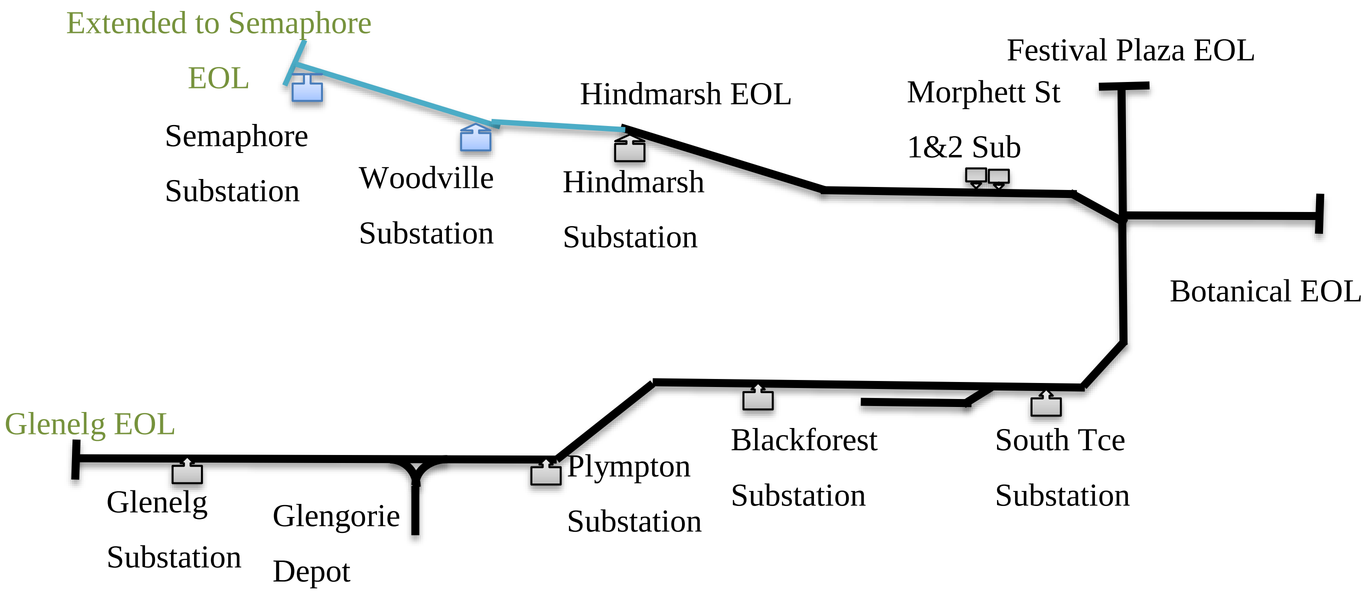


Fig. 19. AMPRN extended Tramline route

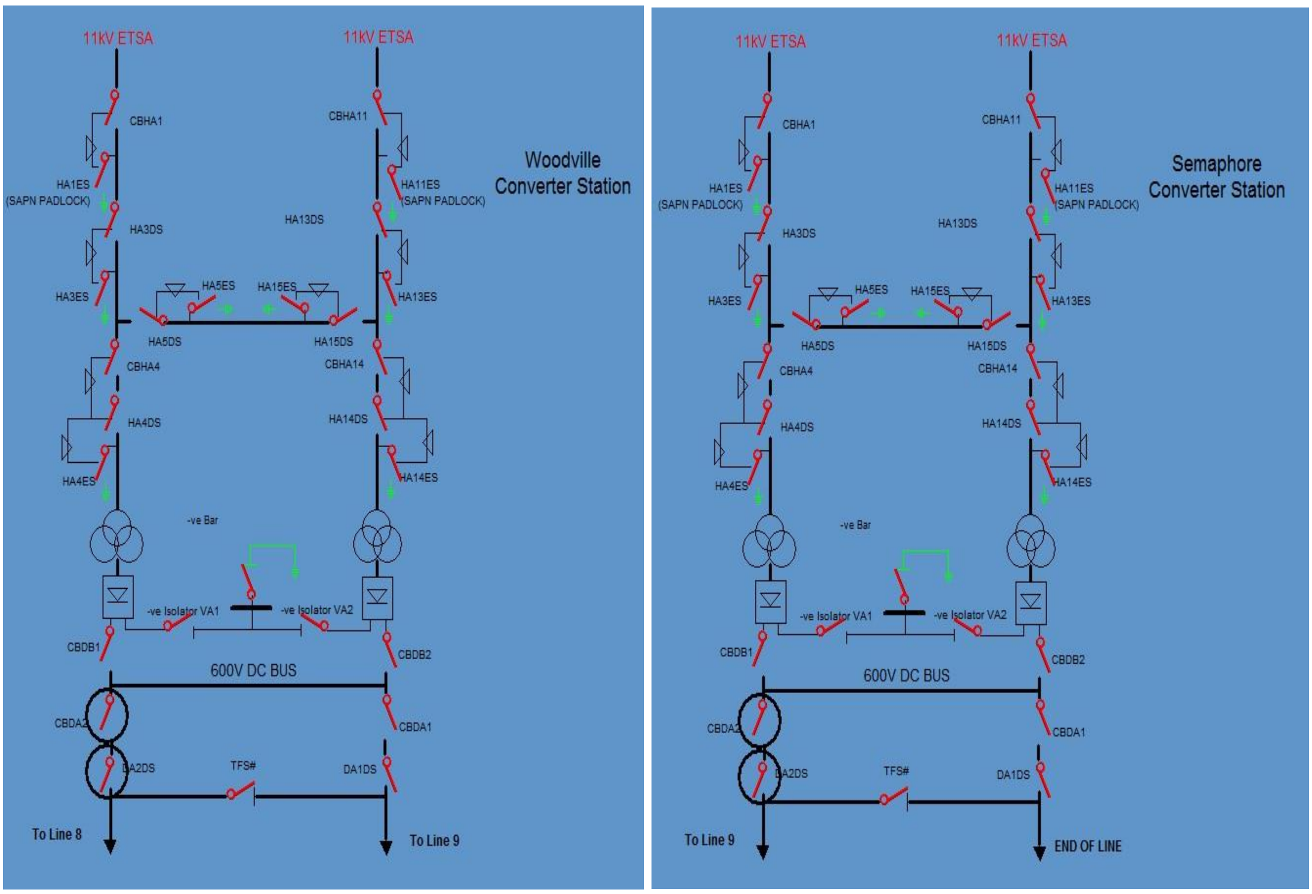


Fig. 20. Woodville substation and Semaphore substation graphic

The catenary systems from Hindmarsh to Woodville and Woodville to semaphore graphics are shown in Fig. 21 and Fig. 22.

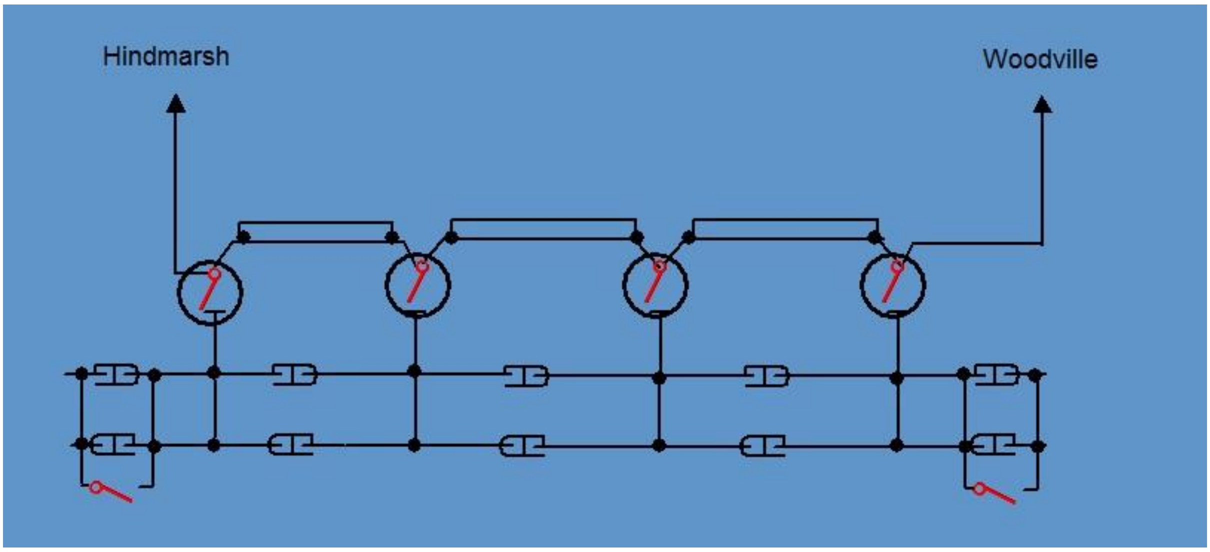


Fig. 21. Line 9 graph from Hindmarsh substation to Woodville substation.

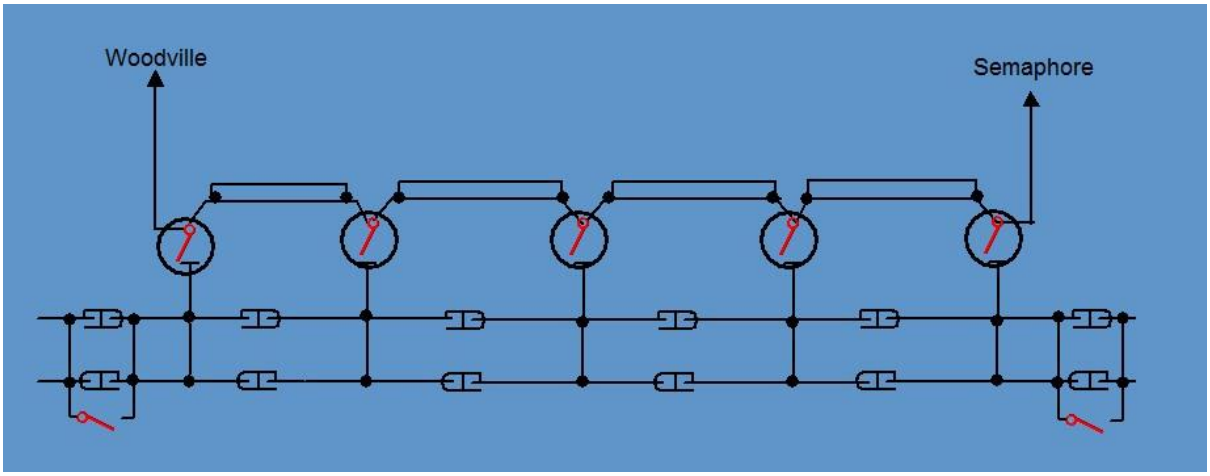


Fig. 22. Line 10 graph from Woodville substation to Semaphore substation.

5.3 Combined Subsystems:

With two added Woodville and Semaphore substations, the diakoptics representation is seen in the Fig. 23. Each shaded area in the figure, represents a substation which also connect to the OHW and parallel UFC section in the Adelaide traction system. That means:

Subsystems 1-11 represent a dual rectifier substation (Semaphore).

Subsystems 14-24 represent a dual rectifier substation (Woodville).

Subsystems 26-36 represent a dual rectifier substation (Hindmarsh).

Subsystems 38-41, 43-45 represent single rectifier substation (Morphett-St 1 & 2).
Subsystems 47-57 represent a dual rectifier substation (South Tce).
Subsystems 60-62 represents a single rectifier substation (Black Forest).
Subsystems 64-66 represents a single rectifier substation (Plympton).
Subsystems 68-78 represent a dual rectifier substation (Glenelg).
Subsystems 12, 13, 25, 37, 42, 46, 58, 59, 63, 67, 79 and 80 represent OHW and UFC catenary system from the Semaphore EOL to Moseley Square Glenelg EOL.

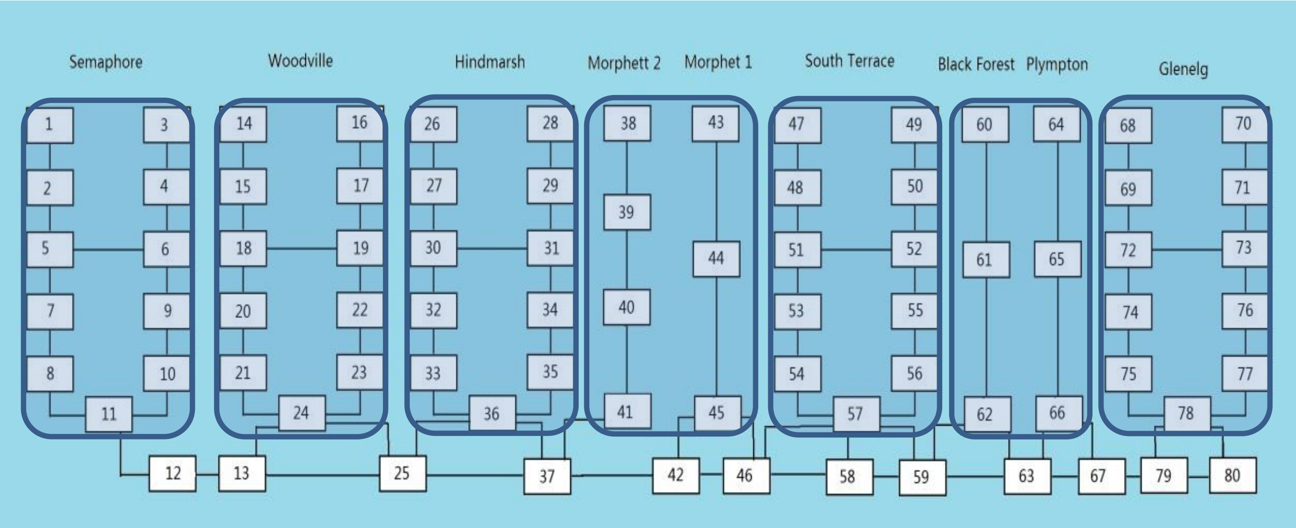


Fig. 23. Combined Subsystems of the Simulation Tool.

Diakoptics implementation has significantly reduced the network switchgear switching state recognition time and automated switching of the isolation-restoration schedule generation time. The entire traction system's true switching state, required change determination at any given POIs, correct mapping to its mimic display and user-friendly automated generation of the isolation-restoration program, takes around two seconds.

5.4 Future proof

The model simulator has been tested and implemented in such a way that supports any further network extensions, bypass and reconstruction. The RIM has approved this approach as they have to deal with the continuous changing network scenario around 24/7 basis. The engineering team has been briefed on the required adopted features and minimal code adjustments to achieve any future readiness on possible operational scenarios during staged practical demonstrations.

5.5 Summary

We have discussed any probable substation or catenary system upgrade and bypassed scenarios in this chapter. Any future system switchgear addition or bypass has been accommodated in the model simulation tool with a minimal effort such as coding, object tagging, mapping and required API integration.

Chapter 6

OVERALL SYSTEM SAFETY INTEGRATION

6.1 Introduction

RIM has asked for a comprehensive system safety demonstration of the model traction simulation tool. The tool user have to gain an overall system safety understanding, act accordingly and meet the critical system safety protocols in due course. It is a regulatory and event driven safety requirement to demonstrate a full proof system safety protocol for their employees. We are looking for a solution to model the overall traction safety assurance in 'one click'. That means, in the simulation tool, the switcher selects the POIs, clicks the 'isolation-restoration' button and operates related CBs. The simulation tool verifies required switchgear chronological interlocking, safe sequential system isolation-restoration steps, buffer for required manual earth locations and safe 'isolation-restoration' steps. The tool has to be accommodated on a sudden isolation-restoration requirement of the entire tram operational network in 'one click'. When the user clicks the soft switch, all substation outgoing operational feeder CBs operate and generates a sequential safe isolation-restoration steps.

To facilitate the 'one click' solution, the Deadman switch integration is considered in the tool. The engineers who are running electrical street vehicles in early 20th century, first introduces the Deadman switch methodology [42]. Electrical traction companies [43] prefer both soft & hardwire intervention of the Deadman's switch in their ECC and NCC to legislate a full proof supervisory control system. So that, any person in the operations control room or from the surrounding tram or train traffic operation controller rooms, can break the seal and pull the Deadman switch's lever to minimize the system damage or increase personnel safety during an absolute catastrophic event. This type of switch is usually equipped with both a SCADA software and hardwire interface in the control center. RIM is looking to implement the Deadman's switching philosophy in their existing AMPRN ECC. But that requires an extensive software demonstration and employee awareness program prior to implementing their required 'one click' methodology.

The model diakoptics based simulation tool has incorporated the Deadman switch philosophy. By clicking the switch, it operates all outgoing feeder CBs and generates isolation-restoration switching programs. The 'one click' inclusion has been thoroughly tested and required functionalities verified by the ECOs.

6.2 Integration of Deadman switch into the simulation

Deadman switch has been utilized to simulate an incident or disarm all EMUs in the vicinity by an electrical controller or network controller in a rare & unwanted critical accident (such as bush fire, dewirement or in any absolute life threatening condition). This soft and hardwire integration is required when the regular operator faint or during an extreme emergency necessitates all incoming power source must be turned OFF with a minimal effort and expertise.

As of the simulator, seven existing substations and two additional new substations as shown in the Fig. 24, have been considered to be covered with the Deadman switch algorithm. Each substation's outgoing two main circuit breakers need to be controlled by this soft switch interface. Therefore, in-total 18 outgoing 600V DC feeder CBs are linked with the control of the Deadman switch. The Cicode for this switch is designed with the value of 1 and 0, which means 1 stands for that all the CBs are CLOSED and 0 stands for that all the CBs are OPEN.

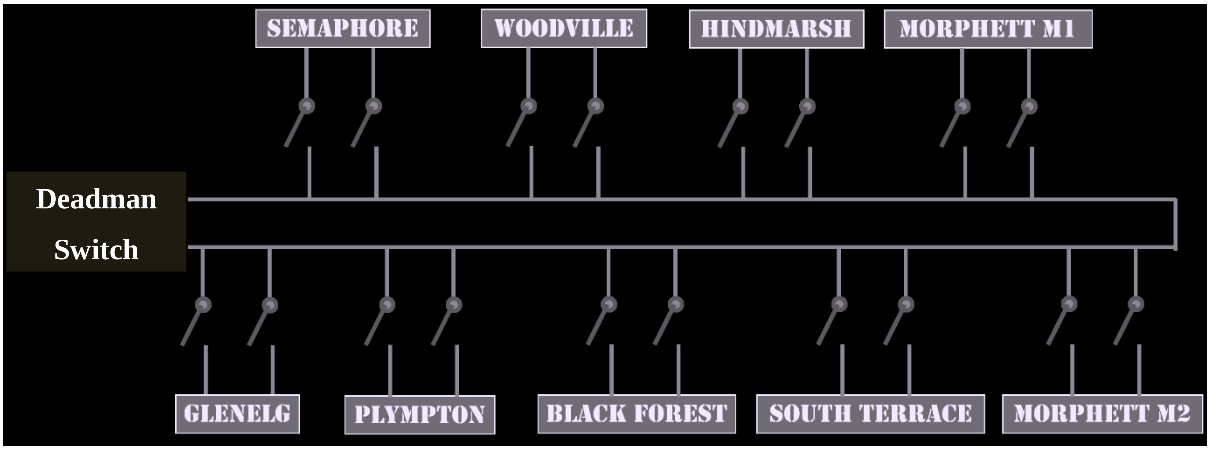


Fig. 24. Deadman Switch Operation

As of the principle of the Deadman switch, the relationship between this switch and CBs are shown in the Fig 24. By clicking the switch, all the outgoing load CBs connecting to the main lines are open and generate a sequence of CB operations as shown on the adjacent substation's network status. The related de-energized system mimic and isolation switching status are shown in the Fig. 25 and Fig. 26.

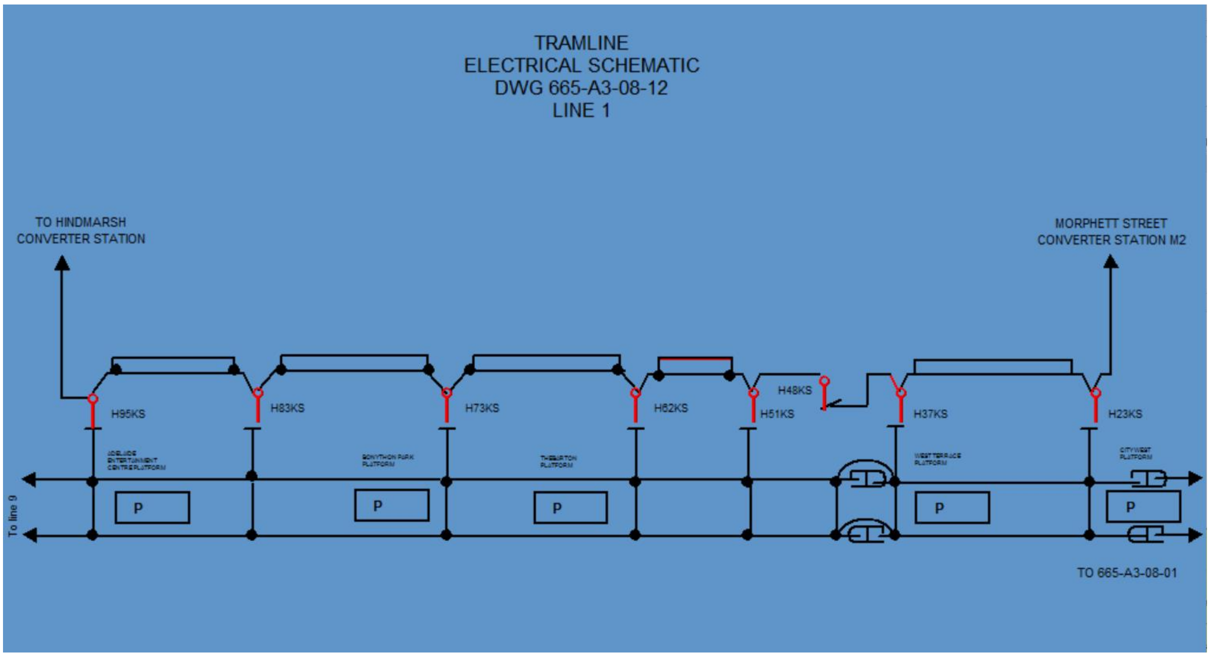


Fig. 25. Adjacent substation’s OHW status after Deadman switch execution

Deadman switch Operation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	At Hindmarsh, Open, lock and tag CBDA1_H	18	At Semaphore, Open, lock and tag CBDA2_SP
2	At Hindmarsh, Open, lock and tag CBDA2_H		
3	At Morphett M2, Open, lock and tag CBDA1_M2		
4	At Morphett M2, Open, lock and tag CBDA2_M2		
5	At Morphett M1, Open, lock and tag CBDA1_M1		
6	At Morphett M1, Open, lock and tag CBDA2_M1		
7	At South Terrace, Open, lock and tag CBDA1_ST		
8	At South Terrace, Open, lock and tag CBDA2_ST		
9	At Black Forest, Open, lock and tag CBDA1_BF		
10	At Black Forest, Open, lock and tag CBDA2_BF		
11	At Plympton, Open, lock and tag CBDA1_P		
12	At Plympton, Open, lock and tag CBDA2_P		
13	At Glenelg, Open, lock and tag CBDA1_G		
14	At Glenelg, Open, lock and tag CBDA2_G		
15	At Woodville, Open, lock and tag CBDA1_WV		
16	At Woodville, Open, lock and tag CBDA2_WV		
17	At Semaphore, Open, lock and tag CBDA1_SP		

Restore

Fig. 26. Isolation schedule of the Deadman switch execution

It is worth to mention (an incident) when a tram pantograph has stuck with the OHW but the tram driver has not realized the incident due to no loss of the tram-cab power. The driver is cruising as usual, nearby platform security guard has called the OCC (Operational Control Center) and the on-duty tram controller (non-electrical operator) immediately has pulled the ‘one stop switch wall mounted lever’ and stopped all trams instantaneously. During another occasion, the South Australian Police has called to stop all trams in the vicinity, as a teenage girl about to commit self-harm. The on-duty ECO has clicked the SCADA soft ‘one click button’ and executed police requirement immediately.

When restoring the traction system by this switch, the CBs close the power flow from each substation to the OHW lines and generate a sequence of outgoing CB closing operations. Fig. 27 has shown the related CBs closing switching program.

Deadman switch Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	At Hindmarsh, remove tag, unlock and close CBDA1_H	18	At Semaphore, remove tag, unlock and close CBDA2_SP
2	At Hindmarsh, remove tag, unlock and close CBDA2_H		
3	At Morphett M2, remove tag, unlock and close CBDA1_M2		
4	At Morphett M2, remove tag, unlock and close CBDA2_M2		
5	At Morphett M1, remove tag, unlock and close CBDA1_M1		
6	At Morphett M1, remove tag, unlock and close CBDA2_M1		
7	At South Terrace, remove tag, unlock and close CBDA1_ST		
8	At South Terrace, remove tag, unlock and close CBDA2_ST		
9	At Black Forest, remove tag, unlock and close CBDA1_BF		
10	At Black Forest, remove tag, unlock and close CBDA2_BF		
11	At Plympton, remove tag, unlock and close CBDA1_P		
12	At Plympton, remove tag, unlock and close CBDA2_P		
13	At Glenelg, remove tag, unlock and close CBDA1_G		
14	At Glenelg, remove tag, unlock and close CBDA2_G		
15	At Woodville, remove tag, unlock and close CBDA1_WV		
16	At Woodville, remove tag, unlock and close CBDA2_WV		
17	At Semaphore, remove tag, unlock and close CBDA1_SP		

Action

Fig. 27. Restoration schedule of the dead man’s switch execution

System restoration by the switch (a single click restoration), is a rare operational restoration in nature. As the on-duty ECO usually make an informed decision and restore the OHW system gradually or as their operational requirements. The OCC controllers usually ask the tram drivers to low all EMU pantographs in the vicinity and issues ‘all clear’ to restore the OHW system. Only then, the on-duty-ECO allows the OHW system restoration progressively to eliminate any tram locomotive internal fault or establish OHW fault in an OHW section or any anomalies in the system. The Deadman switch Cicode functionality has been tested, verified in citectSCADA graphics. A bidirectional interactive presentation has been demonstrated to the engineering team, tram ECC and OCC employees.

The ‘one click system disarm Deadman switch’ function checks the status of the related operational or non-operational CBs, prior to its open-close operation. It generates the switching status of each CB in an automated system switching isolation-restoration program. It does execute the command to open or close all outgoing CBs in one click. If an inline CB is already in open or close position, it doesn’t initiate open or close command again. Simply display the status of the CB in the isolation-restoration program instead. System functionality of the Deadman switch including graphics display and isolation-restoration sequence generation works within a fraction of second.

6.3 Deadman Switch incorporation in the electrical control center:

During the demonstration, the electrical engineering team has showed their discerning interest to implement a real-time interface of the Deadman switch philosophy in their operational tram SCADA system. It ensures the overall system safety and maximizes required time-critical operational interface activities. The model tram traction simulation tool has demonstrated how this soft integration may be implemented within the existing operational CitectSCADA with some minimal variable tagging and mapping. The simulation tool states the required guideline and generic coding for the runtime code integration and implementation. The ‘one click demo’ is used for the Deadman switch methodology demonstration to their new employee training and existing employee awareness program.

6.4 Operational safety and compliance issues:

The RIM has issued a statement about their safety matrix legislative and compliance requirements. The switch inclusion in their OCC and ECC, has significantly boosted their system safety accreditation issues. There was a catastrophic blackout event on 28th September 2016 where a severe weather knocked out three state interconnection transmission lines and 22 electrical network transmission towers [44]. After the event, a full proof system safety has been investigated from the Rail Commissioner. A system safety recommendation also directed from the state coronial inquiry to ensure a full proof system safety for the traction system.

During that statewide blackout, 23 electric trains and 19 electric trams have been stranded across the AMPRN network. Adelaide metro is forced to cancel their services indefinitely to reschedule their operational runtime. Due to the Deadman switch proposal and simulation soft integration into the operational SCADA, the RIM is able to meet the requirements of the rail commissioner recommendations. As they are able to comply with their required system safety matrix at any given time by operating the Deadman switch from remote.

6.5 Summary:

We have discussed overall system safety requirements and how to integrate a 'one click electrical operational interface switch' in this chapter. The Deadman switch mechanism is one of the remote and effective overall system safety features that has been greatly appreciated by the engineering team. The engineering team is convinced to incorporate this system safety feature in both SCADA software and a hardwire interface to enhance their overall system safety compliance requirements. The tool aims to be used as a continual employee training & awareness program tool towards providing new employees a general understanding on how the switching programs of the traction systems work.

Chapter 7

HANDOVER OF THE RESEARCH RESULT

7.1 Introduction

The CitectSCADA offline simulation tool development stages have been progressively verified from time to time. After each demonstration, the end-user feedbacks are fed to fine tune the simulation outcome. The ECC employees are trained and working with the existing operational CitectSCADA. The traction system (as-built simulation tool) is required for a safer operational traction system. Any future substation and associated catenary systems extension or bypass has been verified. The overall system safety features are accommodated as the tool development progressed. This development has been thoroughly considered as of the system requirement verification, iterative coding and debug stages. Each staged level is also required to meet the progressive stage-wise end-user feedback requirements. Hence, the tram traction simulation tool has been developed. It is certainly a very challenging and satisfactory task to take and learn specific real-time operational requirements from the professional team.

It is like a steep curve to learn the traction schematics, system software functional details, functional coding requirements and development of the simulation tool as of those operational requirements. After each set of development stage, we have met with the engineering unit, presented the progress demos and held detail bidirectional discussions. The handover of the simulation tool, feedback from the maintenance and engineering personnel; are the key milestones of the model tool development. The engineering team acceptance of the tool is deemed to be critical for a successful fit-for-the-purpose, functional verification and required operational outcome to be achieved.

The electrical engineering unit has been handed over a disk containing all software and documentation after our successful project completion. A detailed report, the simulator user guide and CitectSCADA software reference guide have been included. The reference guide is focused to navigate how the tool is developed and how to make required edits. The user guide allows the user of the tool to understand how to use the simulation tool and all the required features. An API and detailed description of the functions are also included which provide a very detailed description of the functions that built the simulation including mapping, tagging and variable descriptions.

7.2 The Simulation User Procedure

The user procedure is a complete guideline type report to load and run the traction simulation tool. It consists of all step by step switching execution such as isolation and restoration process. It includes:

- Overview of the general switching activities and how the system switching usually take place on AMPRN systems.

- Loading a project into Citect and familiarity with the Citect main menu from which the user can click to the converter station schematics, OHW schematics, switching schedule demonstrations and electrical engineering template switching programs.

- In depth description of the system schematics and switching demonstrations. As the user have to learn and acquire a clear understanding about the switching to progress in any system switching activities.

- The use of the proper work limit and limits of isolation or POIs to run the simulator. The user has to select informed limits of isolation, prior to execute effective isolation and restoration programs. One of the requirement, from the engineering to make the tool 'as they plan and switching proceed on site' basis. That means the user have to go through on the network schematics as they plan any switching activities and have to make determination to set the work limit and successive POIs. The user have to walk through on the network to set the POIs prior to generate the isolation-restoration programs.

- The user gets familiarization of the organizational switching template and merging to the automated switching program. The automated switching isolation-restoration steps have to be undertaken chronologically, relatively easy to execute and followed the system safety protocols.

- The Automated isolation and restoration switching programs are elaborated and explained graphically in details.

- The simulation tool is compiled to function in any absolute emergency situation such as any massive catenary dewirement, earthquake and police call to disarm the whole network. The user can simulate the de-energization of the entire traction network in one click. The user can also simulate the entire traction system restoration in one click.

This simulation user procedure is shown in the appendix D.

7.3 The Reference Guide

The reference guide explains how the simulation tool is developed and contains:

- Diakoptics subsystem algorithm and its implementation have been explained in details. Each substation is separated into subsystems that have similar line and switch configurations, which allows for repetition in the code.
- The traction system diakoptics representation is discussed in details. This includes the existing network architecture and two new dual rectifier substations and 10 km new double Up and Down lines.
- Overall system switching state representation has been discussed. Specifically, how the algorithm works to determine the operational state of the system switchgear.
- Automated switching sequence generation and appropriate POI selection requirements have been discussed.
- Integrated system safety (the panic button or Deadman switch) requirements and its implementation has been outlined.
- Required APIs such as details description of coded functions, tag and variables have been explained.

This reference guide in shown in the appendix E.

7.4 Summary:

Listening to the end user requirements, functional coding of the required tool development, transfer the required workforce safe switching practice experiences to the tool and its satisfactory handover, have been discussed in this chapter. The ECOs and maintenance staff are using this simulation tool for their day-to-day system switching verification. The management is very grateful to learn the overall system safety integration ‘the Deadman switch’. The RIM already took initiative to implement both hardwire and operational SCADA software ‘one click’ integration in their functional ECC and OCC.

Chapter 8

REMOTE LOCKING AND TAGGING

8.1 Introduction

Engineers Australia [45] has taken a nationwide initiative to bring all transmission, distribution and traction utilities under one platform on remote system locking and tagging. The electrical isolations improvement program [46] will improve the power outage process & reduce the electrical switching time it takes to isolate and restore power, while continuing to achieve & improve safety. That means, all trackside switches will be operated and all POIs earths will be applied remotely prior to undertake an on-site work. The remote locking and tagging will be essential to establish this remote switching promotion. As of the existing electricity regulations, this has to be accommodated to facilitate all extended system of systems [46]. At the moment, only on-site physical locking & tagging is applicable in any traction work-permit process. The workgroup secures the worksite and POIs with their physical lock & tag prior to any work commencement. Once this remote locking & tagging system is introduced, all existing maintenance employees must be trained to the new requirements. The model tramline simulator may be utilized for this remote locking & tagging integration, with minimal object tagging, comment insert and command lock options. Command lock means, the related switch operational status will be locked unless the specified task has been undertaken and 'all clear' has been given to restore.

8.2. How the traction simulator will make a role play

The simulator generates required switching steps by selecting the POIs or work limit. The switcher or checker team usually puts their physical lock & tag on that POIs. Once the new legislation comes into effect, the automated isolation and restoration steps will be accommodated to the POIs locking and tagging with required object coding. The de-energized status of an OHW system is shown in the Fig. 28. Every switch object will be locked and tagged as shown in the figure. The user will enable command lock and insert comments to the remotely locked switch.

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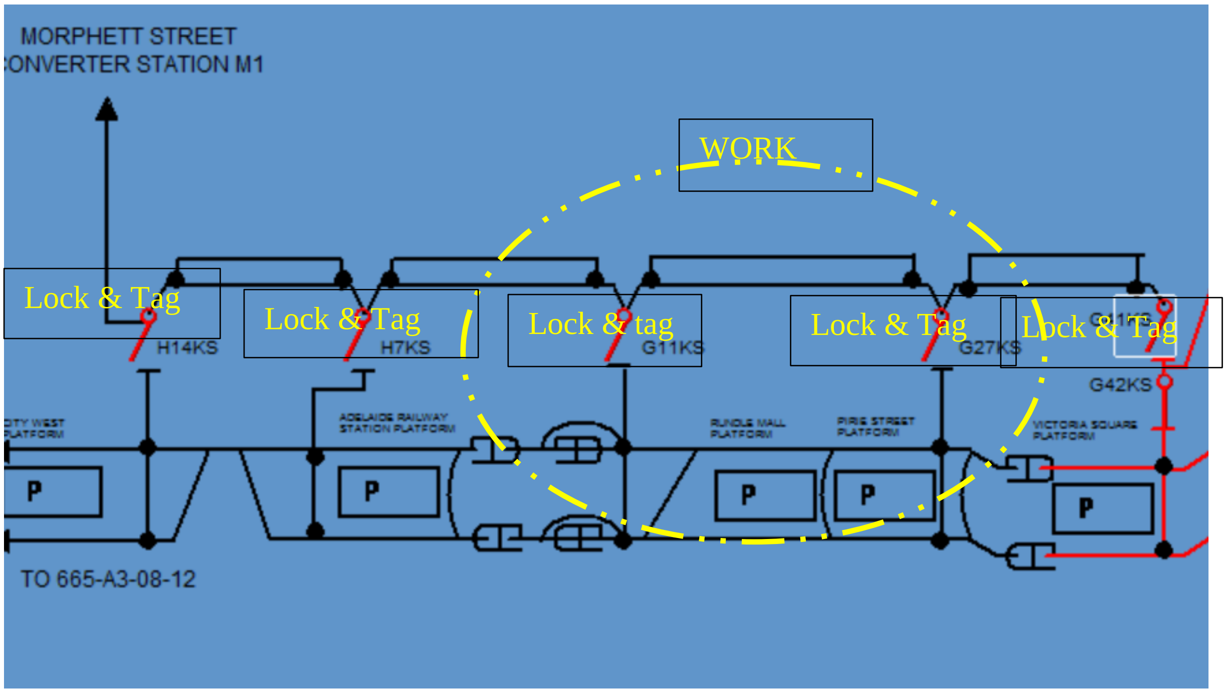


Fig. 28. Remote lock & tag on the worksite

Required remote lock and object tag numbers can be addressed with the simulator with required coding and API interface. Hence the simulator will be incorporated in to the future legislative requirements when needed. The electrical engineering team is very interested on this feature and would like to introduce an interlocking feature with the track-switch closing or opening operation. That means without removing individual ‘lock and tag’, the related switchgear ‘command lock’ cannot be removed prior to the system restoration.

8.3 Summary

Incorporation of the future legislative requirements such as ‘remote system locking & tagging’ has been addressed in this chapter. The engineering team can add those additional features within the simulator with some minimal object coding & tagging including interlocking requirements. The simulator user procedure [chapter 7] and API general functions will guide towards their specific mimic development, object coding, mapping and API integration.

Chapter 9

COMMERCIAL VALUE

9.1 Introduction

The tram traction simulation tool has been functioned and fulfilled operational safety expectations including safe work isolation-restoration practices. The tool is used not only for preparation-verification of real-time isolation-restoration switching schedules but also for L&D employee training switching programs. This generic diakoptics based algorithm may be used for any remote mining, distribution and local distribution grid network management systems.

9.2 Developing the Train simulator

The electrical engineering unit, Government of South Australia has purchased Siemens VICOS train simulator tool from Germany with AUD 250,000.00 in 2013. Any software and maintenance support has to be coordinated directly from German experts and that requires an ongoing contractual agreement with the provider (Siemens). The simulator is not entirely fit for the purpose as of the electrical engineering team. It cannot be used for an automated system isolation-restoration switching generation. Any addition or modification to the simulator, is nearly impossible unless the provider has been contracted to do so.

On the other hand, the tram traction simulator tool is free of charge and also customizable to any specific engineering requirements to their satisfaction. Hence the department is already looking for a suitable and customizable train traction simulation tool after an ample research has been done on this thesis. The tram simulator can easily be converted to the train one with required graphic design, object tagging-mapping and API integration.

The engineering unit is also looking for developing the mobile simulator field user interface to incorporate remote trackside switching approach after this simulator development success.

9.3 Developing the mobile simulator

The RIM is considering to develop the mobile simulator solution for their field crew that will be used for locking & tagging the respective switchgear part of their day to day patrol activities. That simulator may include:

- Detail of each switchgear such as a description of the operational parts and 'insert comment' options.
- User creation (at least 10 active users) and remote access to the simulator server.

- Name tagging of each equipment as of the operational CitectSCADA server.
- Link to the existing Asset Management System.
- Switchgear details, filed report and maintenance feedback inclusion

9.4 Developing remote trackside switching approach

The department has put emphasis on establishing remote sectioning of their overhead systems after this traction simulator success. The engineering team is interested to initiate the concept design of the portable simulator as well as server mapping. By doing so, their electrical controllers will be able to control each overhead electrical section energization remotely. They are keen to implement this strategy in their offline simulator for their employees' continuous refresher and professional development. This generic diakoptics technique can be implemented for the remote trackside switching and employee education training module on remote trackside switches.

Chapter 10

CONCLUSION

10.1 Introduction

Looking into the CitectSCADA (citect code), we are trying to implement a quicker methodological function to integrate into the arithmetic computation of the simulation tool. We initially have tried to implement the prototype function with graph theory based algorithm Depth First Search (DFS) method [33], a method for traversing data structure for trees (nodes). And later we have investigated another graph theory based algorithm Breadth First Search (BFS) method [34], a method that starts at arbitrary root and searches all neighborhood nodes before searching to next level vertices. Even though the prototype functional energy flow (citect code in CitectSCADA) has accommodated the substation energy flow but the multilayer energy flow computational outcome (substation dual supply to the OHW and UFC systems) is too slow.

In AMPRN system, when a converter station transfer switch is open (due to dual outgoing power supply to both OHW and UFC), the graph theory based algorithm has required extensive arithmetic computation on a multilayer energy flow. That is the main reason to reveal a quicker, faster and reliable solution of the model tram traction simulation tool with the implementation of diakoptics based tearing algorithm. This has allowed two systems to be solved separately and then combined to be formed a complete solution for the whole system. Any modification, update or extension of the model OHW-UFC systems, can be accommodated within subsystems functions mapping in Cicode and citectSCADA graphics. It has been explained how to add two new substations and 10km OHW including parallel UFC line extension in the simulator.

Diakoptics algorithm has been proved as a quick and effective simulation tool of the switching state of all areas of the tramline traction system in Adelaide with 159 network switches giving 11,300 unique cases. Before implementing diakoptics in citectSCADA, it is decided to implement diakoptics functions in MATLAB code. The diakoptics functions is completely programed with a runtime of 0.5 seconds. When we have tried to implement the graph theory based algorithms, it has worked optimally within substation and separately within OHW switchgear. But we have experienced difficulties to map the energy flow between the substation and the OHW systems. Both graph theory (substations) and diakoptics (UFC & OHW) could have accelerated the arithmetic computations a bit better (less than 0.5 second) but we haven't initiated that as the diakoptics algorithm has executed optimally to the end user satisfaction.

The algorithm implementation in citectSCADA, has reduced the computational time and effective simulation of the whole network. It has been used for a safe work commencement electrical switching tool on systems and switchgear. The simulator has been proved very handy tool to teach the apprentices or a new employee on a safer approach of system power isolation-restoration, switching program generation and network management in system runtime situations. RIM has admired the tram Traction (citectSCADA) simulation tool for their ongoing operation & maintenance.

10.2 Further development:

The simulation tool works as it is expected. The engineering unit has approved the automated switching tool in their day to day switching checking and verification. The on-duty ECO also uses the simulator for any emergency or inadvertent switching situations when they need to recheck any step immediately. The L&D unit is planning to assign the tool for their new employee or switcher training framework.

However, the simulation tool may be upgraded to a multi POIs levels.

10.2.1 Work Limit and POI:

The simulation tool hasn't got any prescribed work limit at this stage. But in a real maintenance scenario, it is likely that the crew maintain or upgrade a particular section of overhead or underground parallel feeder cable in traction systems. The switching crew has to isolate and earth the system from the feeding point of the adjacent substations to secure and prevent any back feeding to the worksite. For example, when the user would like to generate a switching program to commence a work, isolate and restore the system between G11KS to G27KS as shown in the Fig. 29; the POIs cannot be selected from G11KS to G27KS as shown in the Fig. 30.

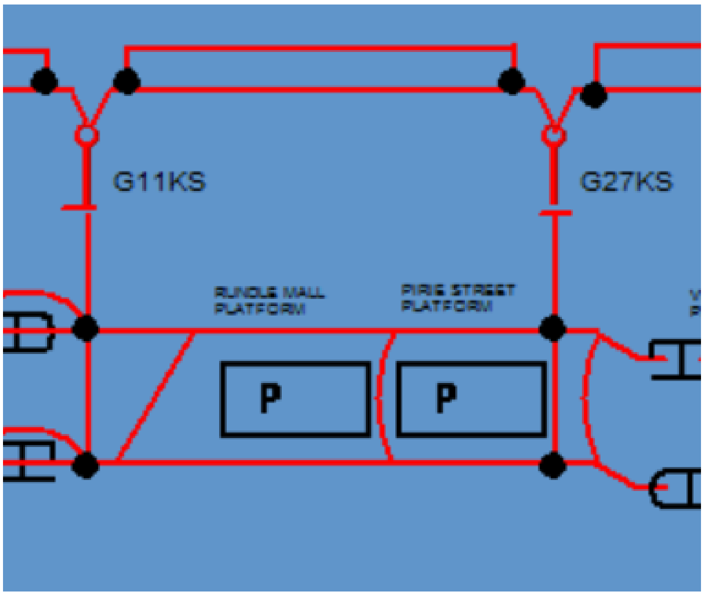


Fig. 29. Worksite: G11KS to G27KS

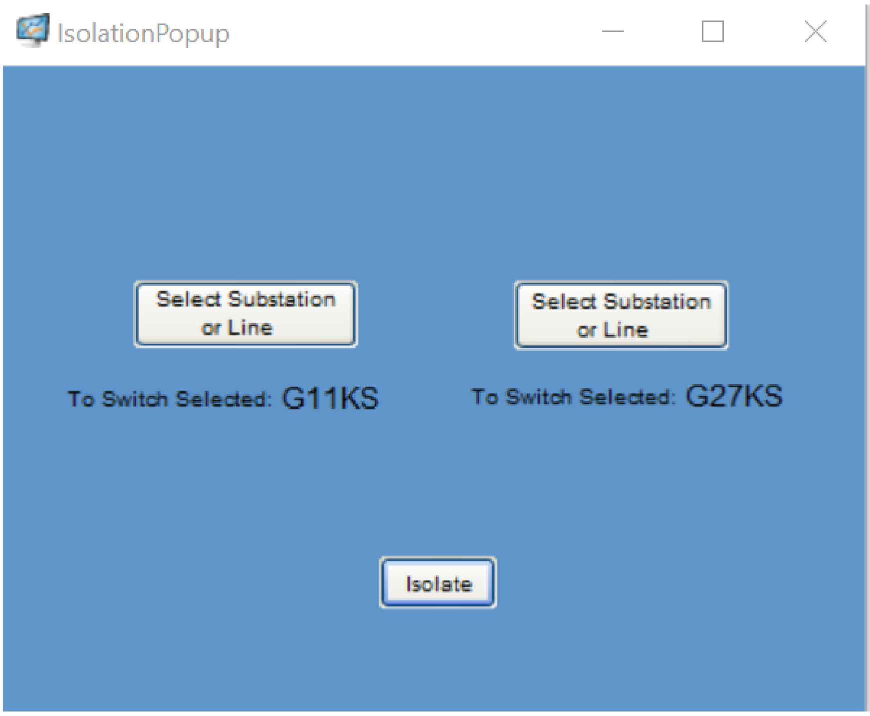
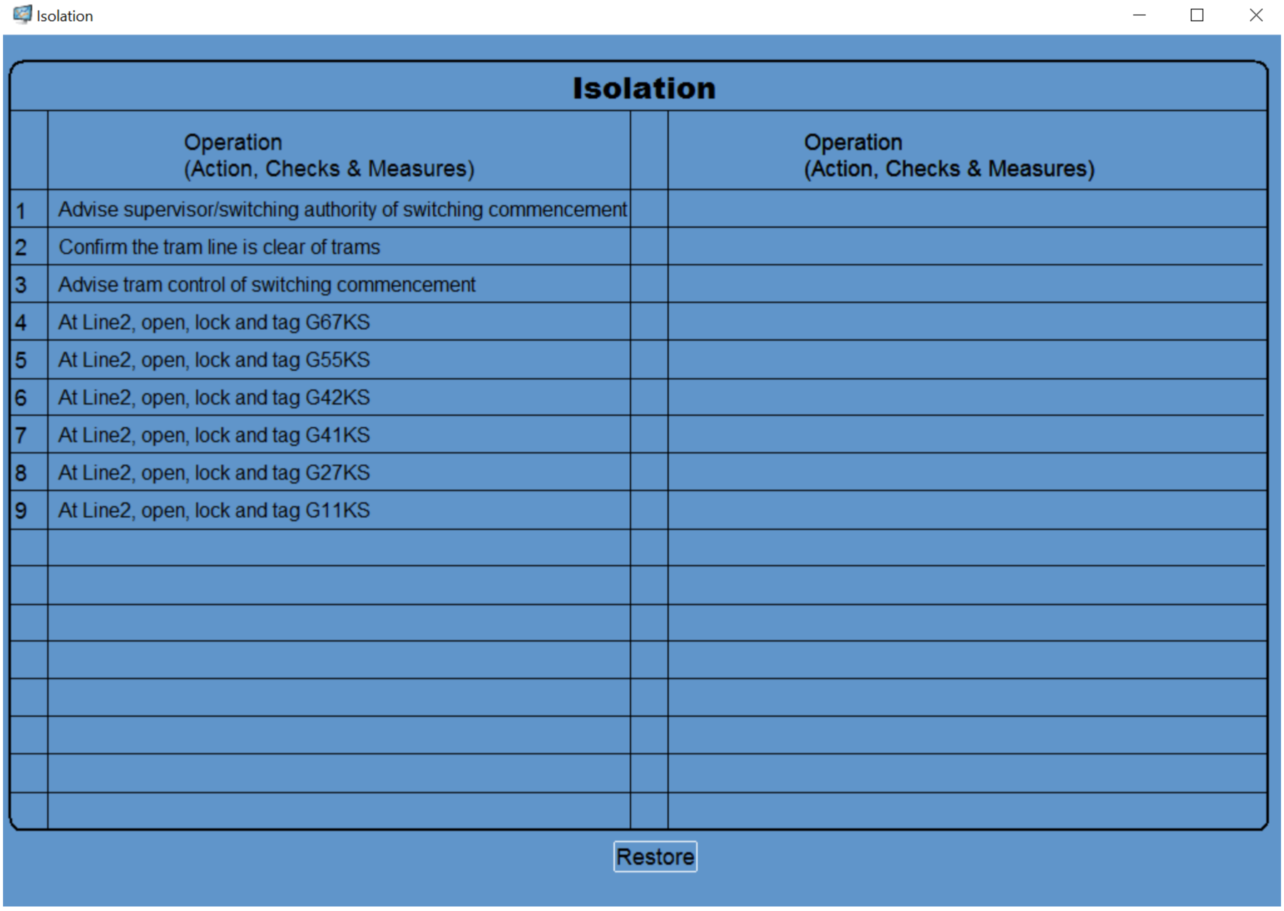


Fig. 30. POIs section: G11KS to G27KS

When the simulation user selects the POIs from G11KS to G27KS, then the isolation schedule generate steps as shown in the Fig. 31, which is not required steps to commence work straightway. These steps open the power flow to the OHW, not to the parallel UFCs. It is very likely, the maintenance crew may need to open related cable junction pits and that requires

UFC isolation as well. The crew must make informed switching steps, as of the system safety and related risk mitigation requirements.



Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Confirm the tram line is clear of trams		
3	Advise tram control of switching commencement		
4	At Line2, open, lock and tag G67KS		
5	At Line2, open, lock and tag G55KS		
6	At Line2, open, lock and tag G42KS		
7	At Line2, open, lock and tag G41KS		
8	At Line2, open, lock and tag G27KS		
9	At Line2, open, lock and tag G11KS		

Fig. 31. Isolation from G11KS to G27KS

Obeying the switching safety requirements, the user clicks on the system schematics, open all incoming switches, secure the worksite and select the required POIs as shown in the Fig. 32.

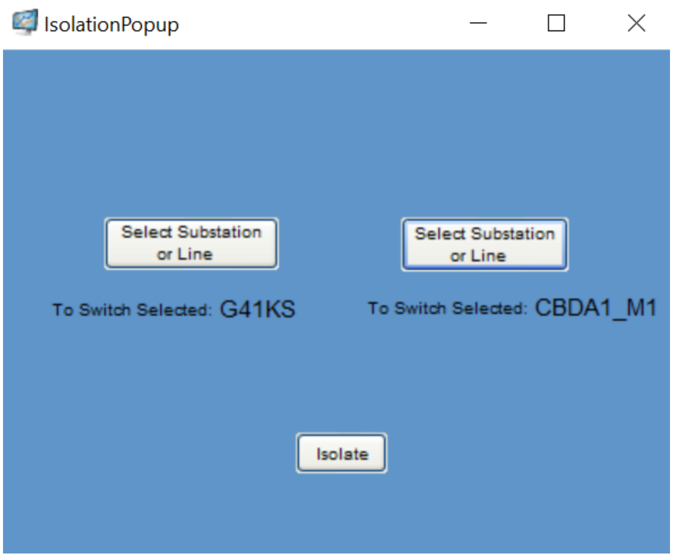


Fig. 32. POIs for work between G11KS and G27KS

The de-energized POIs mimic display is shown in the Fig. 33, where all

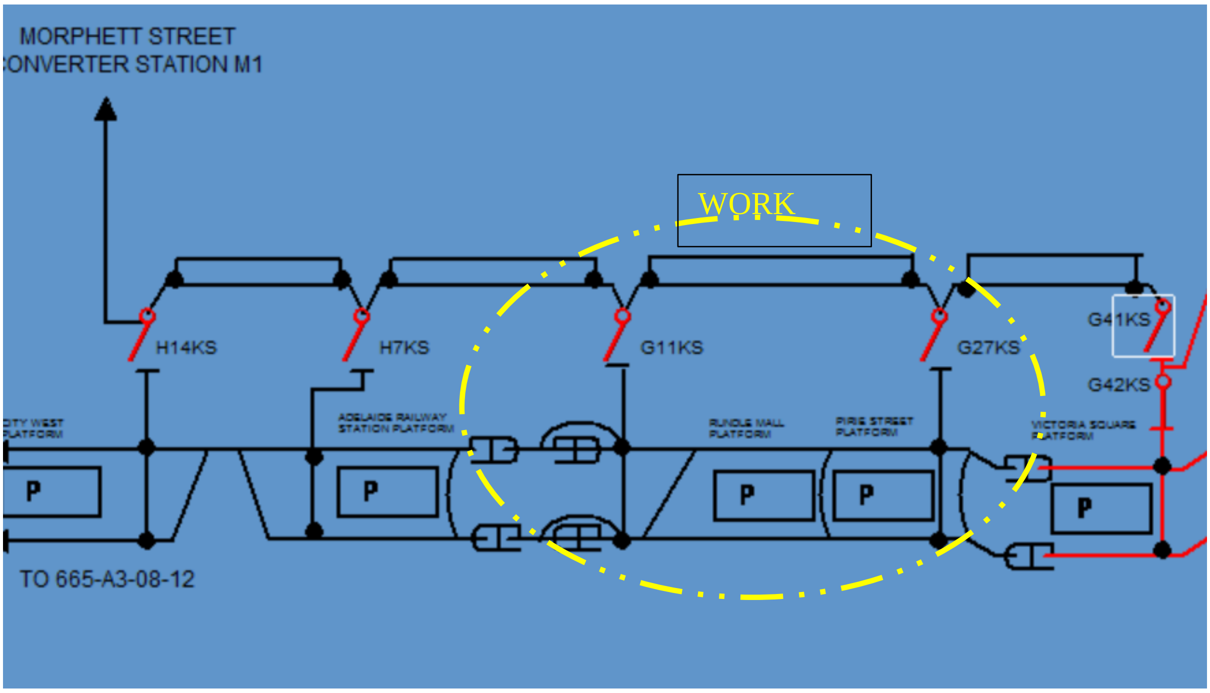
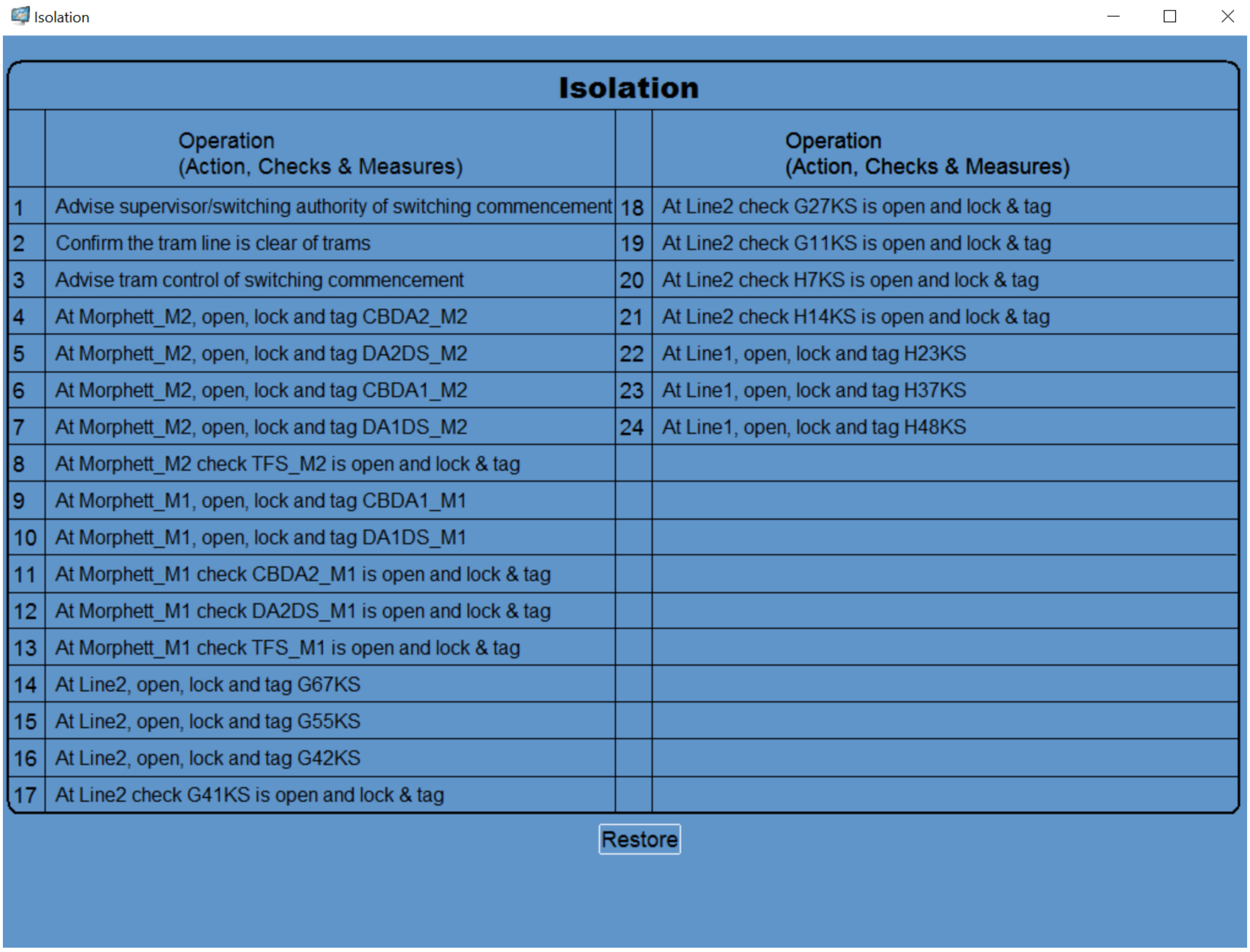


Fig. 33. Isolated Mimic for work between G11KS and G27KS

switches are open and power is de-energized from the related substation outgoing load CBs.

When the user has selected the system mimic as of the verified POIs, clicks on the 'isolate' button, the following isolation switching sequence is generated as shown in the Fig. 34.



Isolation

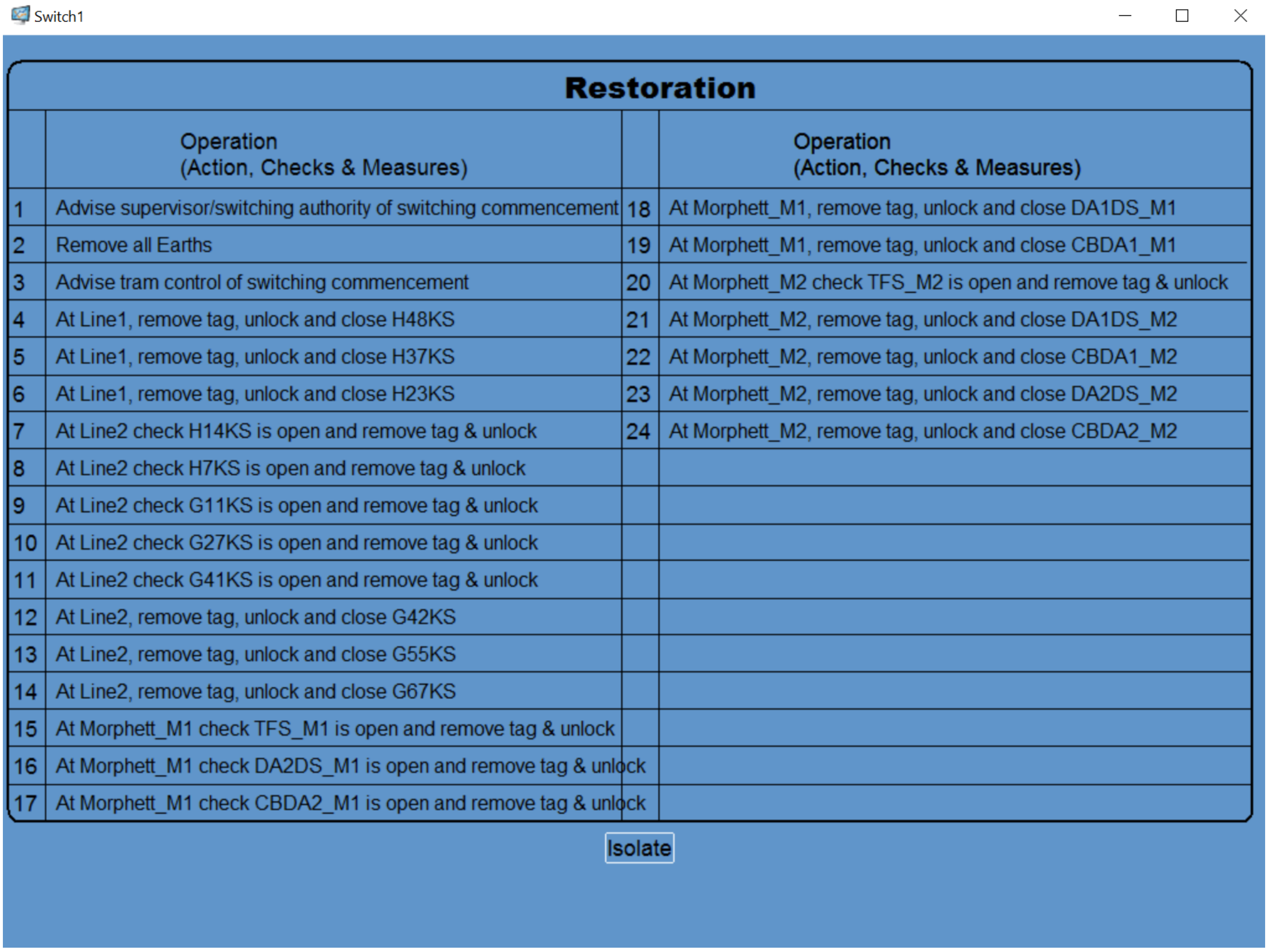
	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Line2 check G27KS is open and lock & tag
2	Confirm the tram line is clear of trams	19	At Line2 check G11KS is open and lock & tag
3	Advise tram control of switching commencement	20	At Line2 check H7KS is open and lock & tag
4	At Morphett_M2, open, lock and tag CBDA2_M2	21	At Line2 check H14KS is open and lock & tag
5	At Morphett_M2, open, lock and tag DA2DS_M2	22	At Line1, open, lock and tag H23KS
6	At Morphett_M2, open, lock and tag CBDA1_M2	23	At Line1, open, lock and tag H37KS
7	At Morphett_M2, open, lock and tag DA1DS_M2	24	At Line1, open, lock and tag H48KS
8	At Morphett_M2 check TFS_M2 is open and lock & tag		
9	At Morphett_M1, open, lock and tag CBDA1_M1		
10	At Morphett_M1, open, lock and tag DA1DS_M1		
11	At Morphett_M1 check CBDA2_M1 is open and lock & tag		
12	At Morphett_M1 check DA2DS_M1 is open and lock & tag		
13	At Morphett_M1 check TFS_M1 is open and lock & tag		
14	At Line2, open, lock and tag G67KS		
15	At Line2, open, lock and tag G55KS		
16	At Line2, open, lock and tag G42KS		
17	At Line2 check G41KS is open and lock & tag		

Restore

Fig. 34. Isolation sequence to commence work between G11KS and G27KS

This automated isolation switching program is ready to commence work on site. The switcher-checker crew verifies the steps as of the operational system mimic de-energized status and ask for engineering approval.

The user promptly generates the restoration sequence by clicking the ‘restore’ button, which is ready to commence system restoration schedule after immediate maintenance work completion. The assigned switcher-checker team verifies the restoration steps as shown in the Fig. 35 and seeks for engineering approval.



Switch1

Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Morphett_M1, remove tag, unlock and close DA1DS_M1
2	Remove all Earths	19	At Morphett_M1, remove tag, unlock and close CBDA1_M1
3	Advise tram control of switching commencement	20	At Morphett_M2 check TFS_M2 is open and remove tag & unlock
4	At Line1, remove tag, unlock and close H48KS	21	At Morphett_M2, remove tag, unlock and close DA1DS_M2
5	At Line1, remove tag, unlock and close H37KS	22	At Morphett_M2, remove tag, unlock and close CBDA1_M2
6	At Line1, remove tag, unlock and close H23KS	23	At Morphett_M2, remove tag, unlock and close DA2DS_M2
7	At Line2 check H14KS is open and remove tag & unlock	24	At Morphett_M2, remove tag, unlock and close CBDA2_M2
8	At Line2 check H7KS is open and remove tag & unlock		
9	At Line2 check G11KS is open and remove tag & unlock		
10	At Line2 check G27KS is open and remove tag & unlock		
11	At Line2 check G41KS is open and remove tag & unlock		
12	At Line2, remove tag, unlock and close G42KS		
13	At Line2, remove tag, unlock and close G55KS		
14	At Line2, remove tag, unlock and close G67KS		
15	At Morphett_M1 check TFS_M1 is open and remove tag & unlock		
16	At Morphett_M1 check DA2DS_M1 is open and remove tag & unlock		
17	At Morphett_M1 check CBDA2_M1 is open and remove tag & unlock		

Fig. 35. Restoration sequence to restore system between G11KS and G27KS

Merging the miscommunication between the work limit and the POIs is one of the areas of improvement of the simulation tool. By implementing so, any user (experienced or a novice) can select the required work limit and the tool generates the required ‘ready to approve’ safe automated system switching steps. On the flip, this merging creates a confusion to a new comer, who hasn’t got any knowledge about system switching and associated safety requirements. The electrical engineering team didn’t approve the idea of merging the work limit to POIs. By doing so, they recommend; making an informed POIs selection, patrol on the work site and determine required switching steps (a pre-work commencement requirement) cannot be achieved. This improvement can be done with required object coding, mapping and variable tagging as of the developed APIs if required.

10.2.2 Multiple POIs inside a Converter Station:

System isolation-restoration and work commencement within a converter station are a bit complicated. That requires precise AC & DC system switchgear interlocking and POIs switchgear knowledge and securing the worksite. In a dual rectifier converter station, if the 11 kV incoming bus-tie falls within the POIs, one set of POIs, simply doesn't achieve the safe work selection as of the existing simulation tool algorithm. It requires multiple (three to four) POIs selection for generating a 'ready to work commence' safe isolation–restoration switching steps. The user clicks on the converter station schematics, operates all required work limit switches, makes an informed decision about multiple POIs and secures the worksite. The tool certainly works for system switching & system interlocking verification as of the Fig. 36 but doesn't generate required automated isolation-restoration steps for more than two POIs. The user has earthed both incoming feeds including traction transformers and completely bypassed the converter station to secure the multiple POIs worksite as shown in the figure.

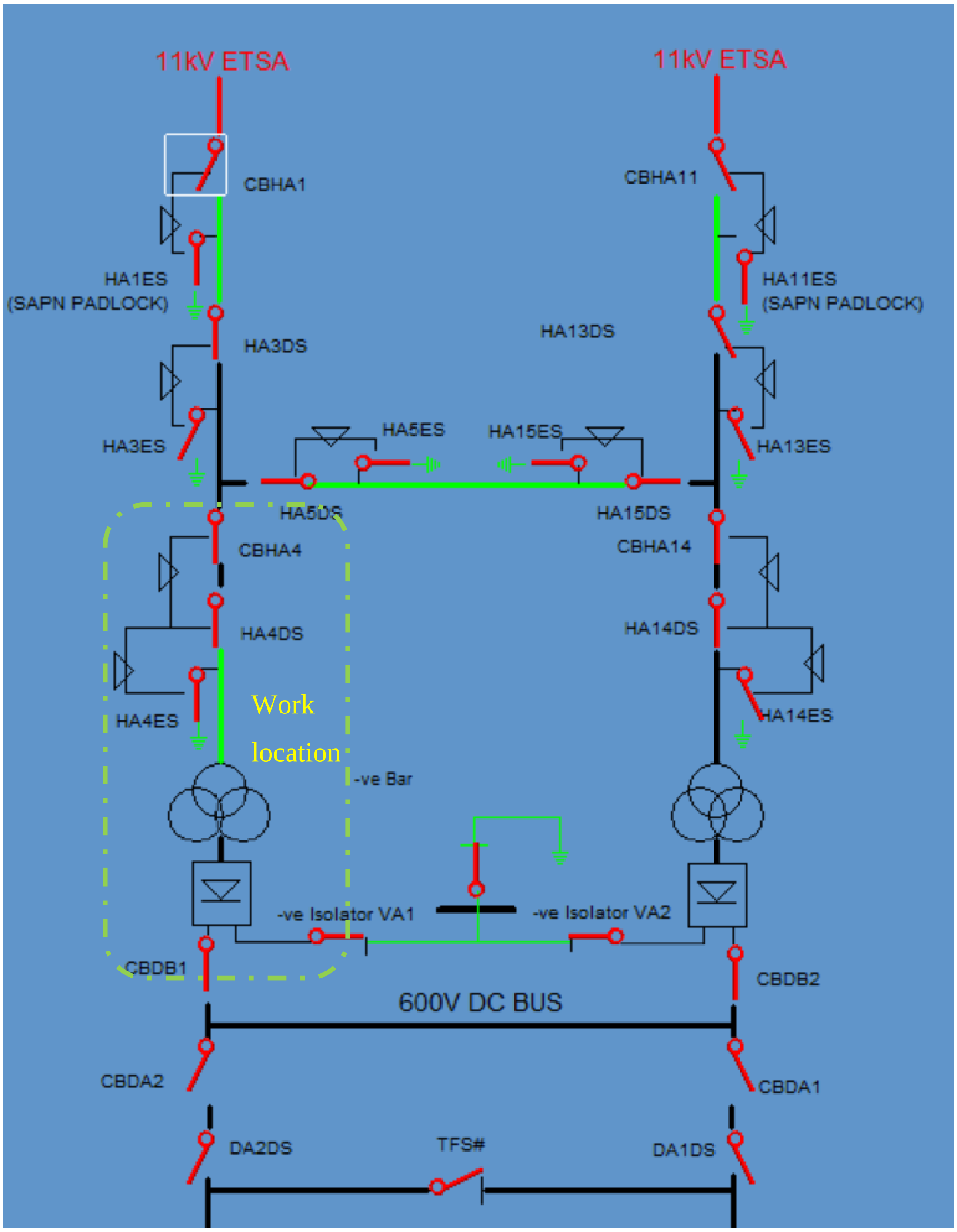


Fig. 36. Isolated and earthed of a dual rectifier converter station

When we consider a POIs within Hindmarsh from CBHA1_H to CBDA2_H (as shown in the Fig. 37) and click on the 'isolate' button, it generates isolation steps as shown in the Fig 38. That is a 'ready to work commence' type isolation program but the relevant inter-departmental padlocks have to be removed and earth switches have to be closed or temporary earths have to be applied manually prior to commence the system maintenance work.

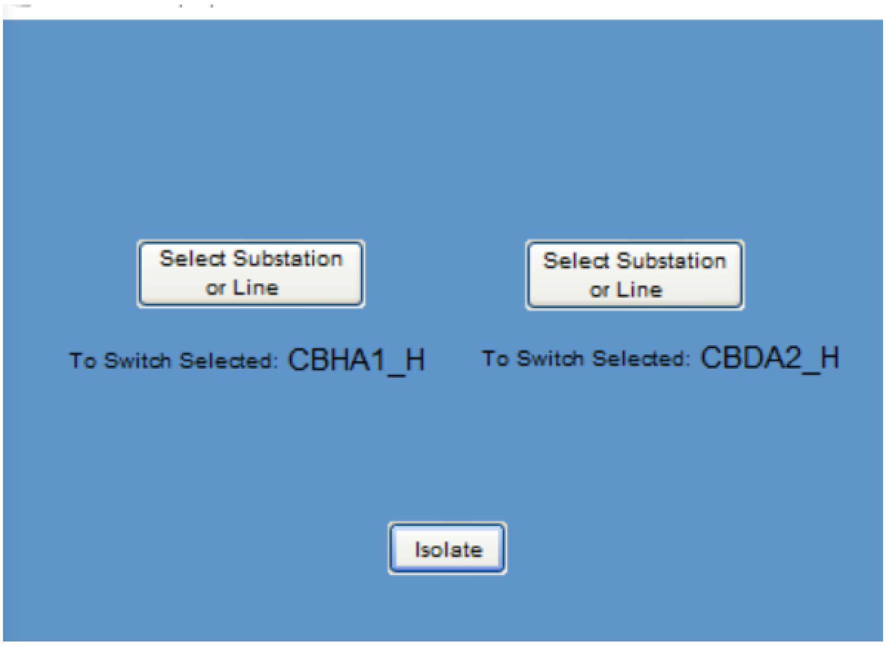


Fig. 37. POIs within Hindmarsh from CBHA1_H to CBDA2_H

Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Confirm the tram line is clear of trams		
3	Advise tram control of switching commencement		
4	At Hindmarsh, open, lock and tag CBHA1_H		
5	At Hindmarsh, open, lock and tag HA3DS_H		
6	At Hindmarsh, open, lock and tag HA5DS_H		
7	At Hindmarsh, open, lock and tag CBHA4_H		
8	At Hindmarsh, open, lock and tag HA4DS_H		
9	At Hindmarsh, open, lock and tag CBDB1_H		
10	At Hindmarsh, open, lock and tag CBDA2_H		
11	At Hindmarsh, open, lock and tag DA2DS_H		
12	At Hindmarsh, open, lock and tag TFS_H		

Restore

Fig. 38. Isolation sequence for POIs CBHA1_H to DA1DS_H (within Hindmarsh)

When we consider to de-energise both incoming feeders CBHA1 and CBHA11, then the simulator requires more information for another set of POIs. The transfer switch and outgoing tap to trolley switches consider as two additional POIs. We cannot select three or four or five POIs inside a substation at this staged algorithm development. The simulator switching steps doesn't work for more than two POIs inside a converter station.

However, the traction simulator tool can be upgraded to a multiple POIs inside a converter station including system switchgear interlocking and operational understanding. This improvement can be done in CitectSCADA with required object coding, mapping, tagging and APIs integration.

10.3 Summary

Further extension of the simulation tool provides a very promising possibility and work flexibility to the operation & maintenance employees. Multiple POIs inside a converter station is one of the examples. But they can utilize the tool visuals during POIs selection inside a substation. The offline tram traction simulation tool certainly works as it is specified and expected. The electrical controller must maintain the operational switching state of the entire network prior to generate the switching programs. No field RTU data has been incorporated to the simulator input. The system switchgear switching state stay as the simulator input. Any extension or network mimic modification must be tagged accordingly. The electrical engineering team already using the automated switching programs in their day to day isolation-restoration switching checking and verification. The engineering team is actively looking to implement the general diakoptics based algorithm to their electric train traction simulation tool at their earliest opportunity.

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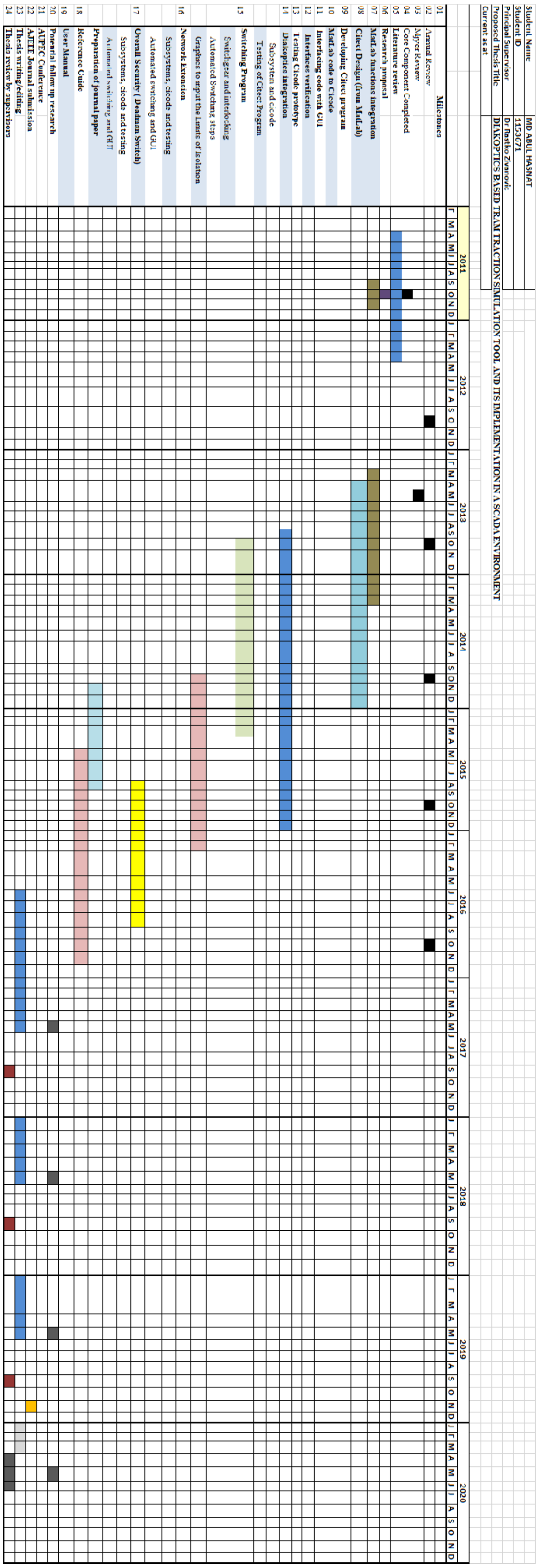
Appendix A

PhD Research Project Completion Chart



Appendix B

System Simulation basic Algorithm

In this example network, area-1 is permanently connected to the traction system via a step down transformer. Area-2 is connected with area-1 via M2DA2 CB. Area-3 is connected with area-1 via M2DA1 CB. Area-4 is connected with area-2 via M2DA2DS isolator. Area-5 is connected with area-3 via M2DA1DS isolator. All relevant isolators and CBs are closed position.

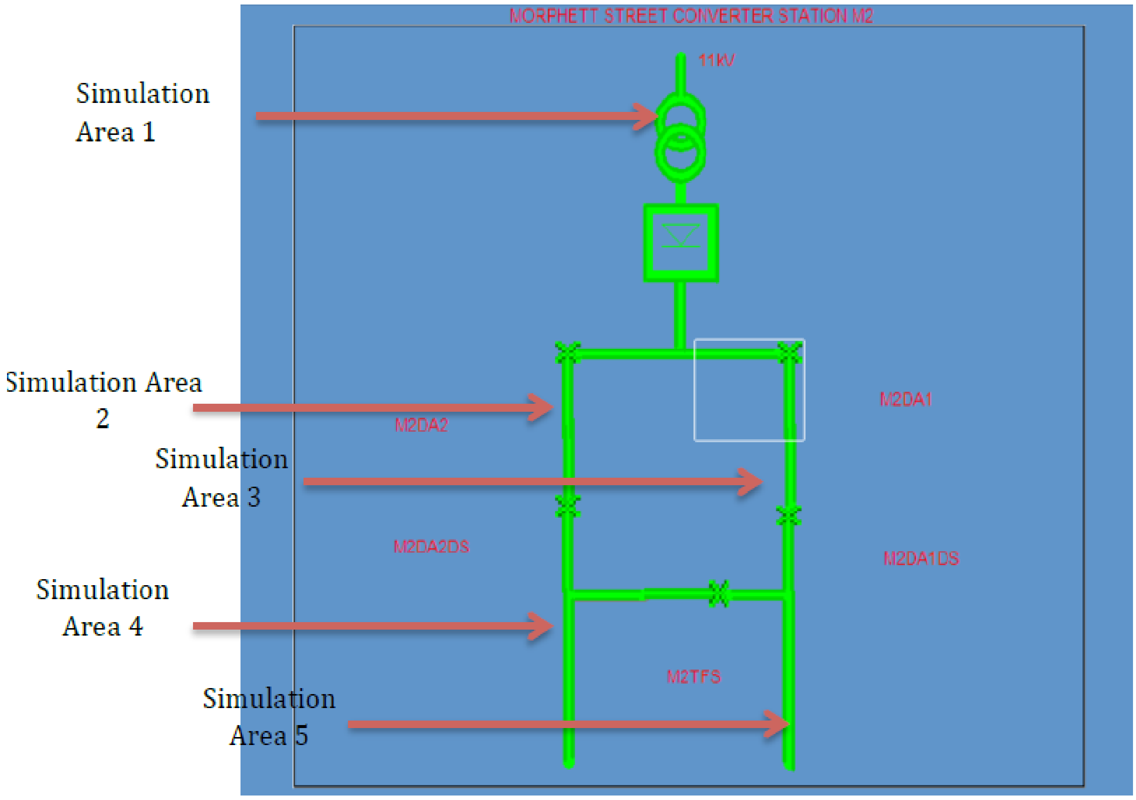


Fig. B1. Initial sample System

After Opening the Circuit Breaker M2DA2

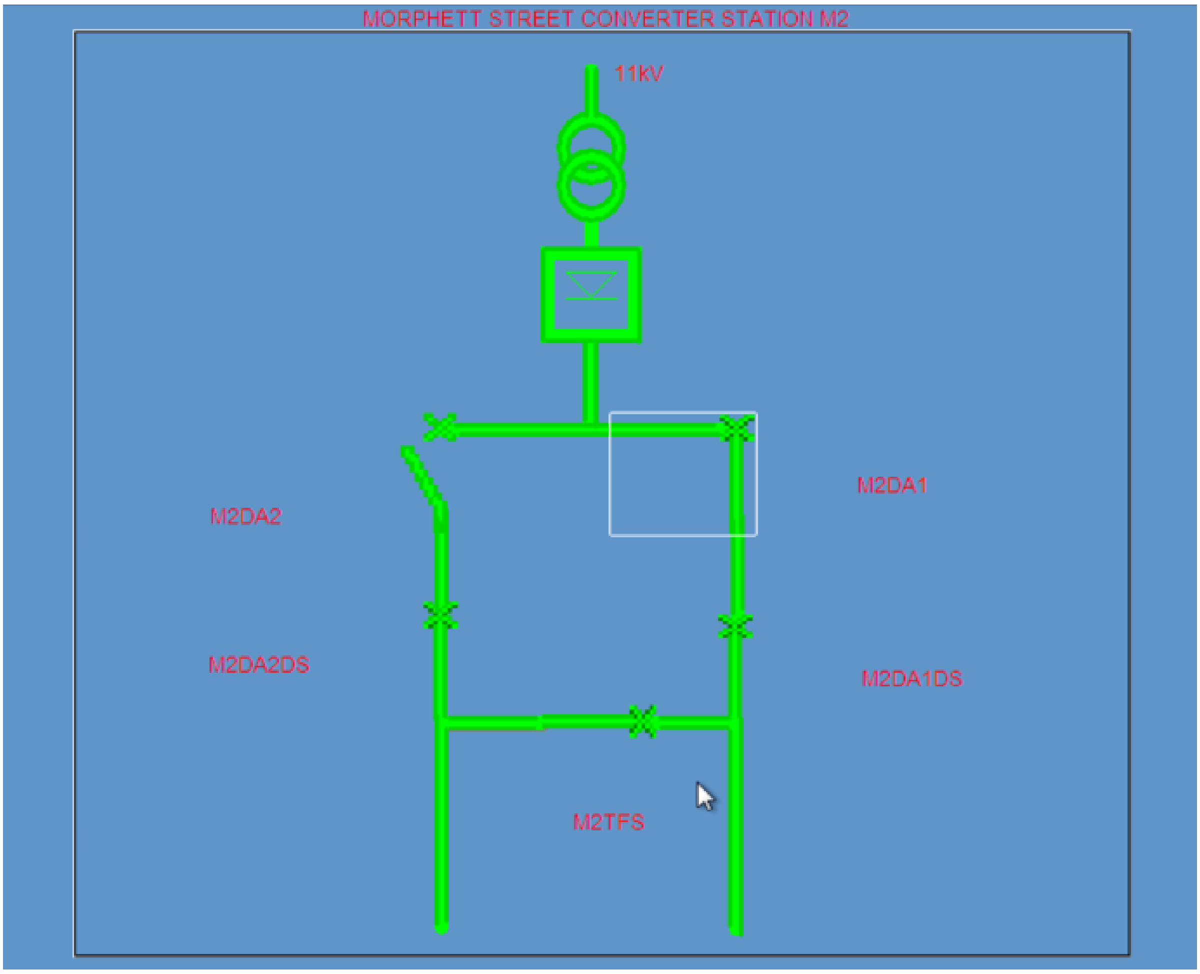


Fig. B2. Initial sample System:

	Area1	Area 2	Area 3	Area 4	Area 5
Area 1	1	0	1	0	0
Area 2	0	1	0	1	0
Area 3	1	0	1	0	1
Area 4	0	1	0	1	1
Area 5	0	0	1	1	1

Switch opened and connection now set to zero

$$\begin{bmatrix}1\\0\\0\\0\\0\end{bmatrix}$$

Only Simulation Area 1 is active initially

Note: The algorithm only cares if the number is zero or one, thus we only ever put a one in or zero in the solution matrix. Thus we only look for two corresponding ones in the connections and initial active matrix and then put a one

Simulation Iteration 1:

$$\begin{bmatrix}1&0&1&0&0\\0&1&0&1&0\\1&0&1&0&1\\0&1&0&1&1\\0&0&1&1&1\end{bmatrix}\times\begin{bmatrix}1\\0\\0\\0\\0\end{bmatrix}=\begin{bmatrix}1\\0\\1\\0\\0\end{bmatrix}$$

Iteration 2:

$$\begin{bmatrix}1&0&1&0&0\\0&1&0&1&0\\1&0&1&0&1\\0&1&0&1&1\\0&0&1&1&1\end{bmatrix}\times\begin{bmatrix}1\\0\\1\\0\\0\end{bmatrix}=\begin{bmatrix}1\\0\\1\\0\\1\end{bmatrix}$$

Iteration 3:

$$\begin{bmatrix}1&0&1&0&0\\0&1&0&1&0\\1&0&1&0&1\\0&1&0&1&1\\0&0&1&1&1\end{bmatrix}\times\begin{bmatrix}1\\0\\1\\0\\1\end{bmatrix}=\begin{bmatrix}1\\0\\1\\1\\1\end{bmatrix}$$

Iteration 4:

$$\begin{bmatrix}1&0&1&0&0\\0&1&0&1&0\\1&0&1&0&1\\0&1&0&1&1\\0&0&1&1&1\end{bmatrix}\times\begin{bmatrix}1\\0\\1\\0\\1\end{bmatrix}=\begin{bmatrix}1\\0\\1\\1\\1\end{bmatrix}$$

Iteration 5:

$$\begin{bmatrix}1&0&1&0&0\\0&1&0&1&0\\1&0&1&0&1\\0&1&0&1&1\\0&0&1&1&1\end{bmatrix}\times\begin{bmatrix}1\\0\\1\\1\\1\end{bmatrix}=\begin{bmatrix}1\\1\\1\\1\\1\end{bmatrix}$$

After five iterations, the simulation has reached a steady state solution and an answer has been found. The solution matrix contains all ones so all areas (area1 to area5) of the example network are still active. That is, after M2DA2 CB is opened, the area-2 is back fed via M2DA1DS isolator and related transfer switch M2TFS.

Now Open Isolator M2DAIDS

New Connections Matrix

	Area1	Area 2	Area 3	Area 4	Area 5
Area 1	1	0	1	0	0
Area 2	0	1	0	1	0
Area 3	1	0	1	0	1
Area 4	0	1	0	1	1
Area 5	0	0	1	1	1

After simulation
Iteration 1:

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

Iteration 2:

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

Simulation reaches steady state and further iteration do not change the solution

The solution matrix now has only two ones, this tells us that only simulation area 1 and 3 are active as shown in the diagram Fig. B3 below.

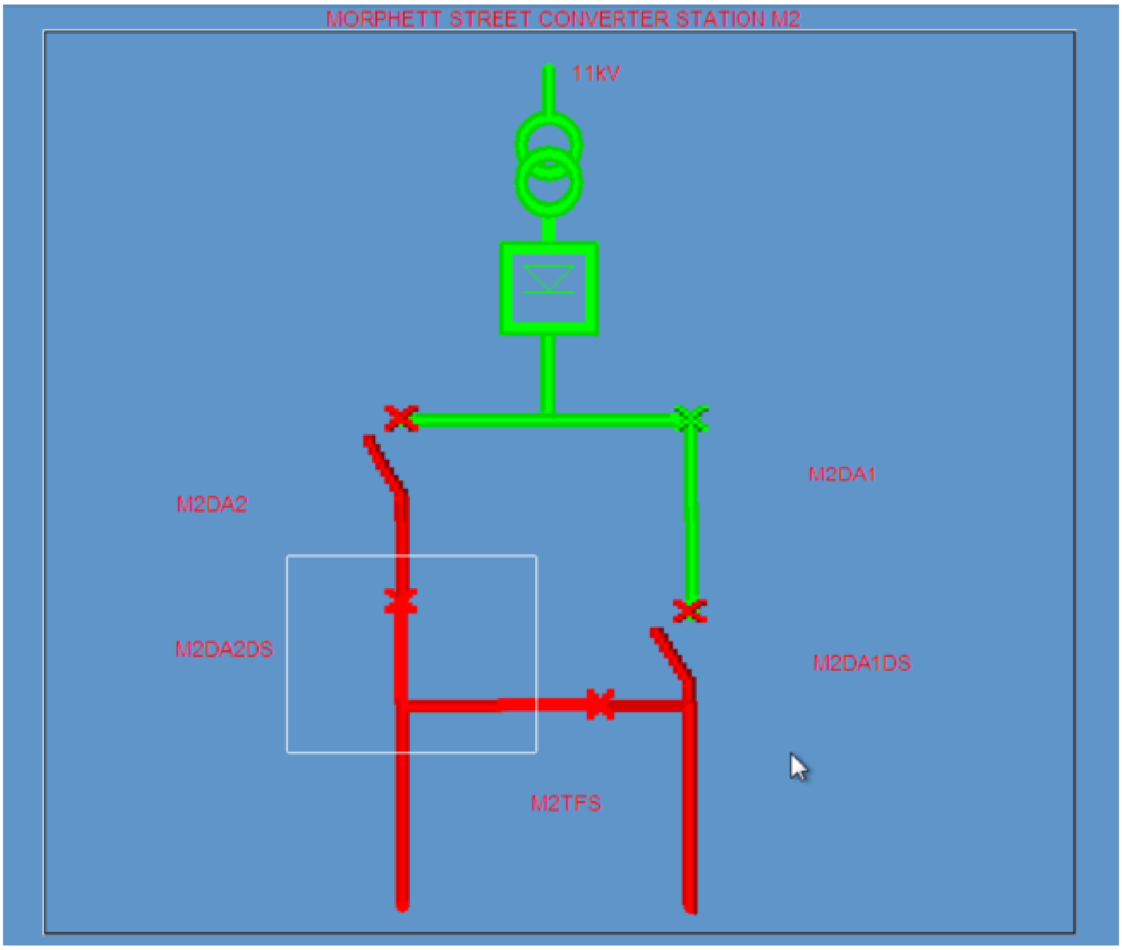
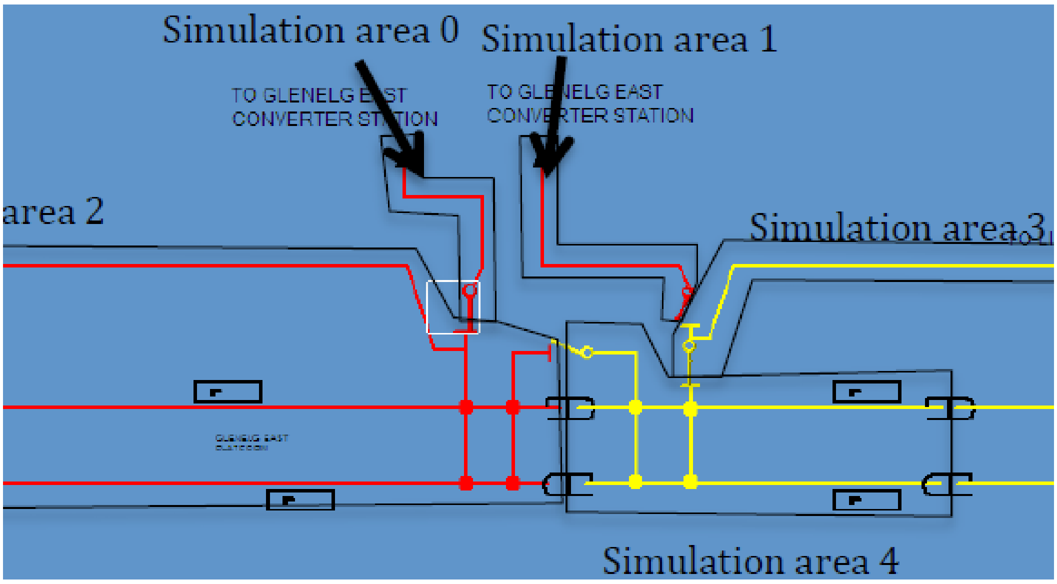


Fig. B3. The sample network after two switches OPEN

The above algorithm can simulate the state change operation (ON or OFF) of the switchgear with some degree of freedom. In the above example, the example system is very small and contained only five parts. The size of the connection matrix was 5×5 and the initial matrix was of size 5×1. In the simulations, it took a maximum of five iterations to reach the steady state. The number of simulations depends on the number of system switches. However, when the system is extended up to 150 system switches of 55 subsystems or extended to 80 subsystems; it would have taken more steps of iterations before reaching steady state.

Overhead section simulation

A similar energy flow for an overhead section may be calculated. Consider an outgoing section, with related tap to trolley switch and section insulators as shown in the figure B4. As explained in the algorithm, this overhead section can be used to produce a connection matrix as of the following electrical state of the OHW section or subsystems i.e. how UP and DOWN network switchgear are connected.



$$
\begin{bmatrix}
true & 0 & true & 0 & 0 \\
0 & true & 0 & true & 0 \\
true & 0 & true & 0 & 0 \\
0 & 0 & 0 & true & true \\
0 & 0 & 0 & true & true
\end{bmatrix}
$$

Fig. B4. A sample overhead section network and associated connection matrix.

Appendix C:

Subsystem connection matrix definition

CitectSCADA is a real-time simulation platform that means the operation time of each circle should be narrowed to the least. Instead of a mathematical calculation, the diakoptics code is a judgement code. We defined a judgement signal ‘temp’, system 5 into 5 diakoptics matrix ‘system[][]’, energy vector ‘Energy[]’ and temporary energy vector ‘tempEnergy[]’.

For clarification, the following Fig. C1 example is shown with both algorithm and application code.

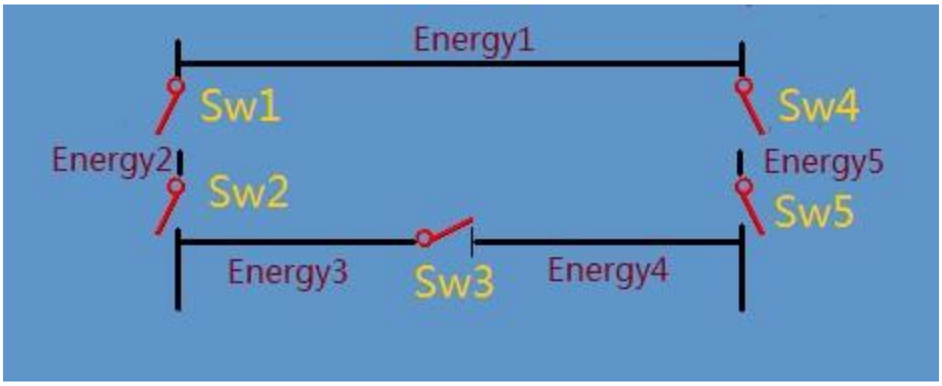


Fig. C1. Diakoptics application example.

System[][]:

The matrix below is the diakoptics matrix for the system above and all these *Sw* variables are switch states. Each switch variable has two states one and zero. As the same as computer language coding, one means energized and zero means de-energized, so if we press switch-1 on this system, the switch will close and line-1 and line-2 is connected.

$$\begin{bmatrix} 1 & Sw1 & 0 & 0 & Sw5 \\ Sw1 & 1 & Sw2 & 0 & 0 \\ 0 & Sw2 & Sw3 & 0 \\ 0 & 0 & Sw3 & 1 & Sw4 \\ Sw5 & 0 & 0 & 1 & Sw4 & 1 \end{bmatrix}$$

Energy[]:

Energy vector have two states. The first state is steady state in which this vector shows all lines energy situation. The second state happens when there are any changes in system such as switches state changing. This vector will be used to calculate the new steady state power.

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

tempEnergy[]:

This vector is an intermediate variable which restores the state of lines' energy in each loop. As we mentioned in chapter 3, when each elements in the tempEnergy vector is equal to the energy vector, diakoptics function will stop and the energy vector is the required energy of the lines.

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

'temp':

Temp is a signal of judging whether a diakoptics matrix reaches its steady state. If temp signal is one, it means the system still need to be calculated.

```
! DIAKOPTICS.CI
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!       FUNCTION: diakoptics()                    !
!       INPUT: 5x5 matrix named 'system'            !
!              1x5 matrix names 'energy'          !
!       OUTPUT:1x5 matrix named 'energy'            !
!       PROCESS: Funtion multiplys out the system matrix!
!          with the energy matrix assigning the result !
!          to matrix, energy.                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
INT tempEnergy[5];
INT energy1[5];

FUNCTION
diakoptics()

   INT L;
   INT J;
   INT K;
   INT temp = 1;

   FOR L = 0 TO 4 DO
      tempEnergy[L] = 0;
   END

   WHILE temp=1 DO
   FOR L = 0 TO 4 DO  ! For each row in connections matrix

      FOR J = 0 TO 4 DO  ! For each column of Connections matrix

         IF system[L][J] AND energy[J] THEN      ! If system and energy are
True then area is true

            tempEnergy[L] = 1;

         END

      END

   END

   IF tempEnergy[0]=energy[0] AND tempEnergy[1]=energy[1] AND
tempEnergy[2]=energy[2] AND tempEnergy[3]=energy[3] AND
tempEnergy[4]=energy[4] THEN

      temp = 0;

   END

   FOR K = 0 TO 4 DO  !assign temperary matrix to energy matrix and return

      energy[K] = tempEnergy[K];

   END
   END
END
```

Appendix D:

Simulator User Procedure

1. Scope:

This outlines how to use the traction simulation tool and includes overall simulator information of the AMPRN traction substation, OHW and UFC arrangement. This features the feasibility of the tool and how to select specific substation, OHW and associated interlocking arrangements to determine switchgear state, switching programs for pre-selected POIs, systems upgradation and overall system safety integration to the tool.

This section doesn't contain any information related to CitectSCADA explorer, Citect project editor and Citect graphics builder which has to be learnt from the Schneider electric Citect online tutorials including related Citect helps.

2. Program in CitectSCADA:

The Citect program is stored as a backup file of extension .ctz. This file contains all the necessary files as such graphics, equipment, tags, alarms, systems, Cicode files which are needed to run or edit the simulator program. This program was developed using CitectSCADA 7.30 but also allows to run in the later versions. CitectSCADA program opening window and associated hotkeys is shown in the figure-E1. After opening the Citect Explorer, it runs with Citect graphics builder and Citect project editor. In the Citect Explorer the simulation project will be opened and run.

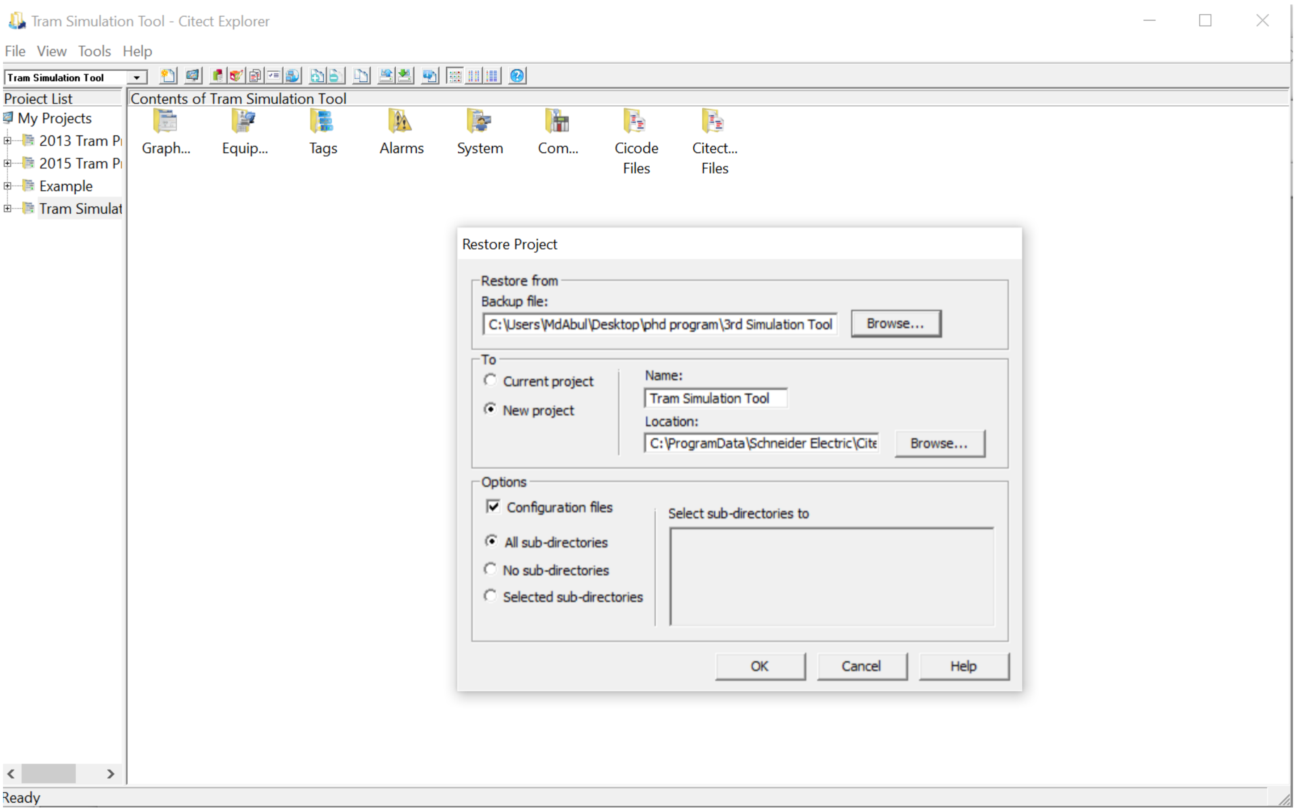


Fig. D1. Citect SCADA program opening

After selecting **Tools > restore,** from the above Citect explorer toolbar menu; the location of the project file has to be selected as shown in the pop-up menu. Under the 'Backup file:' field, insert the location of the backup file. To create a new project, insert a Project name and choose a location for the project to be saved to. Select OK.

Citect explorer will run on demo mode, doesn't require any protection key, and click OK as shown in the Fig. D2.

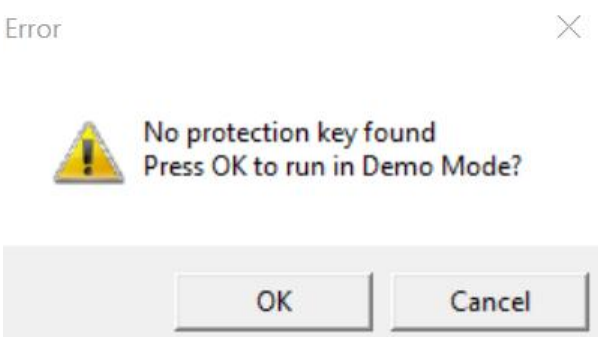


Fig. D2. Citect explorer pop-up window

Now the project has been loaded into Citect. On the left under ‘Project List’, a summary of the components of the project is shown. After selecting **File > run,** the Citect Main menu will open as shown in the Fig. D3.

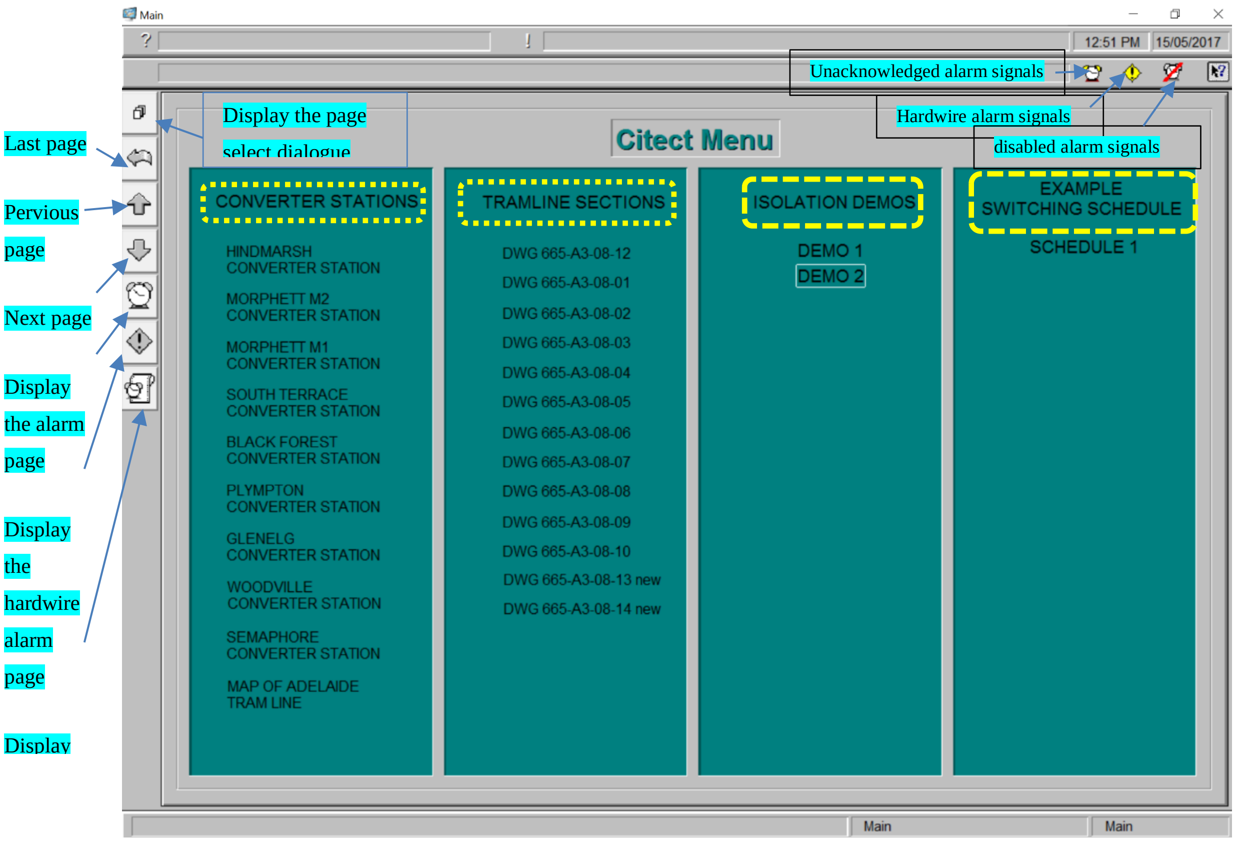


Fig. D3. Citect Main Menu

In the above main menu, it is showed as-built converter stations switching schematics, tramline operational section schematics, isolation demonstrations and example switching programs. This has showed links to associated IEDs alarm signals and can hover on to other pages. In this simulation, we haven’t used any inputs and outputs tag variables from the remote IEDs or RTUs, so any remote hardware and software alarms are not relevant.

Out of the main menu, Converter Station schematics provide all details of switching arrangements of the individual OHW feeding substation and associated HV, rectifier diode and LV switchgears including opening-closing interlocking. This column also accomodated with two new future substations (Woodville and Semaphore).

The tramline schematic column states all OHW and DC UFC such as catenary systems. OHW systems are separated in sections to share section-wise locomotive loads. The parallel UFC system is connected with the OHW system including intermittent TT switches.

The isolation demo column is equipped with switching demonstrations of 'how an isolation could be undertaken' using this isolation simulation tool. Two of those demonstrations have been implemented for initial system switching concept discussion for a new employee training program.

A real-time switcher-checker template scheduled (from the electrical engineering team) isolation-restoration switching program has been discussed to demonstrate step-by-step system switching prior to generate simulator switching programs. Before using the traction simulator, these demo and example switching programs have to be read to have an understanding on system electrical switching.

3. Converter Stations and OHW sections:

There are two types of converter stations: a. double rectifier converter station, and b. single rectifier converter station as shown in Fig. D4 and Fig. D5. Details of the system switchgear have been shown in the figures.

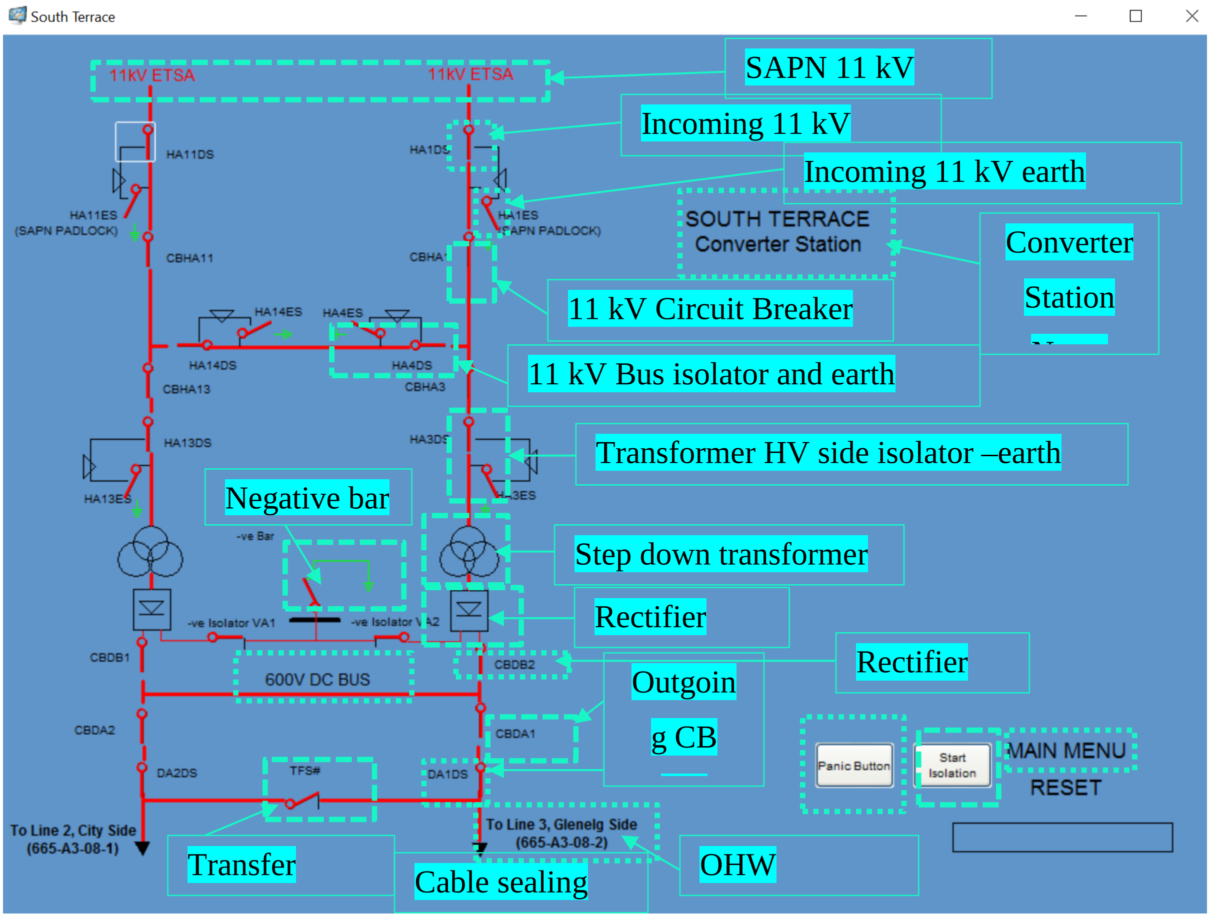


Fig. D4. Dual rectifier converter station

In a double rectifier station, as of Fig. D4, two independent 11 kV feeder come from the adjacent SAPN substation and go to two independent stepdown traction transformer. In a single rectifier station as of Fig. D5, only one 11 kV incoming supply from the nearest SAPN distribution substation and comes into a single 11/0.456 kV step-down transformer.

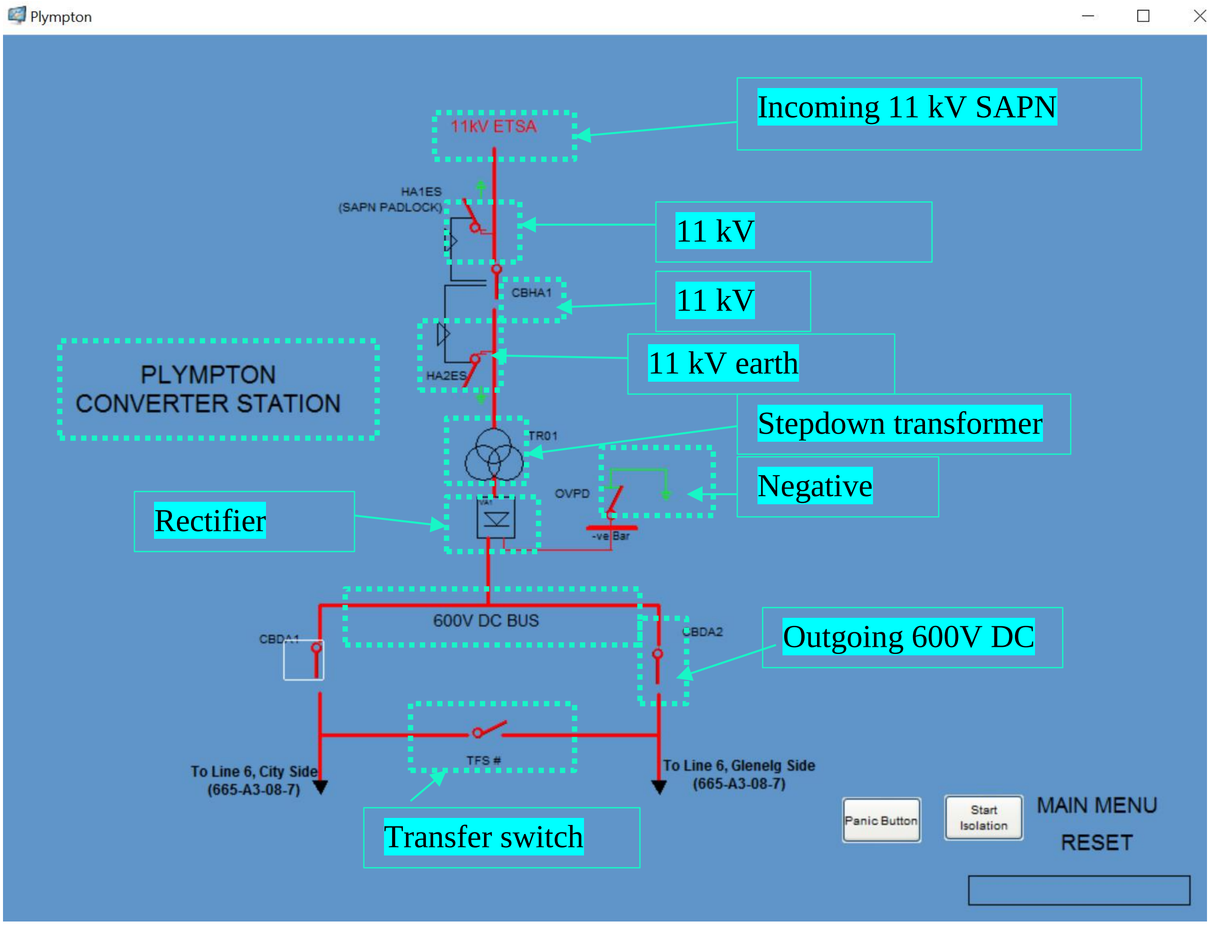


Fig. D5. Single rectifier converter station

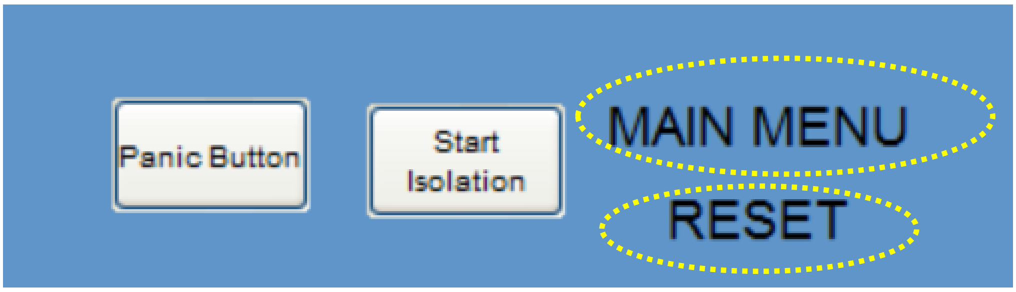


Fig. D6: Sub-menu

As of the Fig. D6, submenu descriptions are outlined below:

MAIN MENU: By clicking the 'main menu', the screen go back to the Citect main menu interface as of Fig. D3.

Panic Button: By clicking this button, the simulator operates all the outgoing feeder operational CBs from all inline converter stations. System usually operates by this button in an absolute emergency situation.

Start Isolation: By clicking this button, on an OHW or in a converter station, the simulator ask for the POIs, and execute subsequent switching steps for a given POIs and work limit.

RESET: By clicking, this button; the system resets and clear all memory.

A bit details of the systems switchgear and catenary systems are stated below:

SAPN 11 kV Supply: SAPN supplies 11 kV stage-3 AC power to the AMPRN substations. For a double rectifier substation, they feed two 11 kV feeder from their preferably two separate distribution 33/11 kV substations to maintain the system supply redundancy. Staged -3 supply means, the system does load shedding to those feeders only and when 300 to 3000 MW distribution load shed is imminent to save the local or national grid.

Incoming 11 kV Isolator: This isolator is the limits of isolation for SAPN incoming feeder cables.

Incoming 11 kV Earth Switch: This earth switch is used to earth the SAPN cable from the converter station-end and has a SAPN padlock so that client cannot operate them without interface switching.

11 kV CB: This is the converter station's incoming 11 kV CB. It also has got the set system settings to protect the SAPN incoming cables. This CB is protected by an ABB REF relay.

11 kV Bus Isolator and Earth Switch: This isolator-earth switch arrangement protect the converter station 11 kV bus for bus tie arrangement. This also equipped with a physical castle key arrangement to bypass any incoming feeder and if both stepdown transformers are required to supply by one 11 kV feeder. These isolator and earth switch are inter-locked.

Transformer HV side isolator-earth switch: This isolator and earth switch mechanism is required when the transformer need to bypass for maintenance. These isolator and earth switch are inter-locked.

Step-down Transformer: This is a 600 kVA 11/0.456 kV step down transformer. The system is designed with 12 pulse 3 phase rectification systems.

Rectifier diode: There are twelve diode for the bridge rectifier system, which rectifies 456 V AC to 600V DC as designed.

Rectifier CB: This is a 600 V DC secheron HSCB. This is the rectifier CB and is protected by a SEPCOS relay.

DC Bus: This is the 600V DC bus that feeds the outgoing CBs.

Outgoing 600 V DC CB: This is a 600 V DC secheron HSCB. This is the outgoing load CB after the DC bus and is protected by a SEPCOS relay.

Outgoing 600 V DC Isolator: This is the outgoing DC isolator switch, which plays a major role for day to day switching operations to connect or disconnect the 600 V DC feeder from the converter station to the OHW catenary systems.

Transfer Switch: This is a 600 V DC CB which is used to connect parallel cables between two converter stations if the converter station is bypassed for system maintenance or overhauling.

UFC Sealing End: Underground parallel feeder cables to tap to trolley cables are terminated at this points.

OHW Schematic: This drawing states the contact wire arrangement, overhead switchgear and radial up and downline platform or pole locations as shown in the figure-E6.

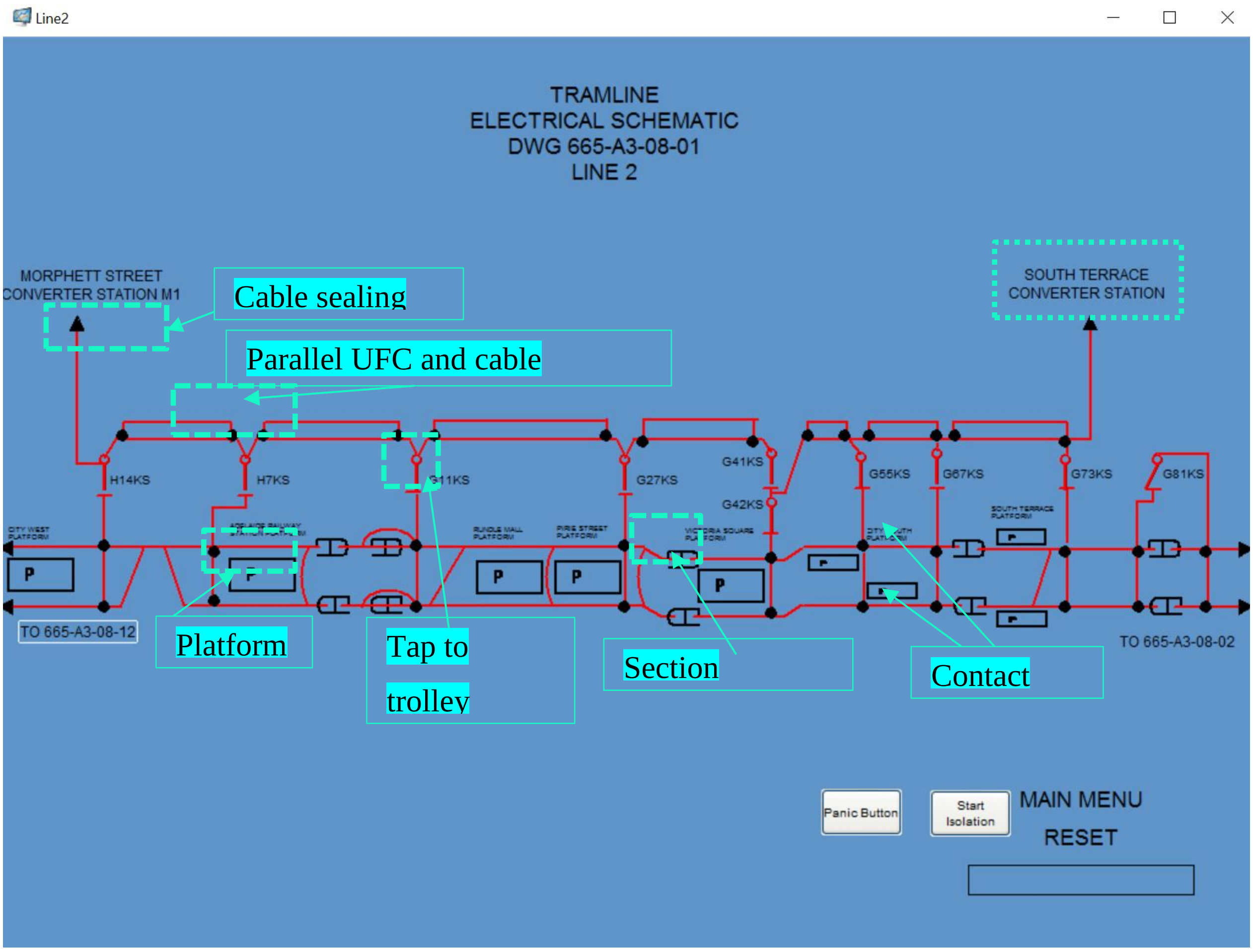


Fig. D6. OHW schematic between Morphett st to South Tce converter station

UP and Down Track: Overhead contact wire and tram travelling towards ARS is called Up track. The catenary systems away from the ARS is named as the Down track. ARS stands at zero point, every pole is marked with a unique name, location and up-down track from ARS.

Parallel 600 DC Cable and junction pit: There is a parallel double 300 mm^2 DC underground feeder cabling systems from the entertainment center to the South Tce converter station. From the South Tce to the Jetty Rd EOL, a single parallel cable is also operational.

TT Switch: This is a 600 V DC KS which connects substation feeder cable to the overhead contact wire. This is not rated as a load switch, which means the switch has to be operated when there is no load or catenary systems already been de-energized.

Contact Wire: This is $107mm^2$ grooved contact wire that feeds power to the rail cars via pantograph.

Section Insulator: This is specially designed isolator with a long optical rod that electrically separates two OHW sections for the system maintenance. By inserting a section insulator in the system, it insulates two elementary sections where the pantograph of the locomotive runs smoothly and maintaining the current continuity to other section.

Platform: It's usually a raised surface level on a station where people can catch and depart from the trams.

ECC: The ECC is equipped with SCADA monitors and Tram and Train SCADA servers to monitor and control on-site remote terminal unit (24/7 real-time manned).

Operations Controller: they are responsible for AMPRN EMU movements and always in discussion with tram and train drivers.

Electrical Control Officer (ECO): ECOs sit in the ECC to monitor and control system switchgear in both normal and emergency situations (24/7 basis).

Switching Crew: This team usually consist with least one competent switcher who carry out the written switching program, one checker who monitor the correctness of the switching activities of the switcher. The most experienced person in the team, always work as the checker.

4. System Switching

Switching of the traction system may be classified:

i. Internal Switching (within converter stations),

ii. ii. External switching (on OHW systems),

iii. iii. Overall switching (from a converter station to another converter station), and

iv. iv. External switching (SAPN interface switching).

Details of the individual system switching is stated below:

i. Internal switching: This type of switching activity usually takes place to maintain or replace a piece of switchgear within a converter station. This could be a partial isolation or full bypass of the converter station when needed. Only experienced and certified electricians with engineering assistance can carry out the required internal switching due to the complexity of the substation switchgear orientation and design.

ii. External Switching: This type of switching activity usually conducted to maintain an OHW switchgear as such section insulator or contact wire registration adjustment or modification. In this activity the switching crew do not enter to the converter stations. The switching crew usually work on OHW and UFC systems and the ECO de-energise the feeder incoming power from remote by operating outgoing converter station's related feeder CBs. Experienced and certified linesmen usually carry out this type switching.

iii. Overall switching: This category of switching activity usually require both OHW and converter station switchgear switching steps. The switching crew usually work in two groups, one stays inside a converter station and other on track to isolate-restore the system as a whole.

iv. External Switching: The switching also referred as the system interface switching. The SAPN crew isolate their incoming distribution system and issue work permit to internal switching crew.

5. Switching Demonstration

Switching demonstration plays a crucial part to learn and get used to with 'how the switching program works'. To understand the related switchgear and as-built interlocking, related switchgear operation manual has to be read. Switching demonstrations of the simulator is a general tutorial to navigate the 'system switching'. If we click the demo-2, the menu popup as shown in figure-6.1. Clicking OK, it guide the user to the related switches to open and close. This demo is not based on chronological sequence of day to day isolation-restoration, it just demonstrate the limits of isolation and how many switches needs to open and close to achieve that. Assuming that the user who will be playing with the 'demo' usually have no understanding of the normal switching practices, which will be discussed in the 'understanding of the switching template' section.

After clicking the 'demo-2', the demo will lead to the required window as shown in the Fig. D7.

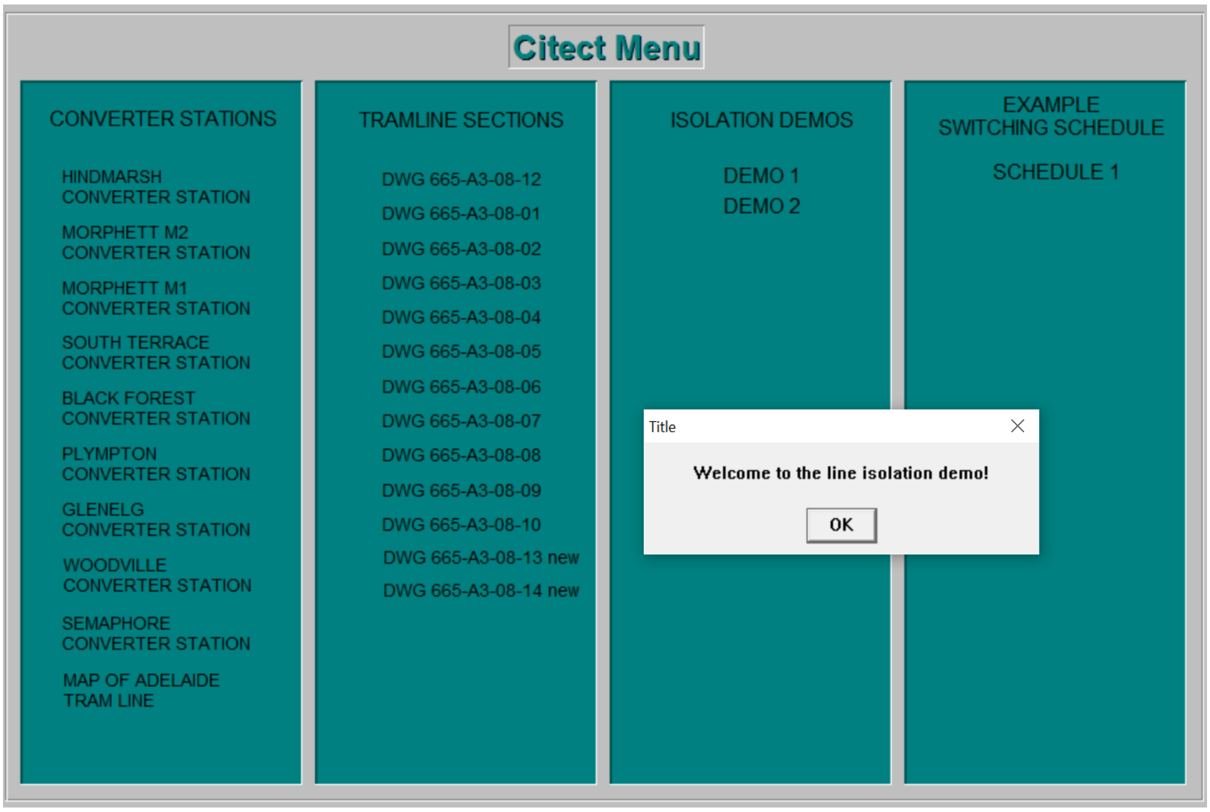


Fig. D7. Isolation demonstration

The demo instructs basic instructions to educate the user to get used to at the beginning of the isolation for instance advise to the controller, make sure all trams have passed the switching POIs, etc. as shown in the Fig. D8. At this point the switcher- checker will be contacting the ECO to advise the commencement. As of their onsite switching, the on-duty ECO usually put the electrical blocking on that specific section prior to commence any on-site switching to the operation controllers who are responsible for the passenger rail traffic. The operation controllers need to make sure that the last tram or test service (if any) or any scheduled movement have passed the worksite and approve the required traffic blocking include the site work commencement.

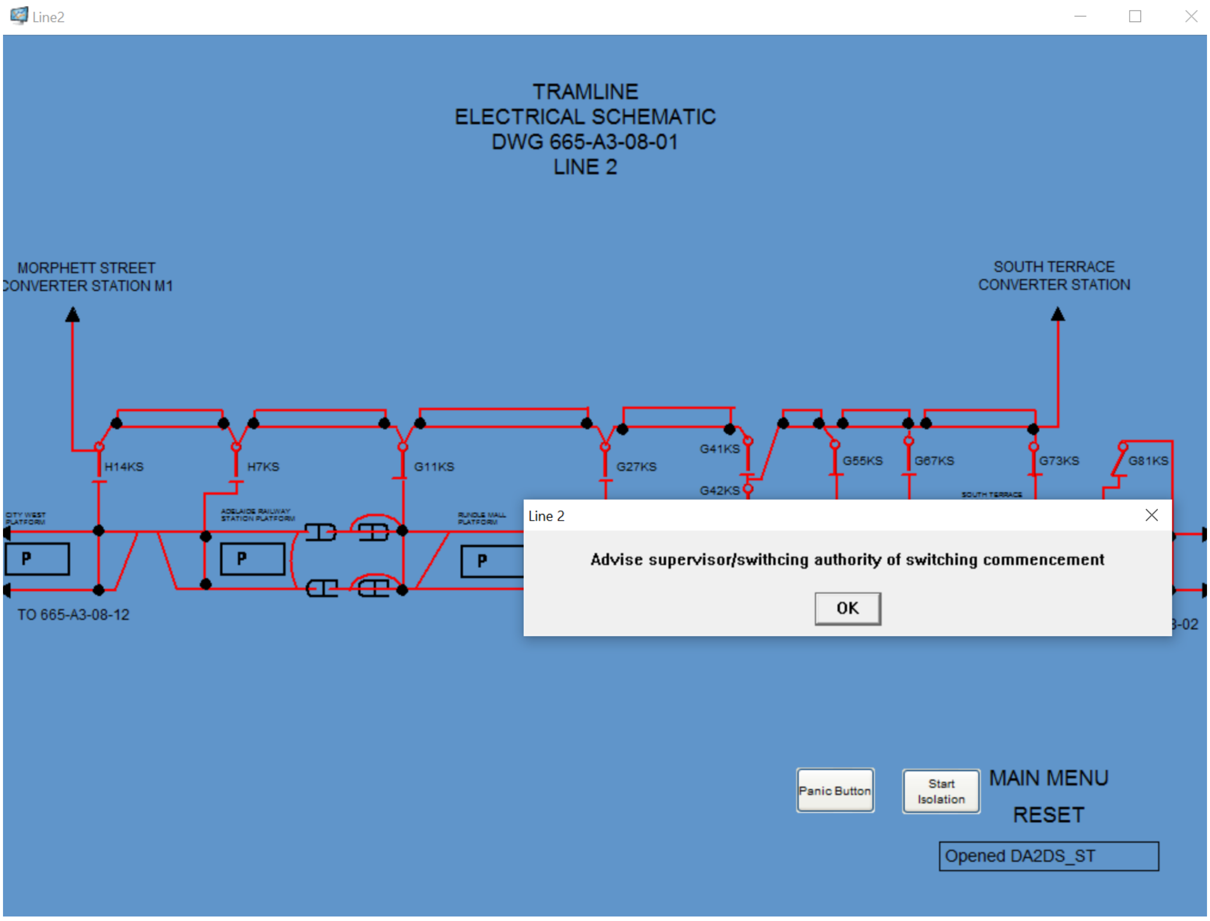


Fig. D8. Isolation demo (advise to parties)

After getting the blocking authority approved, the on-duty ECO usually approve the switching commencement on site. It is very likely multiple switching teams will be contacting to the shift ECO and also waiting on-site for their authority-approval to commence the on-site electrical switching. So this type of site to controller’s notification and their bi-directional discussions is an authority-approval step to commence onsite switching.

Switchgear location and on-time-every time to the switching location, also plays a major role for efficient switching. As the catenary system is a double track 42 km Up and Down track system. Each switchgear got a distinctive name with location as shown the figure-D9. So the switcher-checker must know at which location their workgroup is waiting to commence the work prior to their switching.

This demo-2 shows distinctive switchgear name and location and advises what to do to the user as of the popup window of the Fig. D9.

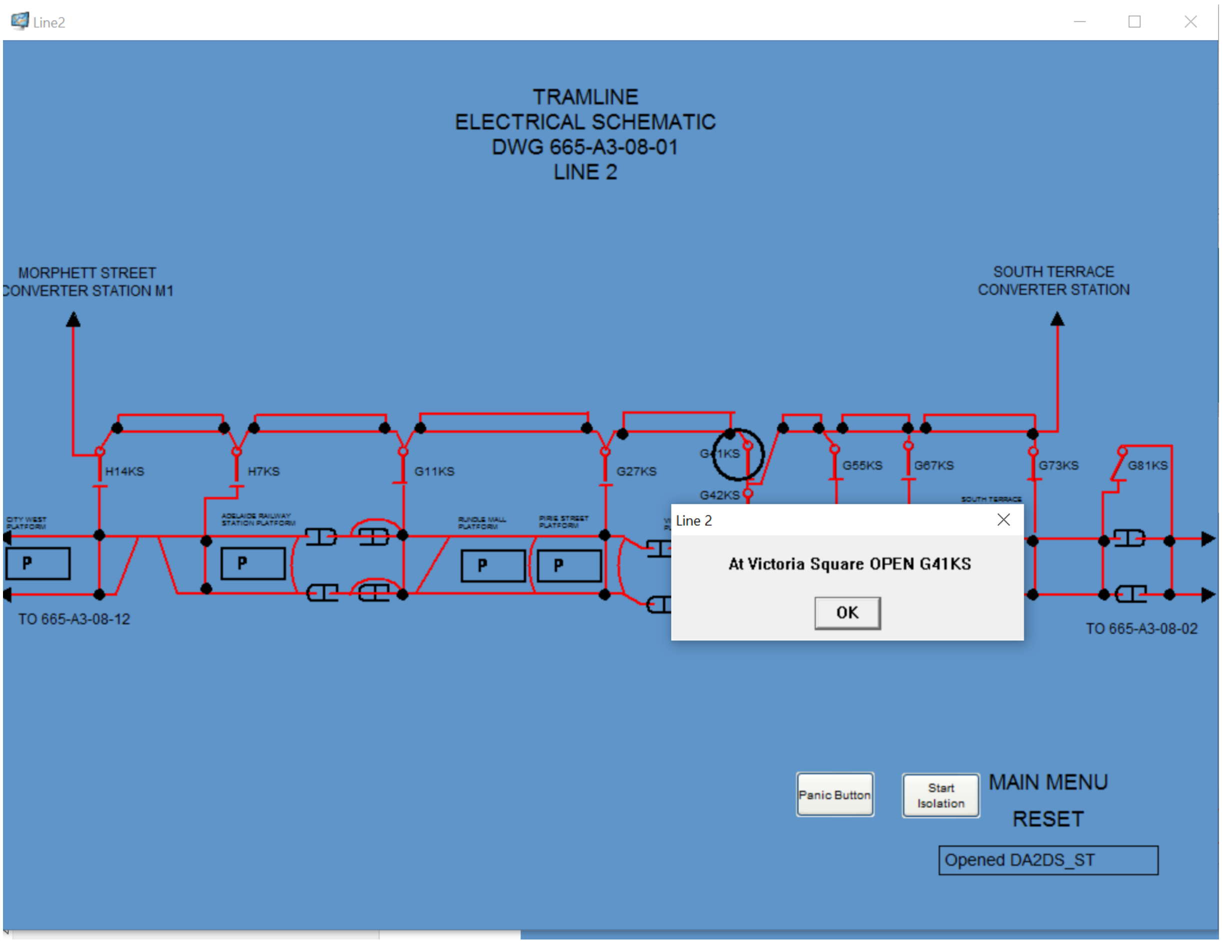


Fig. D9. Isolation demo (distinctive switchgear operation)

Locking & tagging of the isolated switchgear also part of the legitimate process. The required switchgear must be locked and tagged by the workgroup and that advised in the popped up window as shown in the Fig. D10.

When a separate workgroup need to work in that vicinity, they are also in need to use that specific switchgear (what already been isolated and tagged for another work POIs purpose), they are also mandated to lock & tag that open and tagged switch to secure their overlapped worksite.

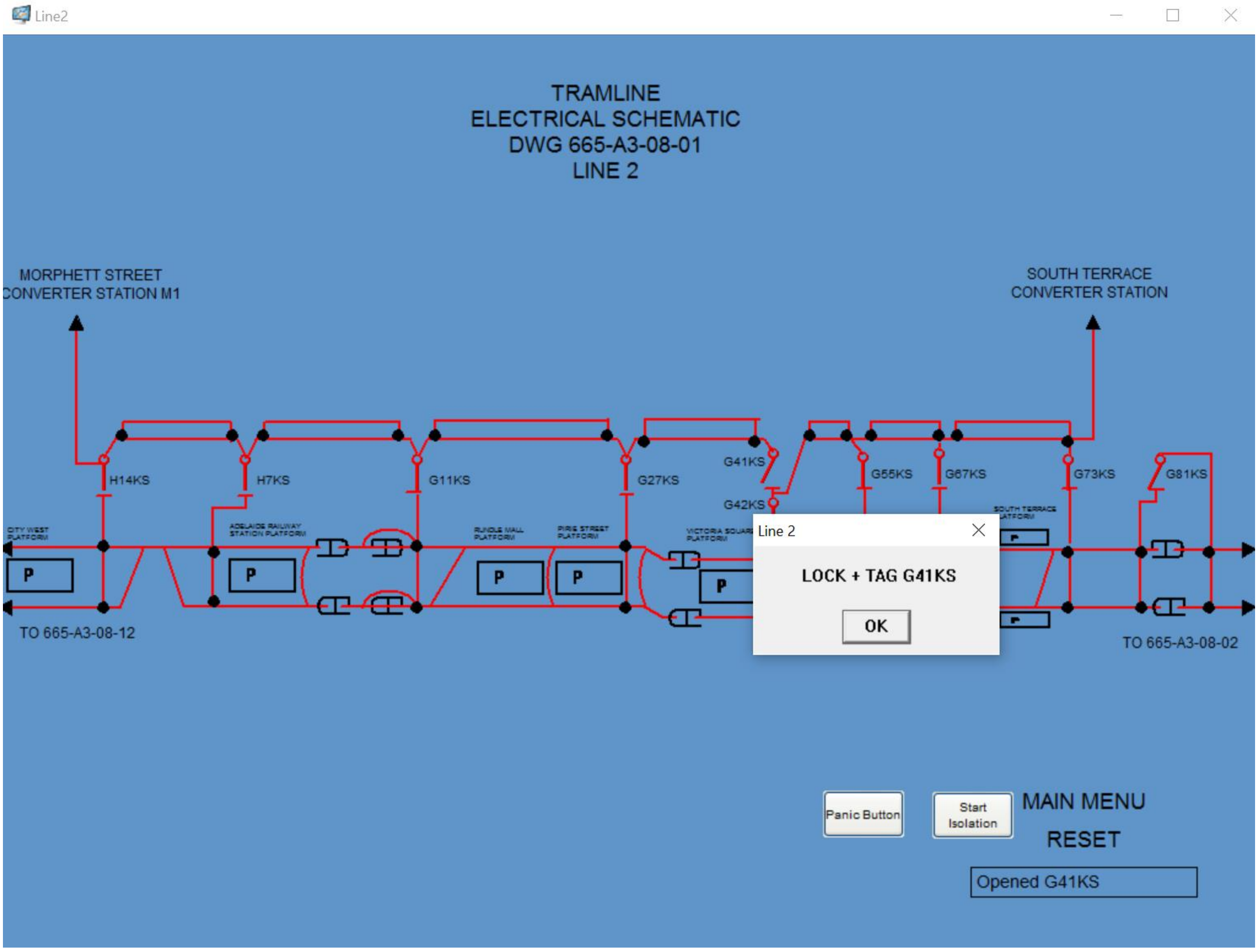


Fig. D10. Isolation demo (locking and tagging)

If any lock key or tag is lost, then it does require a managerial delegate approval prior to any alteration to the written switching process. In the Fig. D10 the demo advises the user about the lock & tag requirements.

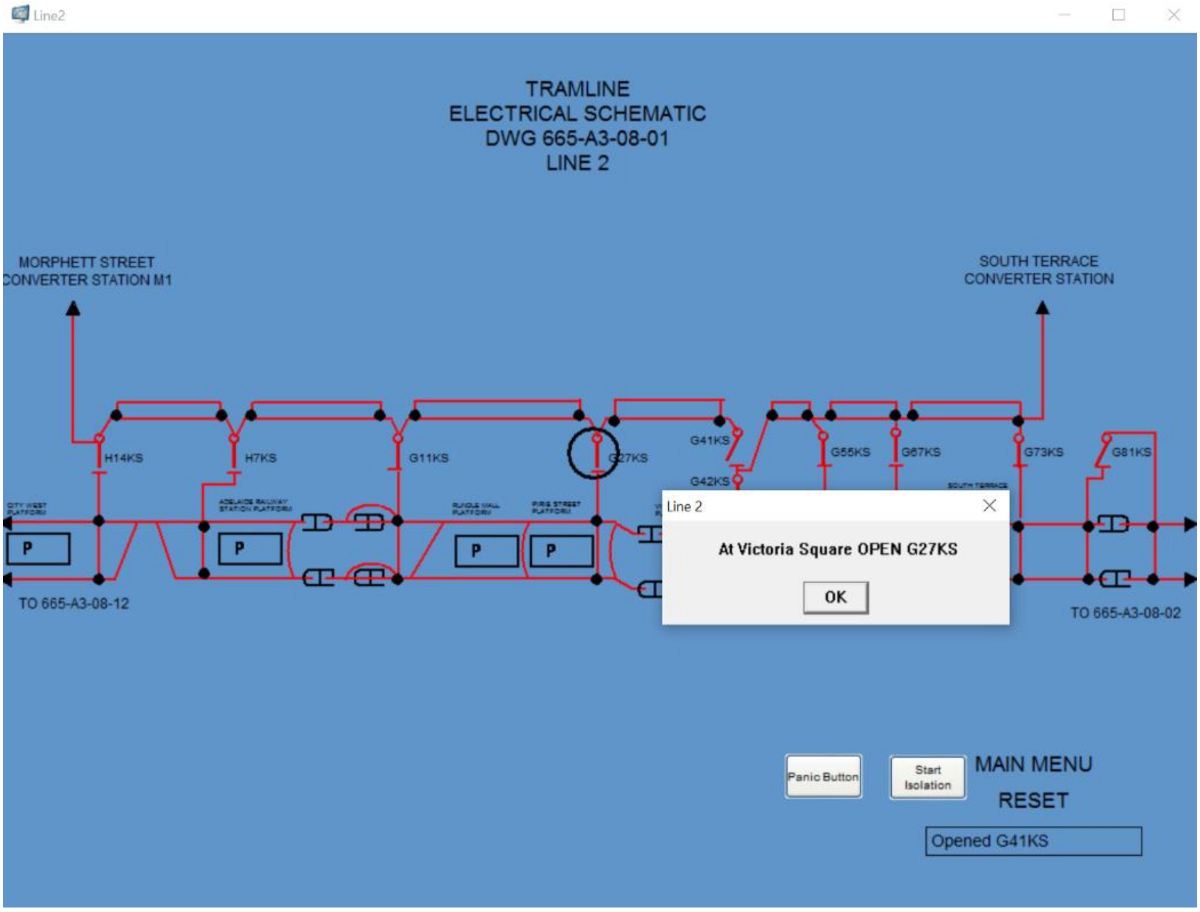


Fig. D11. Isolation demo (switchgear switching)

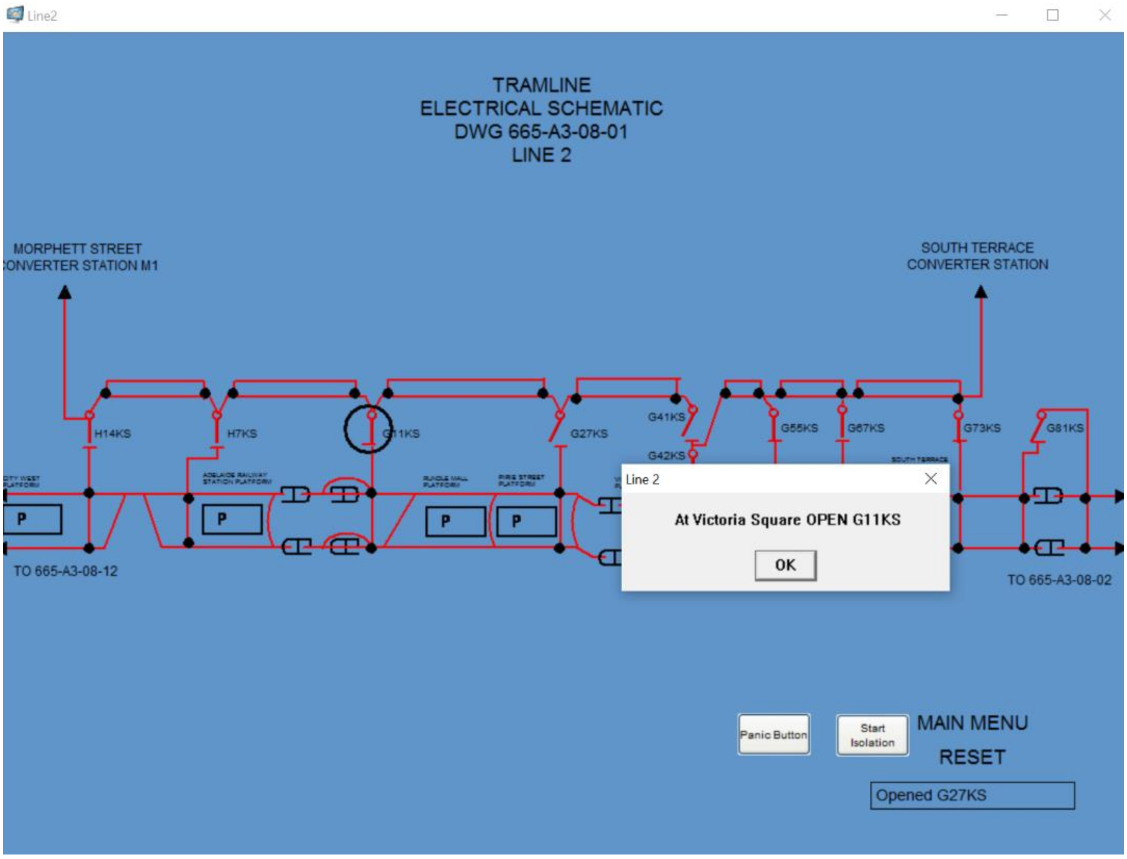


Fig. D12. Isolation demo (switchgear switching)

Fig. D11, Fig. D12 and Fig. D13 tells the user about the work continuity of the system switchgear operation and switching progress continues inside the converter station as shown in the Fig. D14.

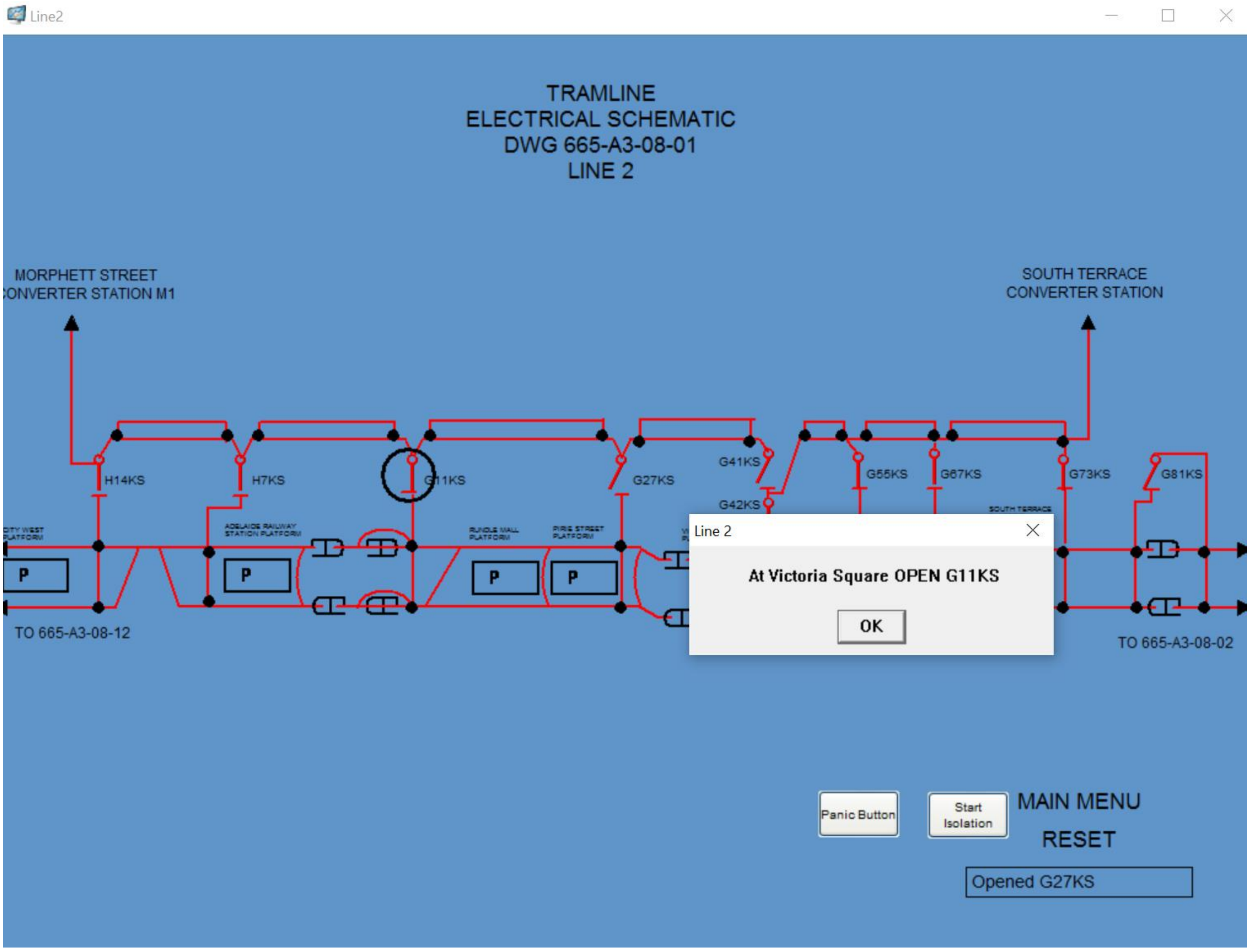


Fig. D13. Isolation demo (switchgear switching)

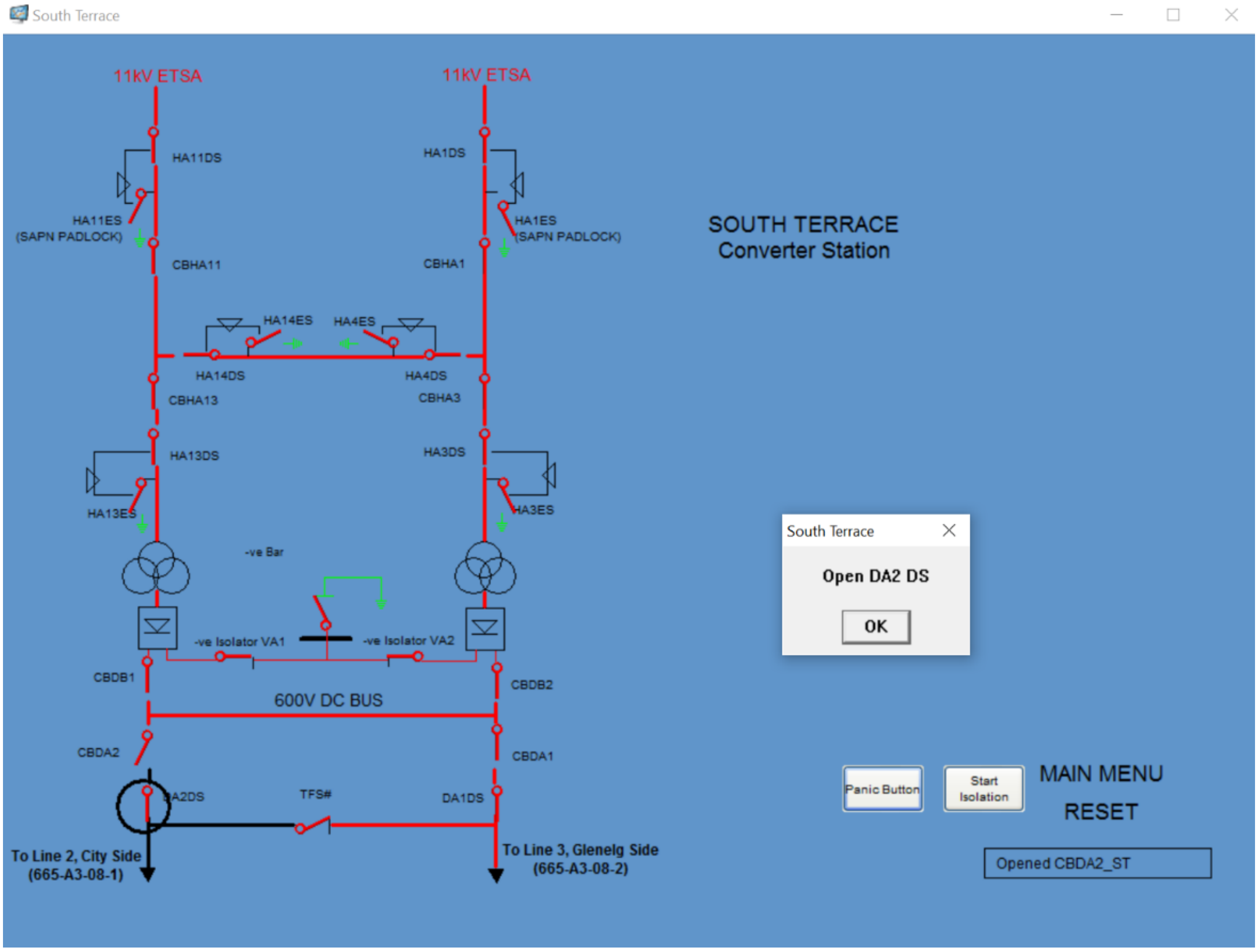


Fig. D14. Isolation demo (inside substation)

The switcher-checker usually travel to the adjacent substation or advise the on duty ECO to operate the required substation switchgear from remote. On duty ECOs usually operate all system CBs from remote unless require otherwise.

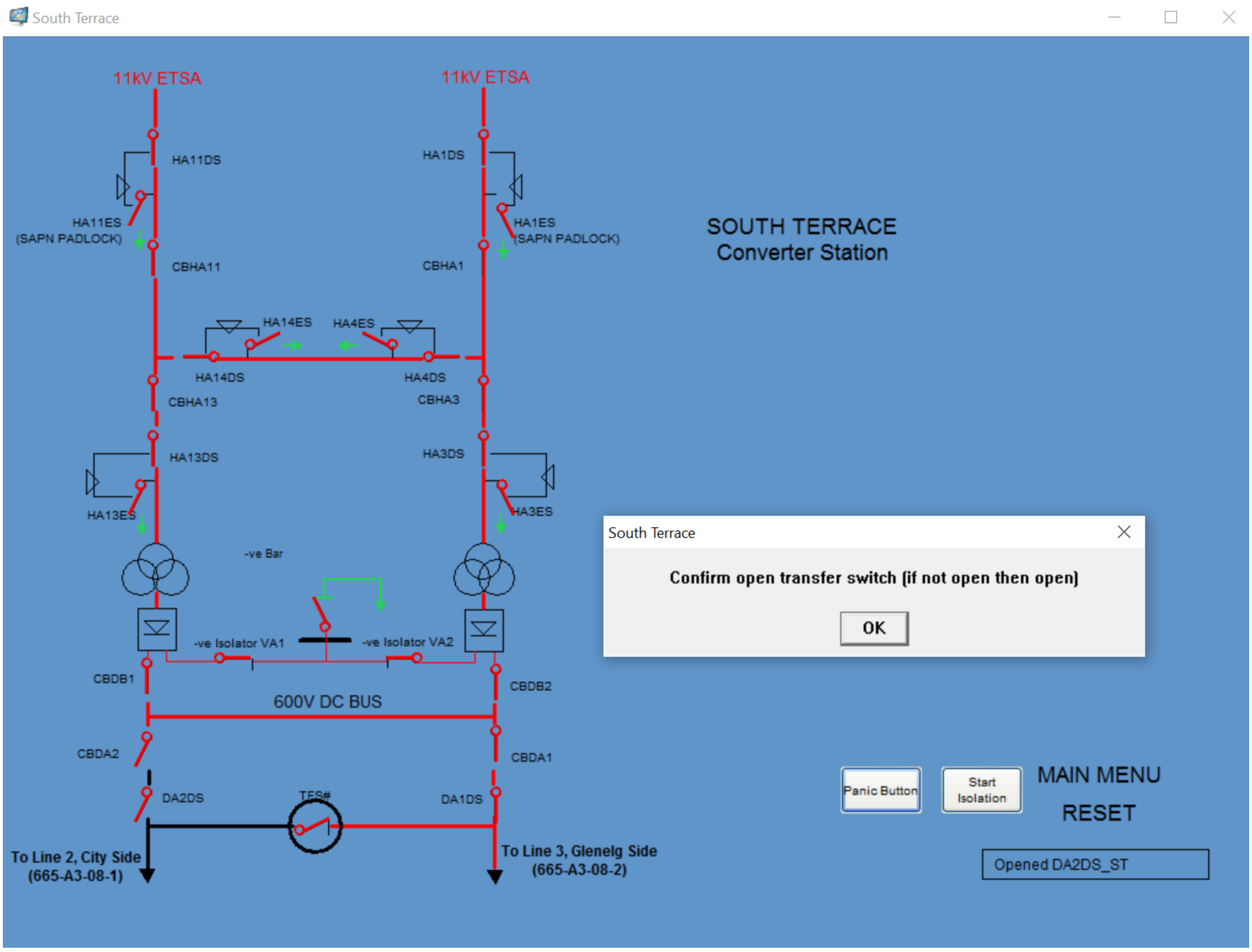


Fig. D15. Isolation demo (inside substation)

The transfer switch usually need to be checked when the related converter station is required to be bypassed or to ensure zero back power feed from the immediate converter station. So, this switch work as a limits of isolation for a given section POIs. In the Fig. D15, the demonstration step reminds the user about the necessity of the Transfer Switch status check. When the switching steps warrant, if so, the transfer switch required to 'confirm open' and 'rack out' and 'locked and tagged'.

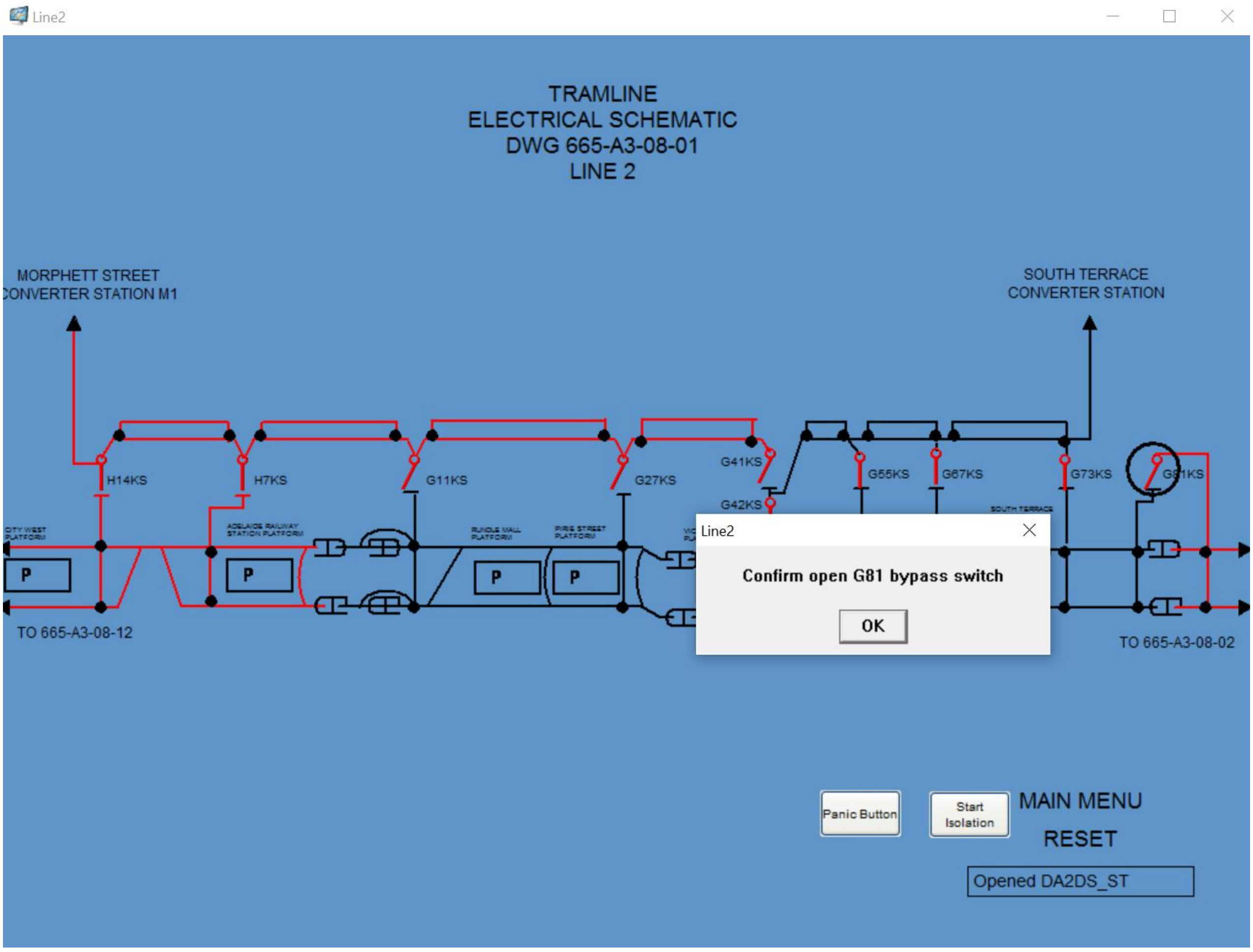


Fig. D17. Isolation demo (bypass switch)

Bypass switch is required to bypass an OHW section insulator, by closing a bypass switch, two adjacent electrical section connect as an independent section. So, this switch also work as a limits of Isolation for a given worksite. In the Fig. D17 the demonstration popup window guide the user to check status of the bypass switch. In the figure, to secure the given limits of isolation, G81 bypass switch must be kept open-locked-tagged to secure the worksite.

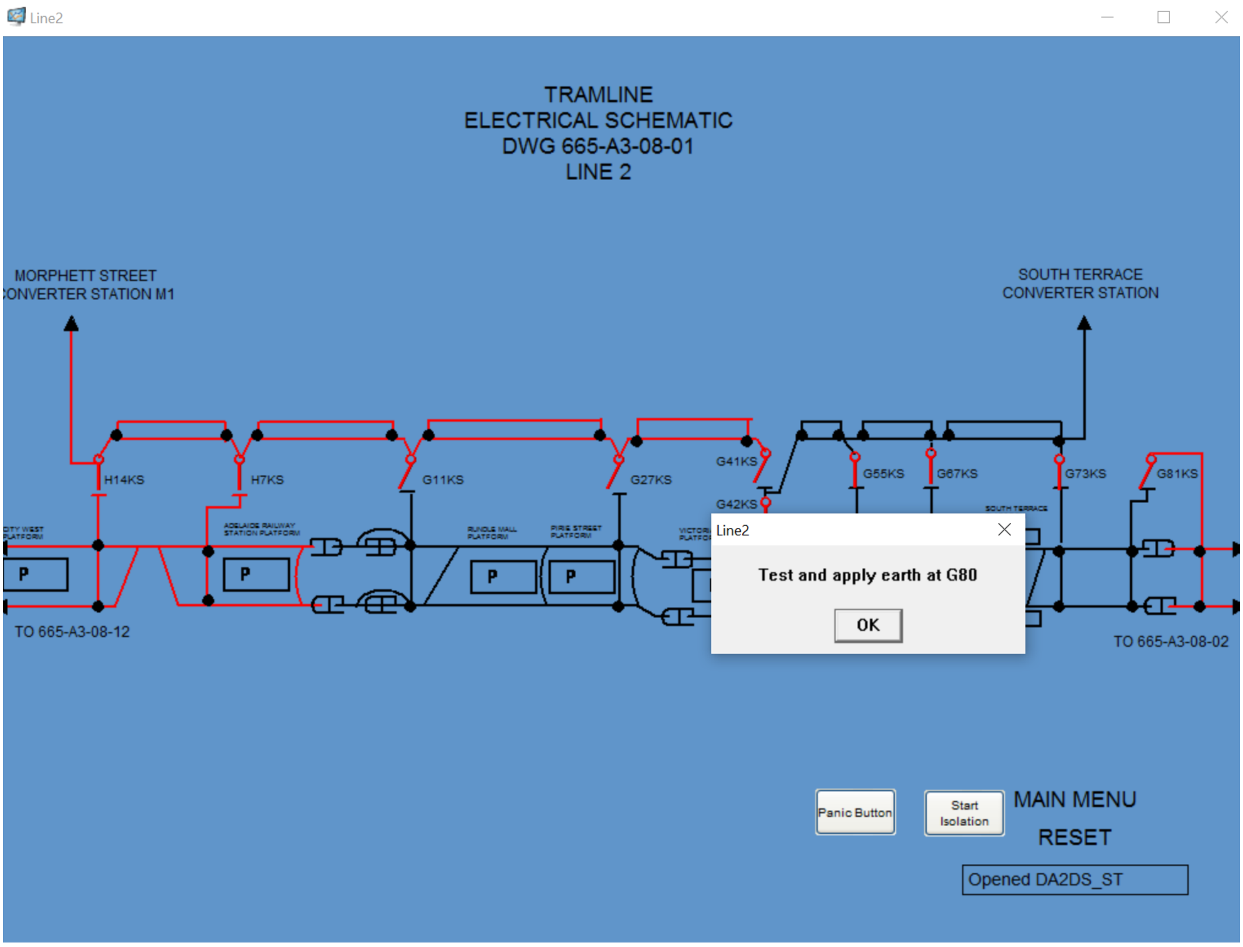


Fig. D18. Isolation demo (test and earth)

The demonstration tells the user about to test the de-energized OHW state and apply manual work earth to the de-energized contact wire at certain designated earthing points. In the Fig. D18, the popup window advise the user to test the de-energized OHW with the live line tester, as the system has to be zero back feed power proved. After de-energizing an OHW, it doesn't automatically ready to work, the system has to be safely earthed for safe work commencement. There are also legitimate requirements for properly apply earth on a de-energised OHW.

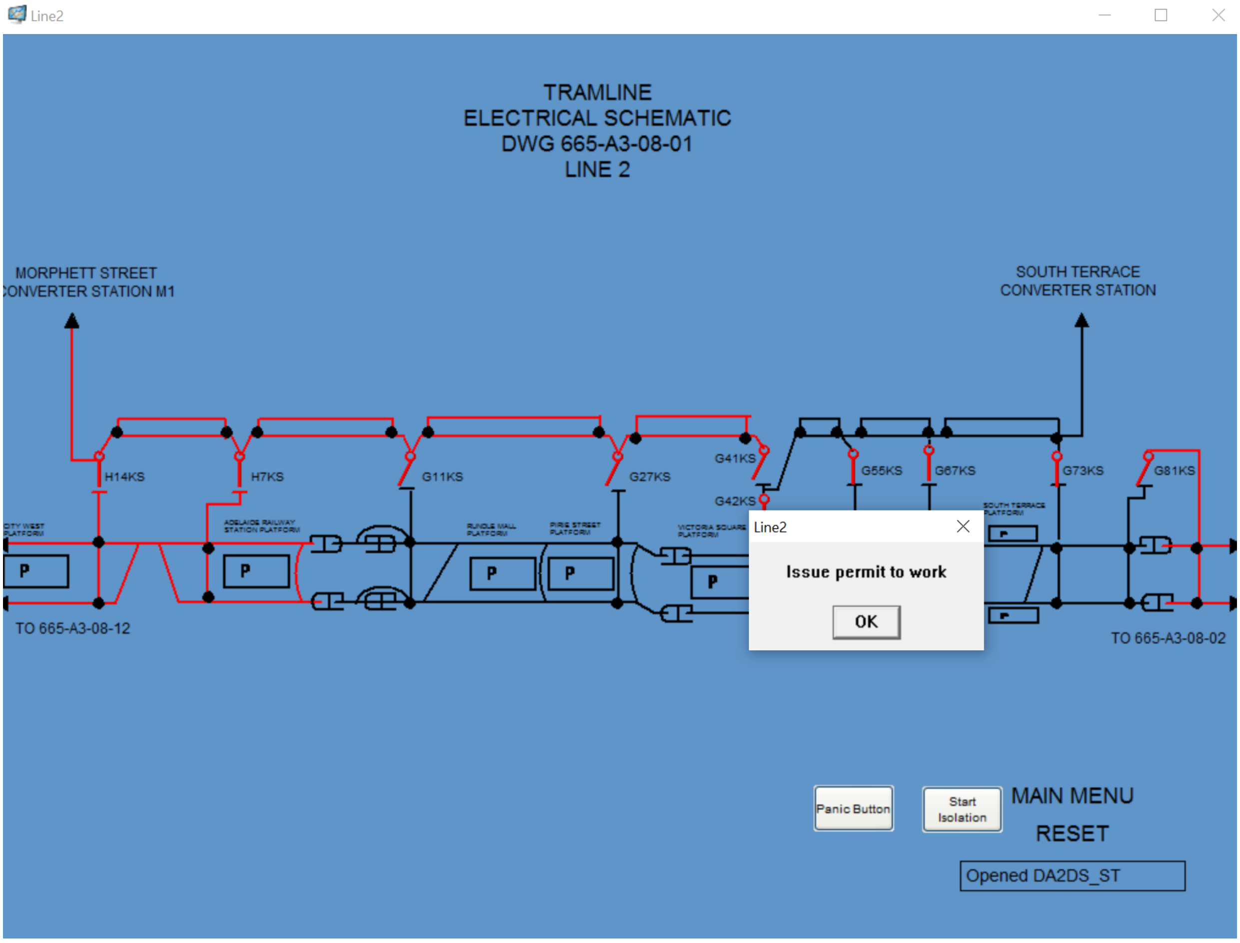


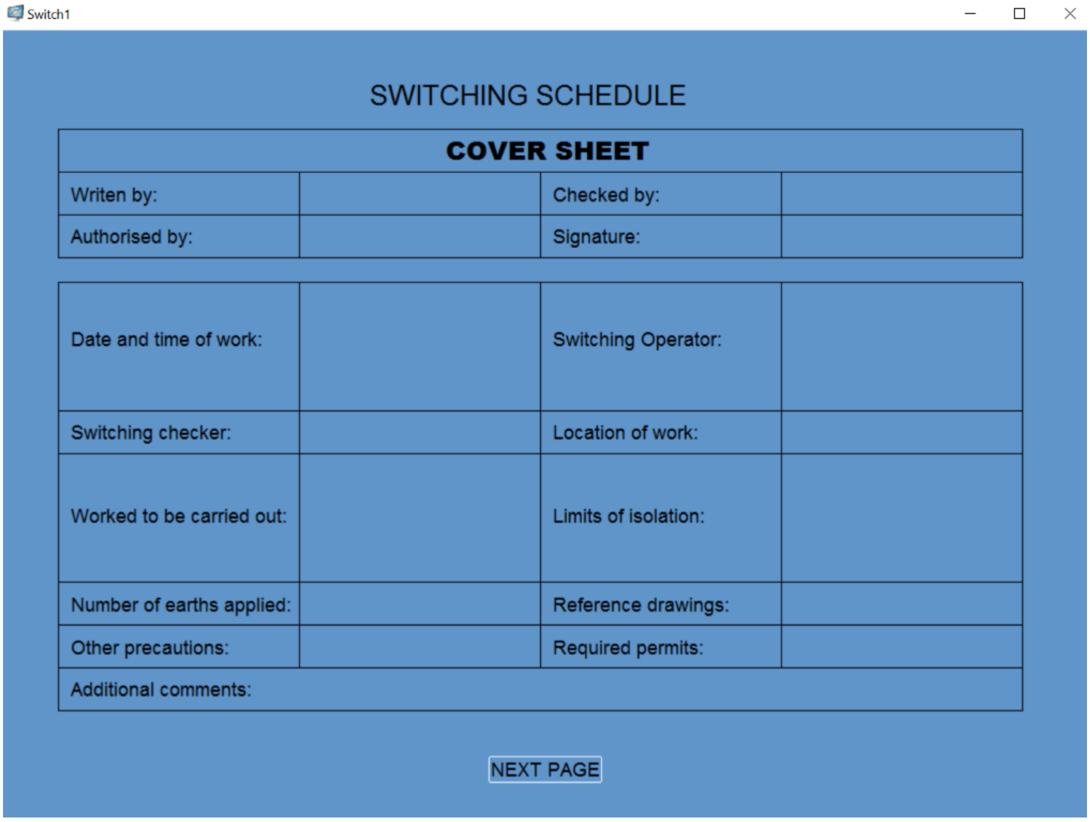
Fig. D19. Isolation demo (work permit)

When the system is isolated (de-energised and earthed), the switching crew usually issue a work permit to the nominated person to commence the maintenance task within isolated section. Issuing work permit also a legitimate process to transfer the work authority within the POIs from the switching crew to the workgroup.

In the Fig D19, the popup window of the demo tells the user about the requirement of 'the work permit' issue. Once the work permit has been issued, the switching crew also advise the on-duty ECO about the work commencement on site.

6. Switching Template

The electrical engineering team have approved generic switching templates that are used for any system switching programs. It has to be duly written for a given POIs, must be authorized and approved by an electrical engineering delegate as shown in the Fig. D20. In this cover sheet, the switching team has to clearly write their names, work commencement date & time, location, work description, limits of isolation, total numbers of earth applied (after isolation), reference drawings details, permit details, etc. as of Fig. D21.



Switch1

SWITCHING SCHEDULE

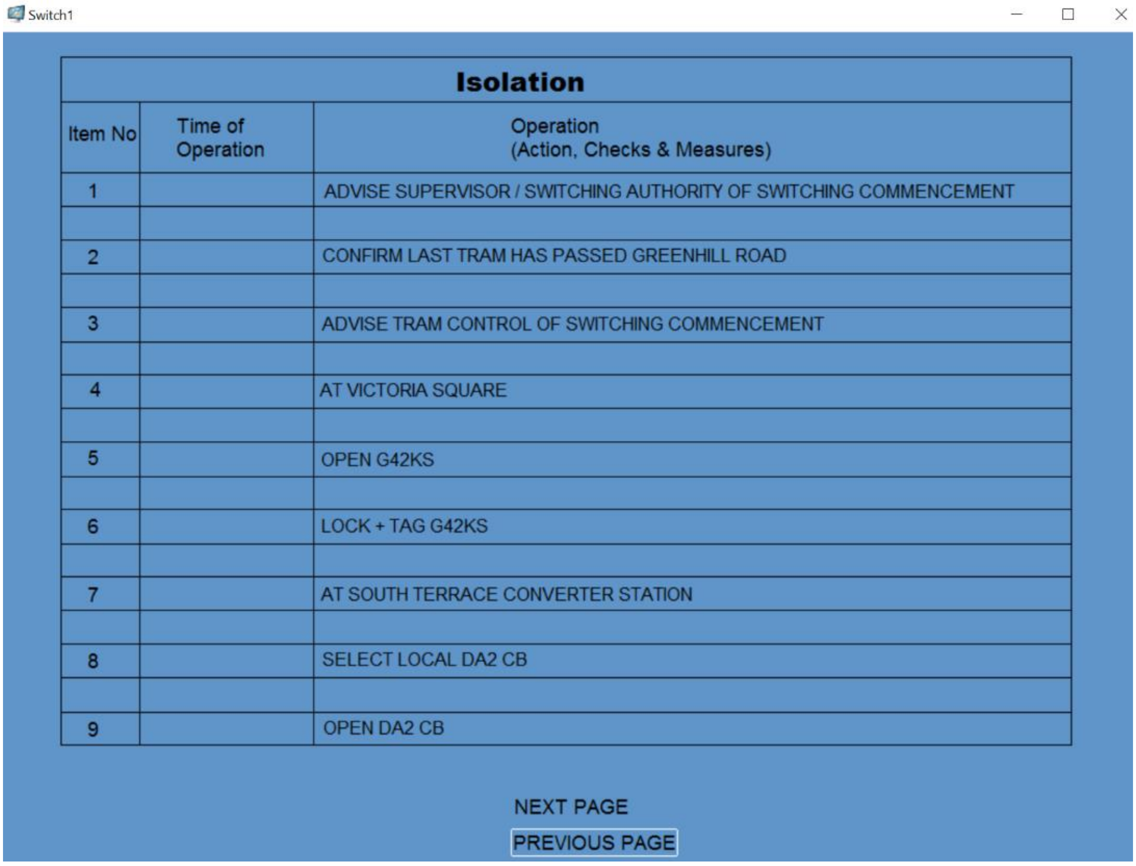
COVER SHEET			
Writen by:		Checked by:	
Authorised by:		Signature:	

Date and time of work:		Switching Operator:	
Switching checker:		Location of work:	
Worked to be carried out:		Limits of isolation:	
Number of earths applied:		Reference drawings:	
Other precautions:		Required permits:	
Additional comments:			

NEXT PAGE

Fig. D20. Switching program template (cover sheet)

Then the each switching statements are also listed as shown in the Fig. D21 and Fig. D22, switching teams are always aware about their next step: what to open and where to proceed as of the approved switching program.



Switch1

Isolation		
Item No	Time of Operation	Operation (Action, Checks & Measures)
1		ADVISE SUPERVISOR / SWITCHING AUTHORITY OF SWITCHING COMMENCEMENT
2		CONFIRM LAST TRAM HAS PASSED GREENHILL ROAD
3		ADVISE TRAM CONTROL OF SWITCHING COMMENCEMENT
4		AT VICTORIA SQUARE
5		OPEN G42KS
6		LOCK + TAG G42KS
7		AT SOUTH TERRACE CONVERTER STATION
8		SELECT LOCAL DA2 CB
9		OPEN DA2 CB

NEXT PAGE

PREVIOUS PAGE

Fig. D21. Switching program template (switching steps)

The switching crew must time stamp their individual switching step execution as they proceed (no exception, a sackable offence). Due to an optical or human error, if any inadvertent switching happens, they have to stop their switching progress immediately and need to report to the ECC. The on-duty ECO need to correct the switching steps as of the real-time simulator and may ask for engineering approval to proceed (if that mistake is deemed to be a critical one).

Switch1

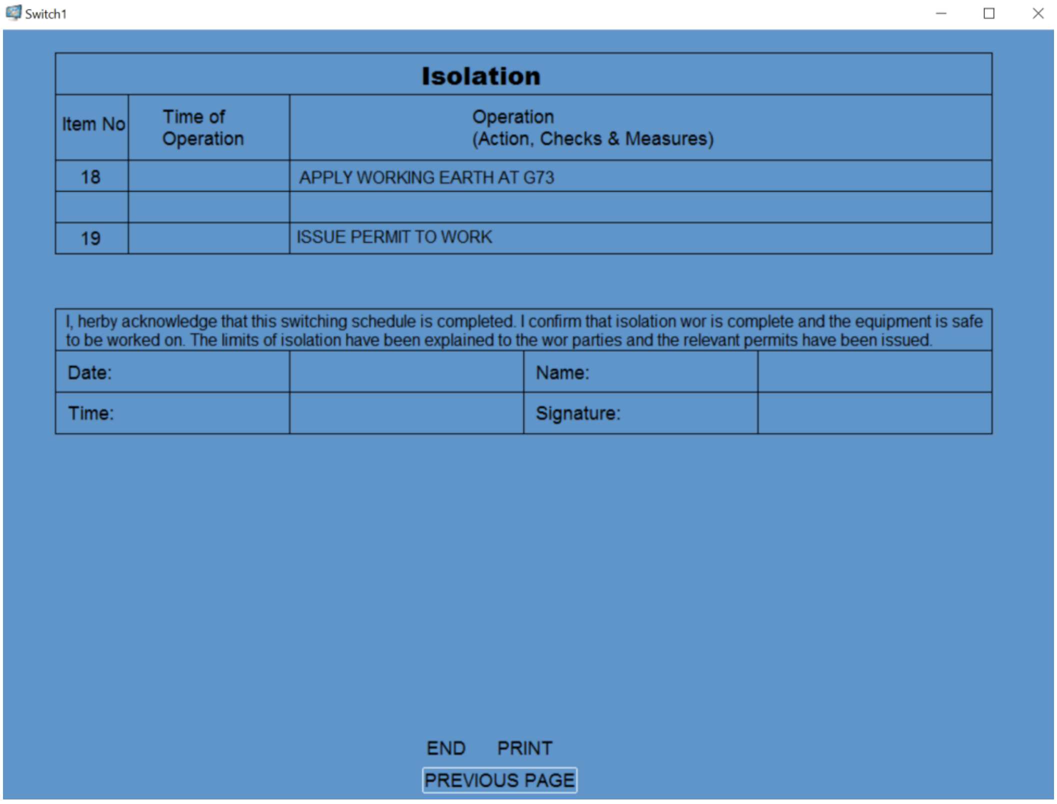
Isolation		
Item No	Time of Operation	Operation (Action, Checks & Measures)
10		OPEN DA2 DS
11		LOCK + TAG DA2 DS
12		CONFIRM OPEN TRANSFER SWITCH (IF NOT OPEN THEN OPEN)
13		RACK OUT TRANSFER SWITCH
14		LOCK + TAG TRANSFER SWITCH
15		CONFIRM OPEN G81 BYPASS SWITCH
16		LOCK + TAG G81 BYPASS SWITCH
17		TEST & APPLY EARTH AT G80
18		APPLY WOKRING EARTH AT G42

NEXT PAGE

PREVIOUS PAGE

Fig. D22. Switching program template (switching steps continues)

At the end of the isolation, both switcher and checker have to individually sign off (with date and time) in their respective switching sheet.


Switch1

Isolation		
Item No	Time of Operation	Operation (Action, Checks & Measures)
18		APPLY WORKING EARTH AT G73
19		ISSUE PERMIT TO WORK

I, herby acknowledge that this switching schedule is completed. I confirm that isolation wor is complete and the equipment is safe to be worked on. The limits of isolation have been explained to the wor parties and the relevant permits have been issued.			
Date:		Name:	
Time:		Signature:	

END PRINT
PREVIOUS PAGE

Fig. D23. Switching program template (end of isolation steps)

The completed switching sheets have to be returned to the ECC for their archiving after switching (isolation-restoration) completion with all issued and duly returned completed permits. The restoration process is included all isolation steps in opposite and reverse order and that also needed to be duly signed by both switcher and checker.

7. Automated Switching Programs

After learning the basic switching demo and organizational switching template, the user is well versed with system understanding and switching steps execution requirements. The user can go for automated switching program for a given worksite by the simulator sub-menu. The user need to select a specific POIs and follows the sequential steps to generate require isolation-restoration steps.

From the Citect main menu, the user will select any line or converter station to commence a switching program as shown in the Fig. D24. The user selects any line or substation as POIs and select to generate isolation and subsequent restoration switching steps.

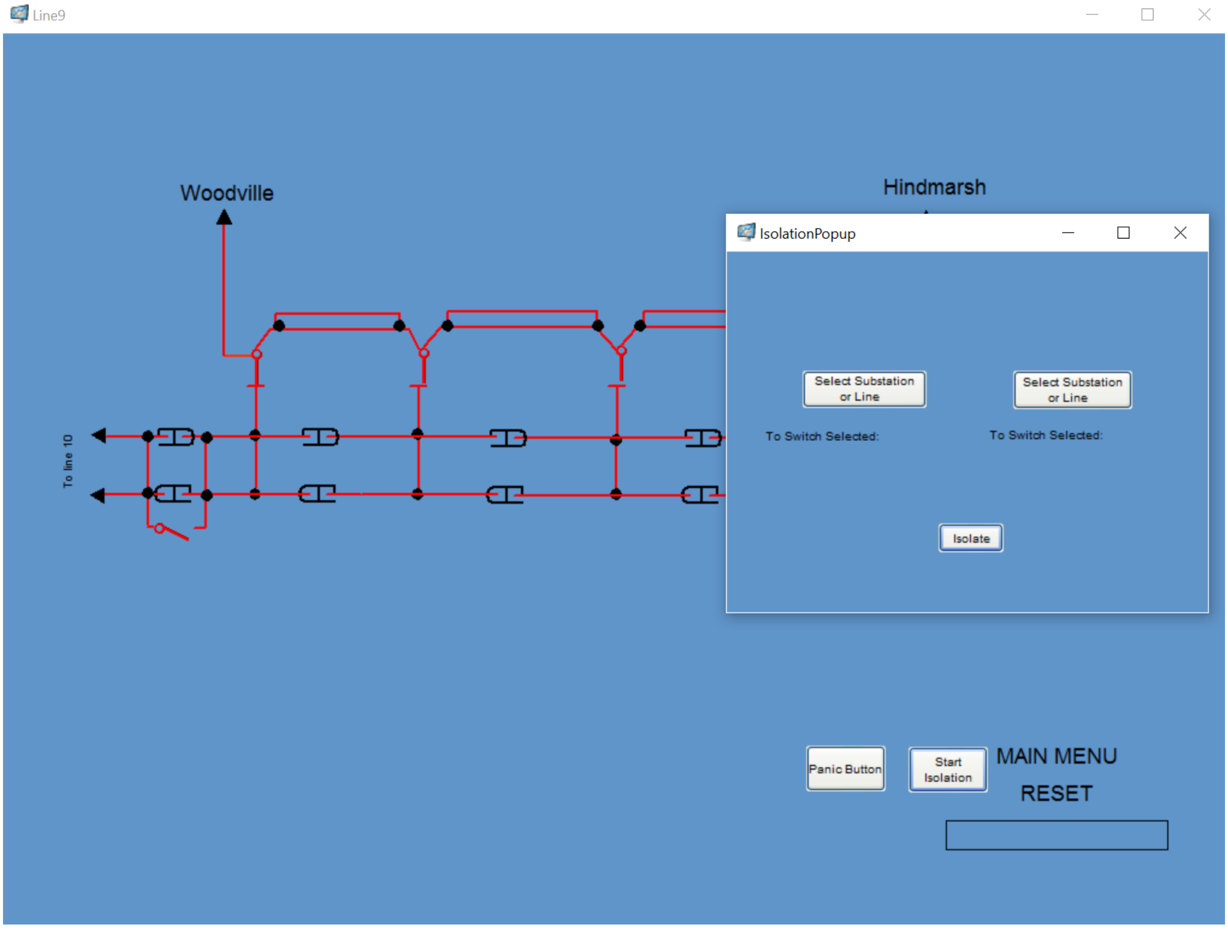


Fig. D24: POIs selection

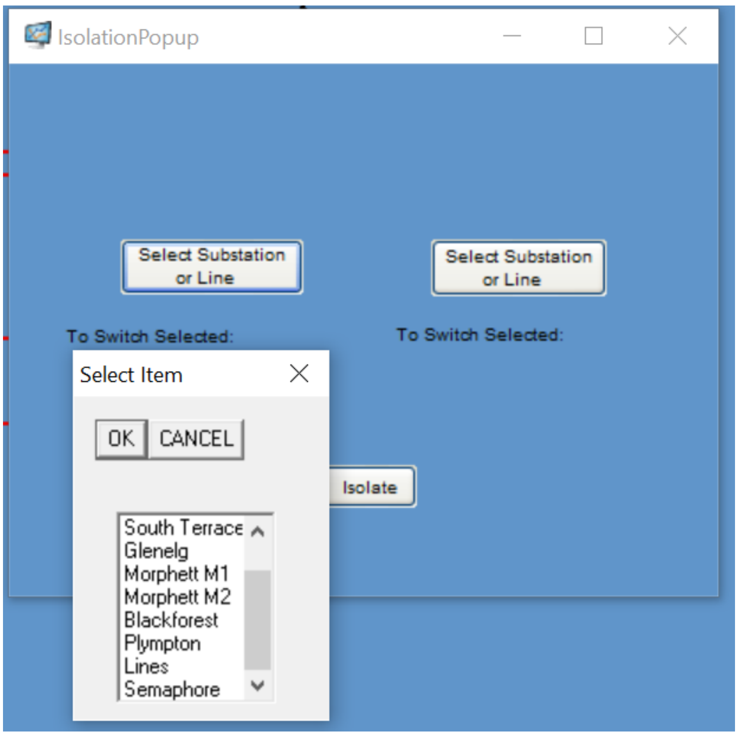


Fig. D24.1: POIs selection (lines or substation)

If the user select the line, it shows all listed OHW switches in the dropdown menu and need to select a given switch as the isolation commencement point as shown in the Fig. D25.

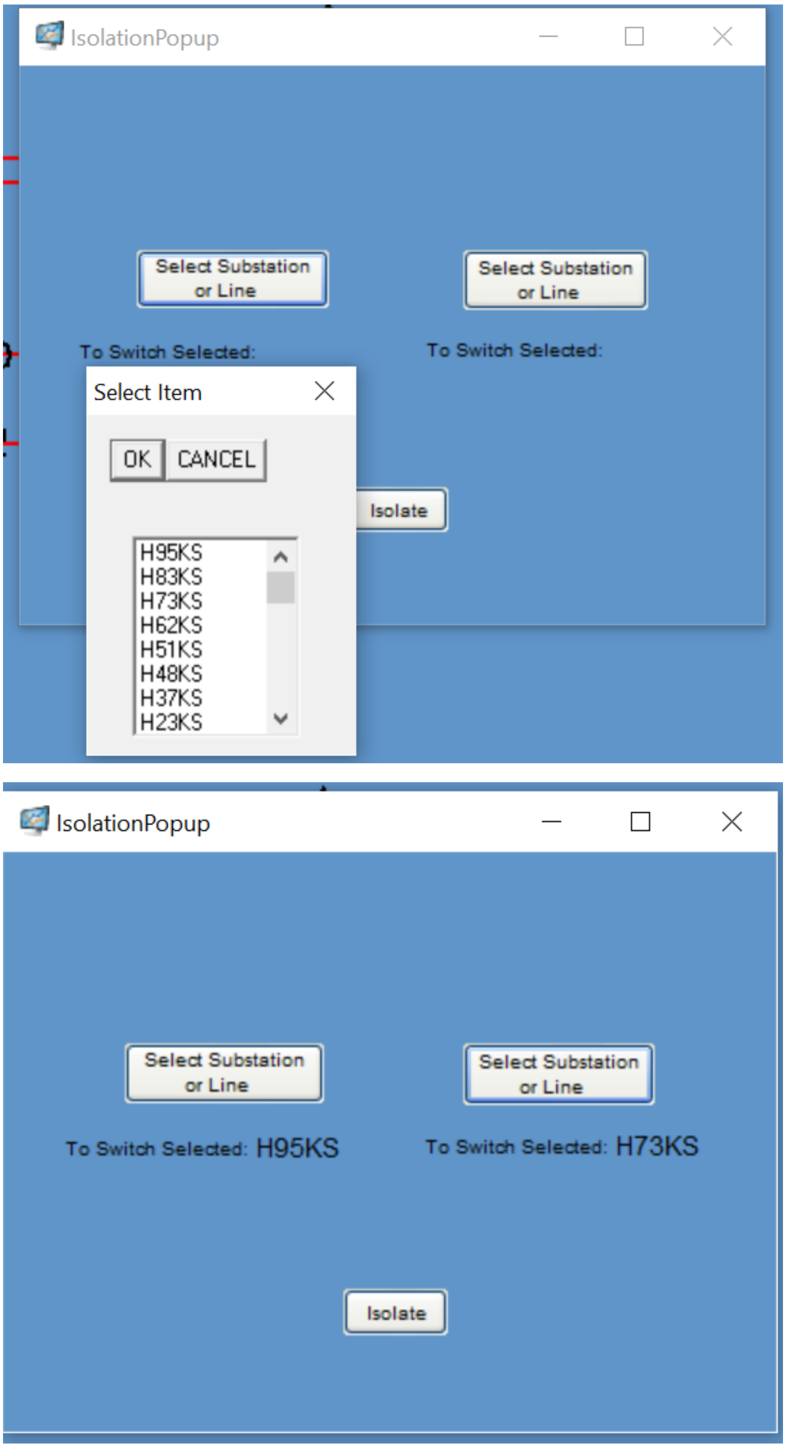
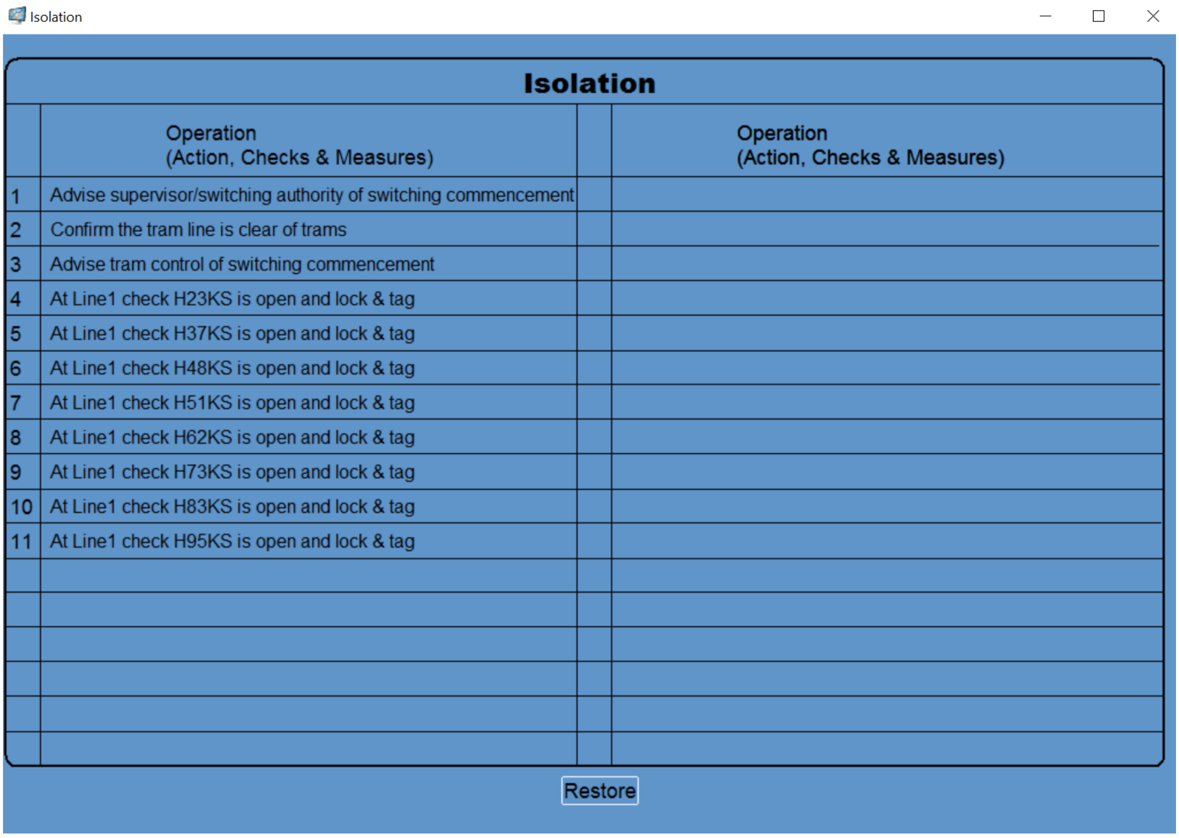


Fig. D25. POIs selection (lines)

For instance, when the user has selected H95KS to H73KS, as shown in the Fig. D25, then the user clicks the ‘isolate’ button, to generate the isolation sequence as shown in the Fig. D26.



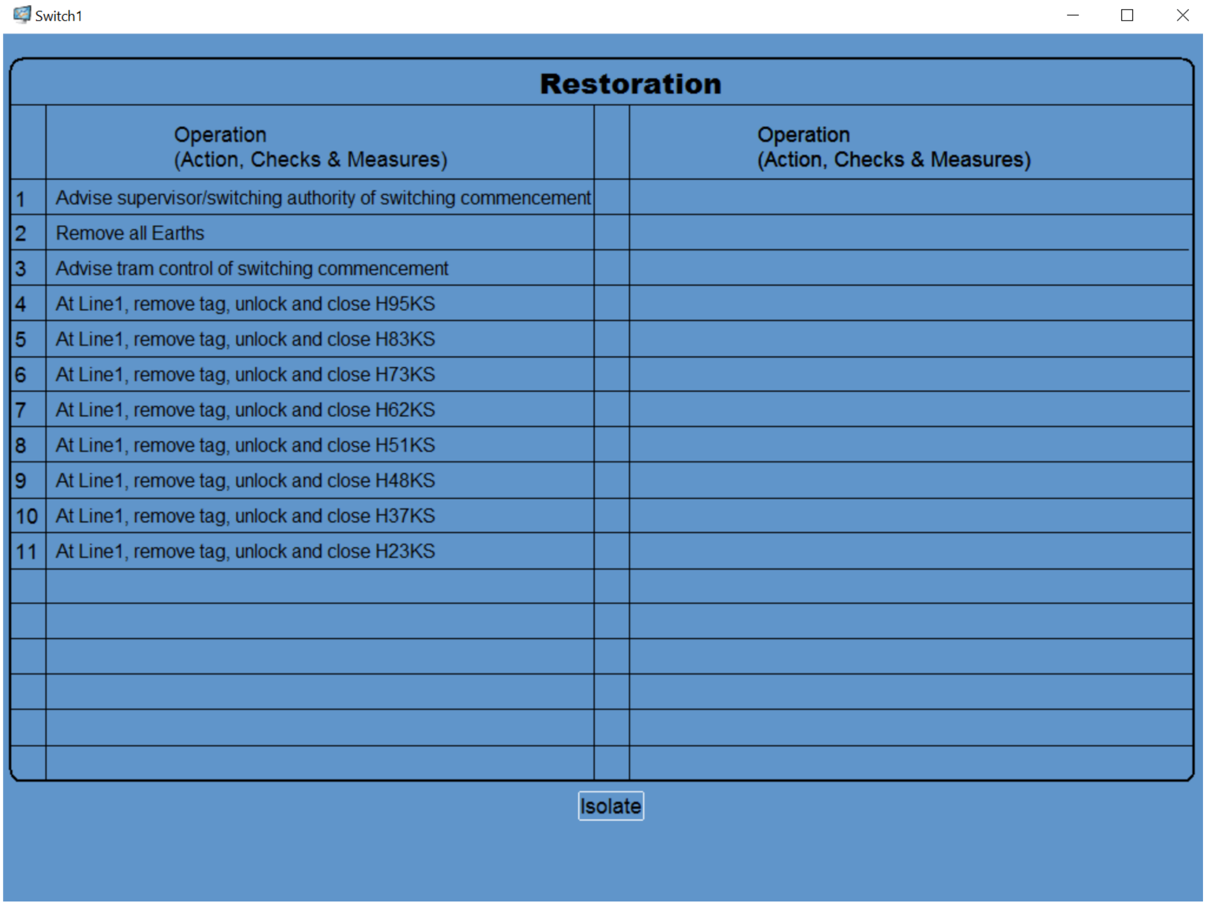
Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Confirm the tram line is clear of trams		
3	Advise tram control of switching commencement		
4	At Line1 check H23KS is open and lock & tag		
5	At Line1 check H37KS is open and lock & tag		
6	At Line1 check H48KS is open and lock & tag		
7	At Line1 check H51KS is open and lock & tag		
8	At Line1 check H62KS is open and lock & tag		
9	At Line1 check H73KS is open and lock & tag		
10	At Line1 check H83KS is open and lock & tag		
11	At Line1 check H95KS is open and lock & tag		

Restore

Fig. D26. Automated Isolation Sequence

The tool has generated the isolation steps as shown in the Fig. D26. When the user clicks the ‘restore’ button, the simulation generates the ‘restoration’ schedule as shown in the Fig. D27.



Switch1

	Restoration		
	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Remove all Earths		
3	Advise tram control of switching commencement		
4	At Line1, remove tag, unlock and close H95KS		
5	At Line1, remove tag, unlock and close H83KS		
6	At Line1, remove tag, unlock and close H73KS		
7	At Line1, remove tag, unlock and close H62KS		
8	At Line1, remove tag, unlock and close H51KS		
9	At Line1, remove tag, unlock and close H48KS		
10	At Line1, remove tag, unlock and close H37KS		
11	At Line1, remove tag, unlock and close H23KS		

Isolate

Fig. D27. Automated Restoration Sequence

Nevertheless, as of above isolation-restoration schedule, the OHW doesn't completely de-energize to commence work as of the electrical engineering simulation tool specifications requirements. Then the user need to run on the OHW schematic mimic (as walking through under de-energised lines) and inline substation schematic, to open the CBs from the incoming substation until the required POIs have become grey as shown in the Fig. D28. This is very important as the informed and 'must open all feeding power' POIs have to be selected from the feeding points. Just working between two adjacent switches, doesn't mean the system has to be isolated between two points.

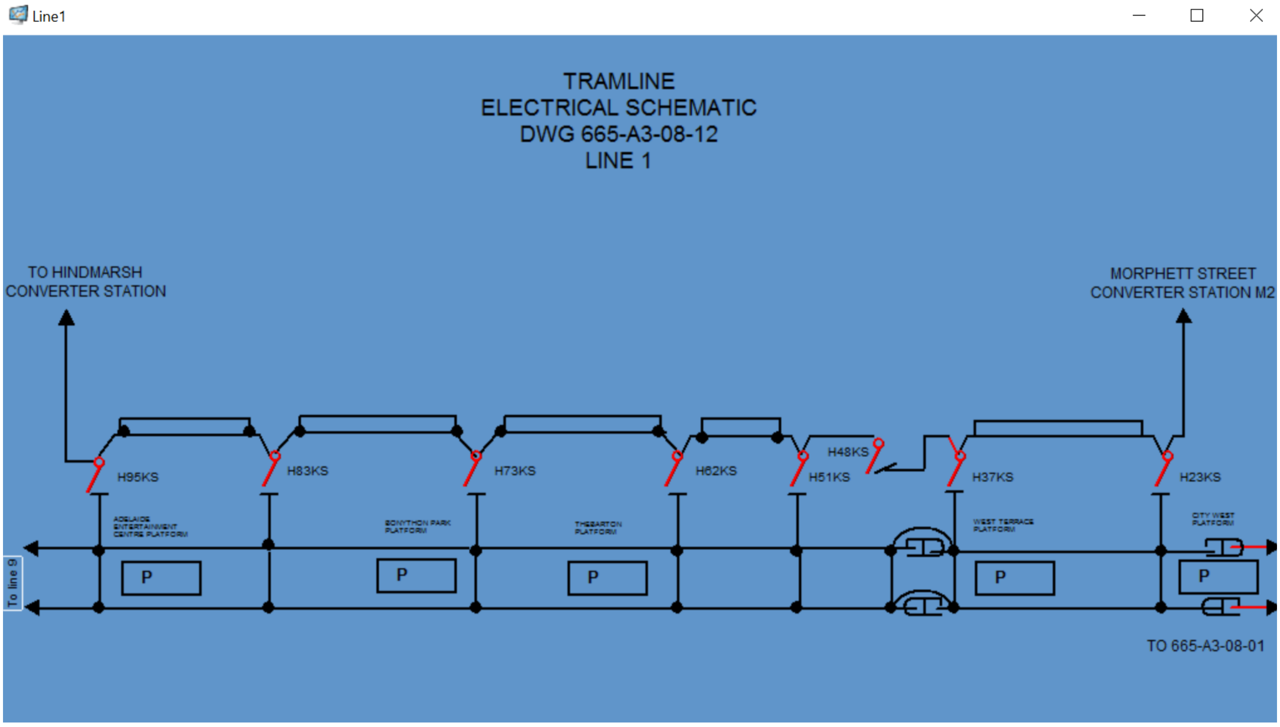


Fig. D28. Automated Restoration Sequence

That's why the work limit and isolation limits play a critical role for switching programs. The simulated grey sections and open switches and substation switchgear tell the user how many switches need to be opened and how many need to be added in the switching template to be approved. By this assessment, a trained switching crew can make an informed simulated decision and select required POIs for limit of isolation. For instance, to commence work between H95KS to H73KS, POIs has to be selected from the Hindmarsh CB DA1 (CBDA1_H) to Morphett St-2 CB DA2 (CBDA2-M2) as shown in the Fig. D29 and required automated isolation schedule is shown in the Fig. D30

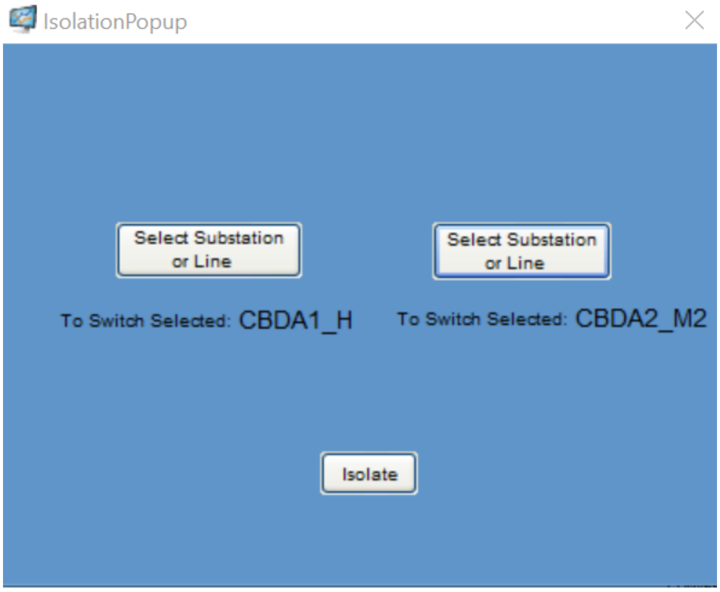


Fig. D29. POIs selection for work between H95Ks to H73KS

Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Line1, open, lock and tag H62KS
2	Confirm the tram line is clear of trams	19	At Line1, open, lock and tag H73KS
3	Advise tram control of switching commencement	20	At Line1, open, lock and tag H83KS
4	At Hindmarsh, open, lock and tag CBDA2_H	21	At Line1, open, lock and tag H95KS
5	At Hindmarsh, open, lock and tag DA2DS_H		
6	At Hindmarsh, open, lock and tag CBDA1_H		
7	At Hindmarsh, open, lock and tag DA1DS_H		
8	At Hindmarsh check TFS_H is open and lock & tag		
9	At Morphett_M2, open, lock and tag CBDA2_M2		
10	At Morphett_M2, open, lock and tag DA2DS_M2		
11	At Morphett_M2, open, lock and tag CBDA1_M2		
12	At Morphett_M2, open, lock and tag DA1DS_M2		
13	At Morphett_M2 check TFS_M2 is open and lock & tag		
14	At Line1, open, lock and tag H23KS		
15	At Line1, open, lock and tag H37KS		
16	At Line1, open, lock and tag H48KS		
17	At Line1, open, lock and tag H51KS		

Restore

Fig. D30. Isolation Schedule for work between H95KS to H73KS

Above automated isolation showed correct isolation steps to commence work between H95KS to H73KS. When the user clicks the restoration button, it has showed the required restoration steps as shown in the Fig. D31.

Switch1

Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement	18	At Hindmarsh, remove tag, unlock and close DA1DS_H
2	Remove all Earths	19	At Hindmarsh, remove tag, unlock and close CBDA1_H
3	Advise tram control of switching commencement	20	At Hindmarsh, remove tag, unlock and close DA2DS_H
4	At Line1, remove tag, unlock and close H95KS	21	At Hindmarsh, remove tag, unlock and close CBDA2_H
5	At Line1, remove tag, unlock and close H83KS		
6	At Line1, remove tag, unlock and close H73KS		
7	At Line1, remove tag, unlock and close H62KS		
8	At Line1, remove tag, unlock and close H51KS		
9	At Line1, remove tag, unlock and close H48KS		
10	At Line1, remove tag, unlock and close H37KS		
11	At Line1, remove tag, unlock and close H23KS		
12	At Morphett_M2 check TFS_M2 is open and remove tag & unlock		
13	At Morphett_M2, remove tag, unlock and close DA1DS_M2		
14	At Morphett_M2, remove tag, unlock and close CBDA1_M2		
15	At Morphett_M2, remove tag, unlock and close DA2DS_M2		
16	At Morphett_M2, remove tag, unlock and close CBDA2_M2		
17	At Hindmarsh check TFS_H is open and remove tag & unlock		

Isolate

Fig. D31. Restoration Schedule for work between H95KS to H73KS

The above restoration steps is required ‘to restore the system back to normal’ after successful completion of work between H95KS to H73KS.

Similarly, the simulation user may select any limits of isolation within a converter station, and generate required isolation –restoration steps as shown in the Fig. D32 and Fig. D33.

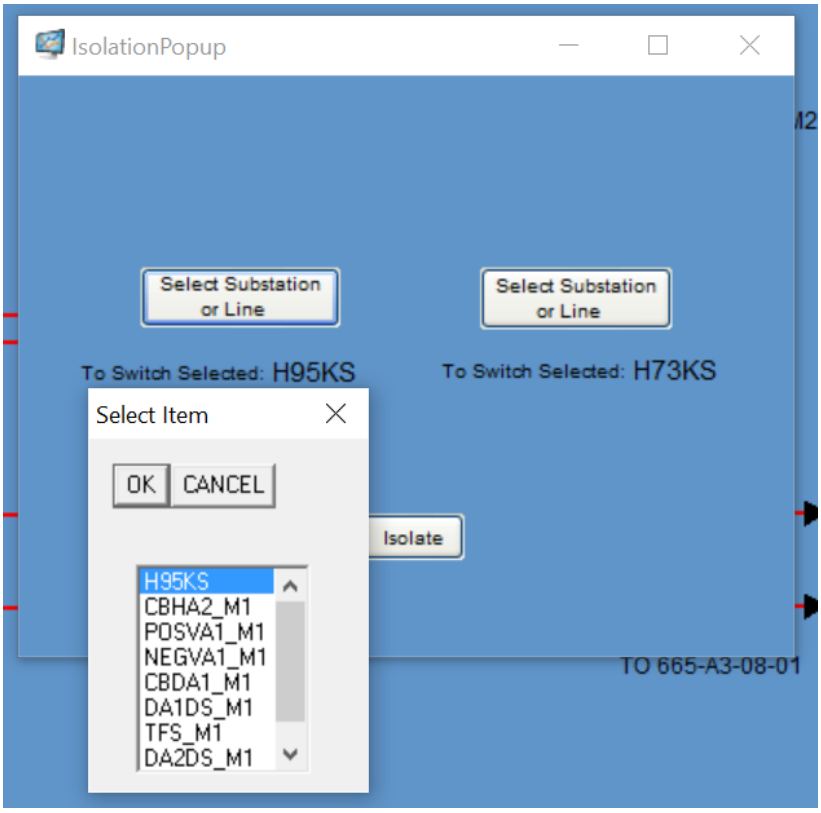


Fig. D32. POIs selection within a converter station

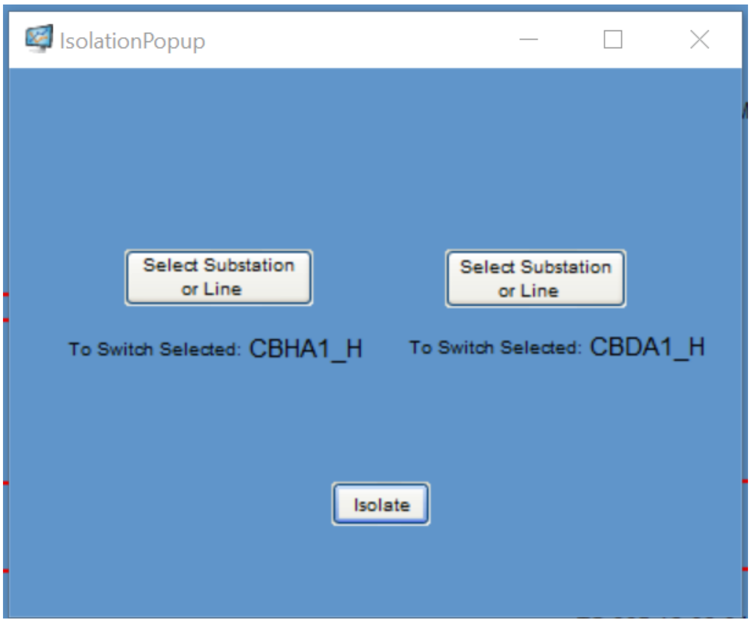
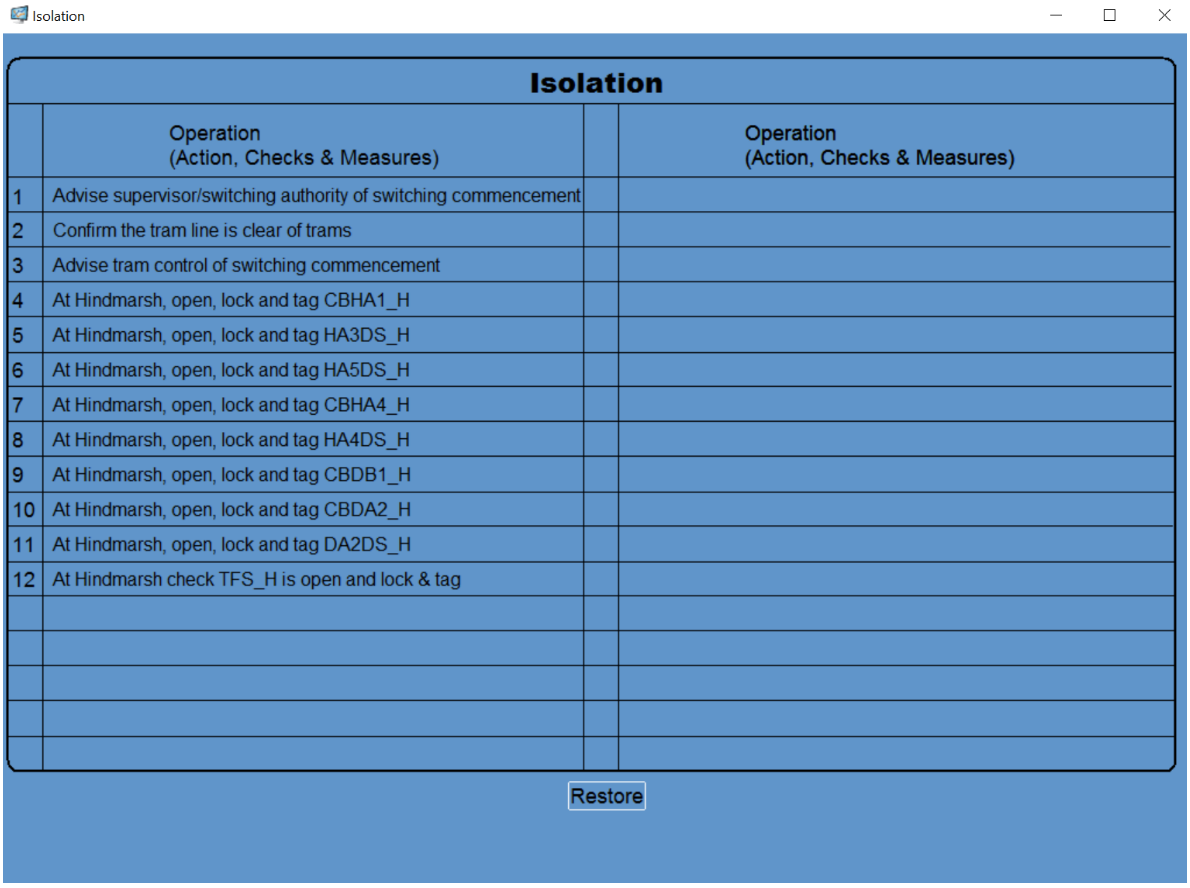


Fig. D33. POIs selected within a converter station

As of above, the POIs have been selected within a converter station, after clicking the 'isolate' button; it will generate the required solation steps as shown in Fig. D34 and restoration steps in the Fig. D35.

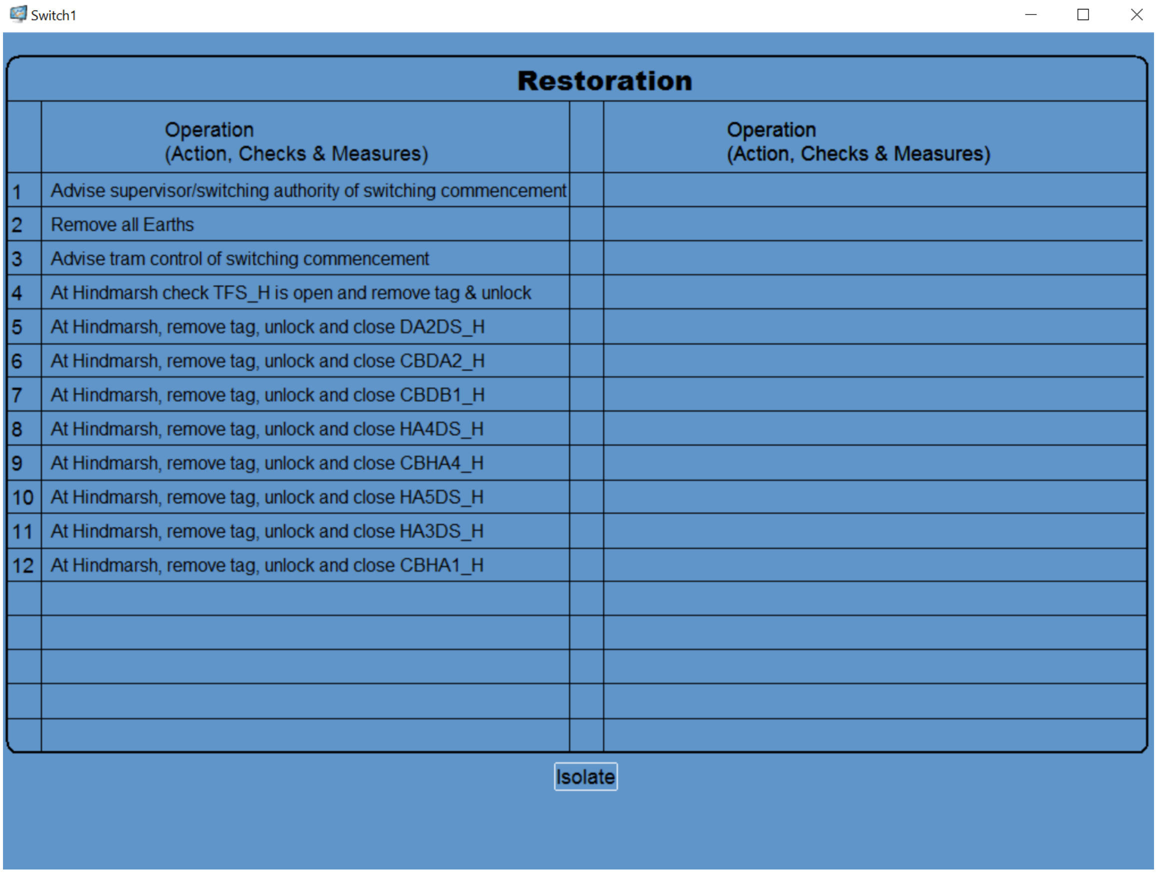


Isolation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Confirm the tram line is clear of trams		
3	Advise tram control of switching commencement		
4	At Hindmarsh, open, lock and tag CBHA1_H		
5	At Hindmarsh, open, lock and tag HA3DS_H		
6	At Hindmarsh, open, lock and tag HA5DS_H		
7	At Hindmarsh, open, lock and tag CBHA4_H		
8	At Hindmarsh, open, lock and tag HA4DS_H		
9	At Hindmarsh, open, lock and tag CBDB1_H		
10	At Hindmarsh, open, lock and tag CBDA2_H		
11	At Hindmarsh, open, lock and tag DA2DS_H		
12	At Hindmarsh check TFS_H is open and lock & tag		

Restore

Fig. D34. Isolation Schedule



Switch1

Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	Advise supervisor/switching authority of switching commencement		
2	Remove all Earths		
3	Advise tram control of switching commencement		
4	At Hindmarsh check TFS_H is open and remove tag & unlock		
5	At Hindmarsh, remove tag, unlock and close DA2DS_H		
6	At Hindmarsh, remove tag, unlock and close CBDA2_H		
7	At Hindmarsh, remove tag, unlock and close CBDB1_H		
8	At Hindmarsh, remove tag, unlock and close HA4DS_H		
9	At Hindmarsh, remove tag, unlock and close CBHA4_H		
10	At Hindmarsh, remove tag, unlock and close HA5DS_H		
11	At Hindmarsh, remove tag, unlock and close HA3DS_H		
12	At Hindmarsh, remove tag, unlock and close CBHA1_H		

Isolate

Fig. D35. Restoration Schedule

The above restoration schedule is not ready to commence work inside a converter station as the user have to select the appropriate POIs and need to close required earth switches as shown in the Fig. D36.

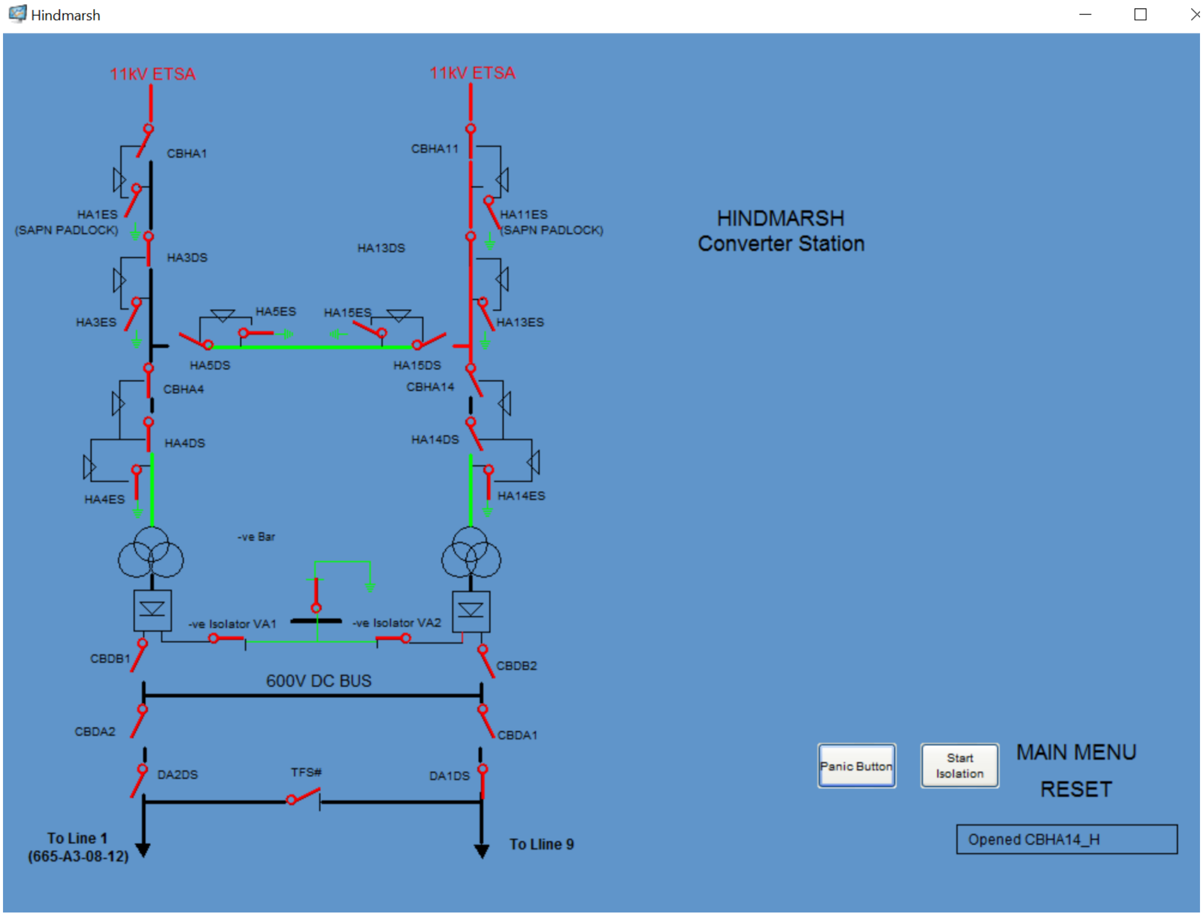


Fig. D36. Isolated mimic of the converter station

So the user clicks on the converter station mimic display, opens or closes required switches. The related earth switches are manually operated and the mimic exactly shows which switches have to be operated to secure the safe worksite for the workgroup. Switching inside a substation is always a bit critical in nature, require proper trained switcher and engineering expertise to authorize and approve. The simulator will help the user to assess the isolation-restoration requirements with the given limits of isolation as shown in the Fig. D36.

8. Overall System safety integration (the Deadman Switch)

The simulator is equipped with the Deadman switch (panic button) to simulate the de-energization of the whole traction system in one click at any given emergency situation. Presumably, when the regular ECO is not available or faint, any non-electrical operator can operate this button if there is an absolute threat, natural disaster that requires immediate de-energization of the entire OHW system instantaneously. When the user clicks the switch, it operates all converter stations outgoing load CBs. Isolation sequence is shown in the Fig. D37,

Deadman switch Operation

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	At Hindmarsh, Open, lock and tag CBDA1_H	18	At Semaphore, Open, lock and tag CBDA2_SP
2	At Hindmarsh, Open, lock and tag CBDA2_H		
3	At Morphett M2, Open, lock and tag CBDA1_M2		
4	At Morphett M2, Open, lock and tag CBDA2_M2		
5	At Morphett M1, Open, lock and tag CBDA1_M1		
6	At Morphett M1, Open, lock and tag CBDA2_M1		
7	At South Terrace, Open, lock and tag CBDA1_ST		
8	At South Terrace, Open, lock and tag CBDA2_ST		
9	At Black Forest, Open, lock and tag CBDA1_BF		
10	At Black Forest, Open, lock and tag CBDA2_BF		
11	At Plympton, Open, lock and tag CBDA1_P		
12	At Plympton, Open, lock and tag CBDA2_P		
13	At Glenelg, Open, lock and tag CBDA1_G		
14	At Glenelg, Open, lock and tag CBDA2_G		
15	At Woodville, Open, lock and tag CBDA1_WV		
16	At Woodville, Open, lock and tag CBDA2_WV		
17	At Semaphore, Open, lock and tag CBDA1_SP		

Restore

Fig. D37. Panic button execution isolation sequence

The simulation demonstrate the status of the all outgoing CBs in mimic display as shown in the Fig. D38 and Fig. D39 including de-energized status of the entire OHW systems.

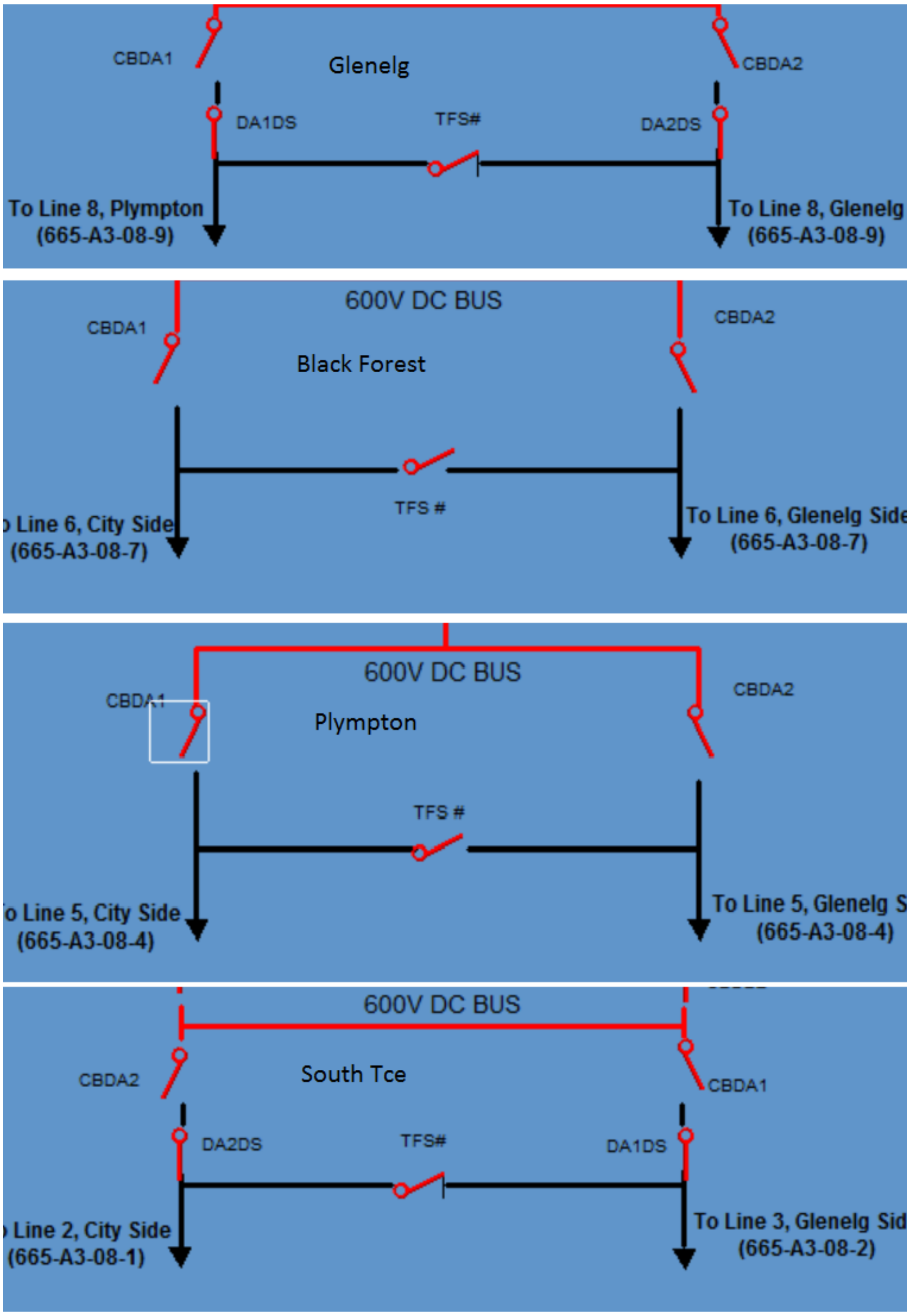


Fig. D38. Outgoing CBs operation for Glenelg, Blackforest, Plympton and South Tce converter stations.

In the above figures, all outgoing load CBs for Glenelg, Blackforest, Plympton and South Tce converter stations have been open as shown in the Fig. D37 isolation status.

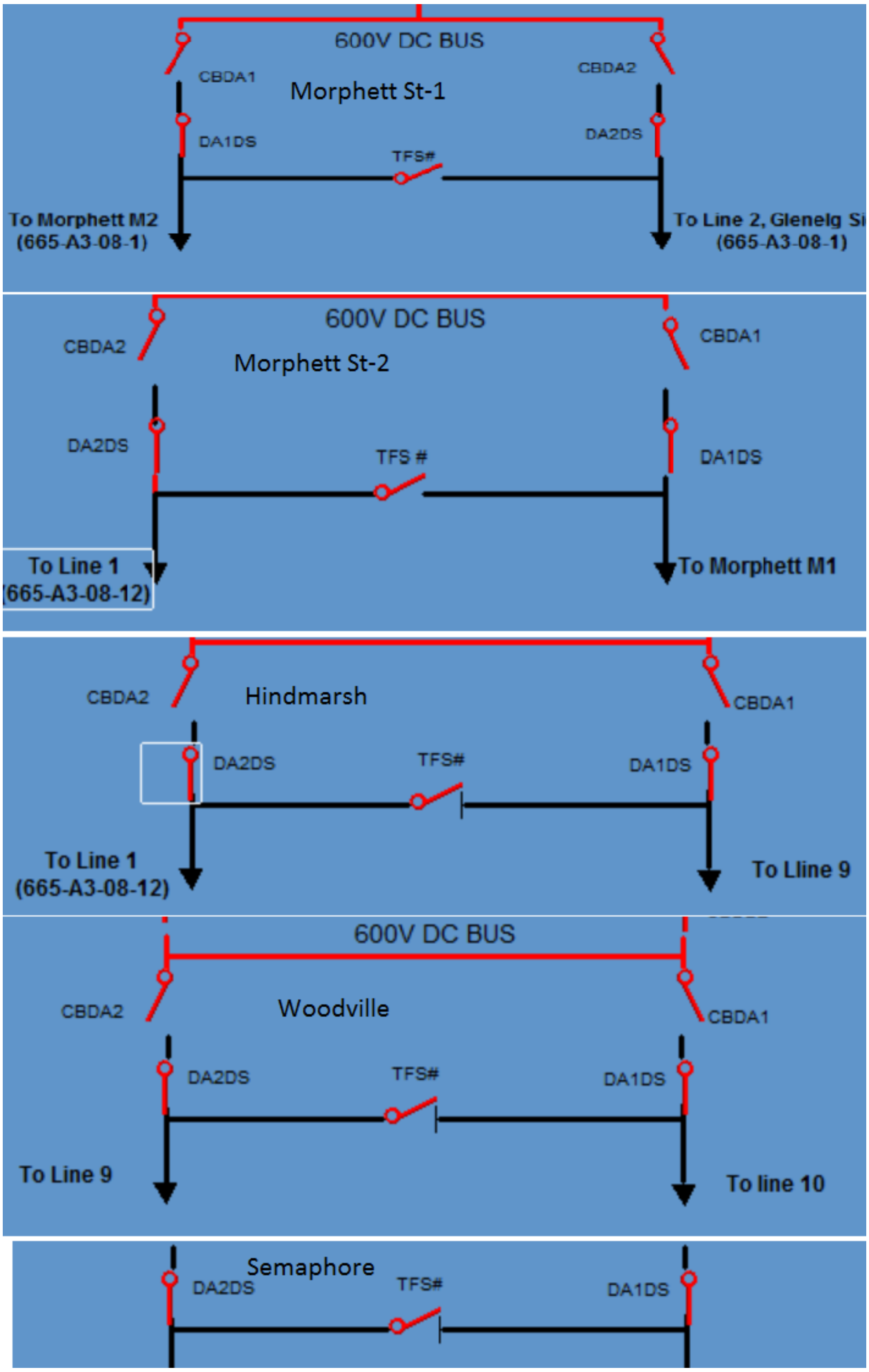


Fig. D39: Outgoing CBs operation for Morphett St-1&2, Hindmarsh, Woodville and Semaphore converter stations

In the above figures, all outgoing load CBs for Morphett St-1&2, Hindmarsh, Woodville and Semaphore converter stations have been open as shown in the Fig. D37 isolation status.

The entire traction system may be restored by a single click on the ‘restore’ if the operator wants to energise the entire system in one click when needed.

Deadman switch Restoration

	Operation (Action, Checks & Measures)		Operation (Action, Checks & Measures)
1	At Hindmarsh, remove tag, unlock and close CBDA1_H	18	At Semaphore, remove tag, unlock and close CBDA2_SP
2	At Hindmarsh, remove tag, unlock and close CBDA2_H		
3	At Morphett M2, remove tag, unlock and close CBDA1_M2		
4	At Morphett M2, remove tag, unlock and close CBDA2_M2		
5	At Morphett M1, remove tag, unlock and close CBDA1_M1		
6	At Morphett M1, remove tag, unlock and close CBDA2_M1		
7	At South Terrace, remove tag, unlock and close CBDA1_ST		
8	At South Terrace, remove tag, unlock and close CBDA2_ST		
9	At Black Forest, remove tag, unlock and close CBDA1_BF		
10	At Black Forest, remove tag, unlock and close CBDA2_BF		
11	At Plympton, remove tag, unlock and close CBDA1_P		
12	At Plympton, remove tag, unlock and close CBDA2_P		
13	At Glenelg, remove tag, unlock and close CBDA1_G		
14	At Glenelg, remove tag, unlock and close CBDA2_G		
15	At Woodville, remove tag, unlock and close CBDA1_WV		
16	At Woodville, remove tag, unlock and close CBDA2_WV		
17	At Semaphore, remove tag, unlock and close CBDA1_SP		

Action

Fig. D40. Panic button execution restoration sequence

Normally, in an absolute emergency isolation, the system doesn’t need to be restored immediately. The operator or the ECC has to make an informed decision and gradually restore the OHW system as of their EMU movement requirement.

Appendix E:

Simulator Reference Procedure

1. Scope:

This procedure outlines the diakoptics implementation and also how the program is built in Citect explorer including a detailed description of each function and how it fits into the system.

2. Subsystems definition:

In implementing the Diakoptics solution, we have defined subsystems. After looking over the schematics of the line and substations five reoccurring combinations of switches such as CB, Isolator, ES, KS and TT Switches were considered as of the following single and double rectifier feeder stations of Fig. E1 and Fig. E2. The subsystem allows to spilt the whole traction network into different pages. Those reoccurring combinations of switches can be seen below along with the connection matrices for each subsystem. The connection matrix is written so that it can be applied generically to any substation's subsystem. The point of the connection matrix is to provide the functions with a picture of how the subsystem is connected. Then the connections matrix is multiplied with the energization matrix. The initial energization matrix only shows the 11kV input power supply is energized from the incoming supply provider. By multiplying the connections matrix and energization matrix until a steady state matrix is reached, this matrix shows the current energy state of each section of the system.

Each substation is separated into subsystems that have similar line and switch configurations that allows for repetition in the code. The subsystem types are listed in Fig. E1 and Fig. E2 with labelling 'Subsystem 1" to "Subsystem 5". How the subsystem connection matrix and its switching state (*Sw* variables) diakoptics implementation works can be found in the appendices B & C.

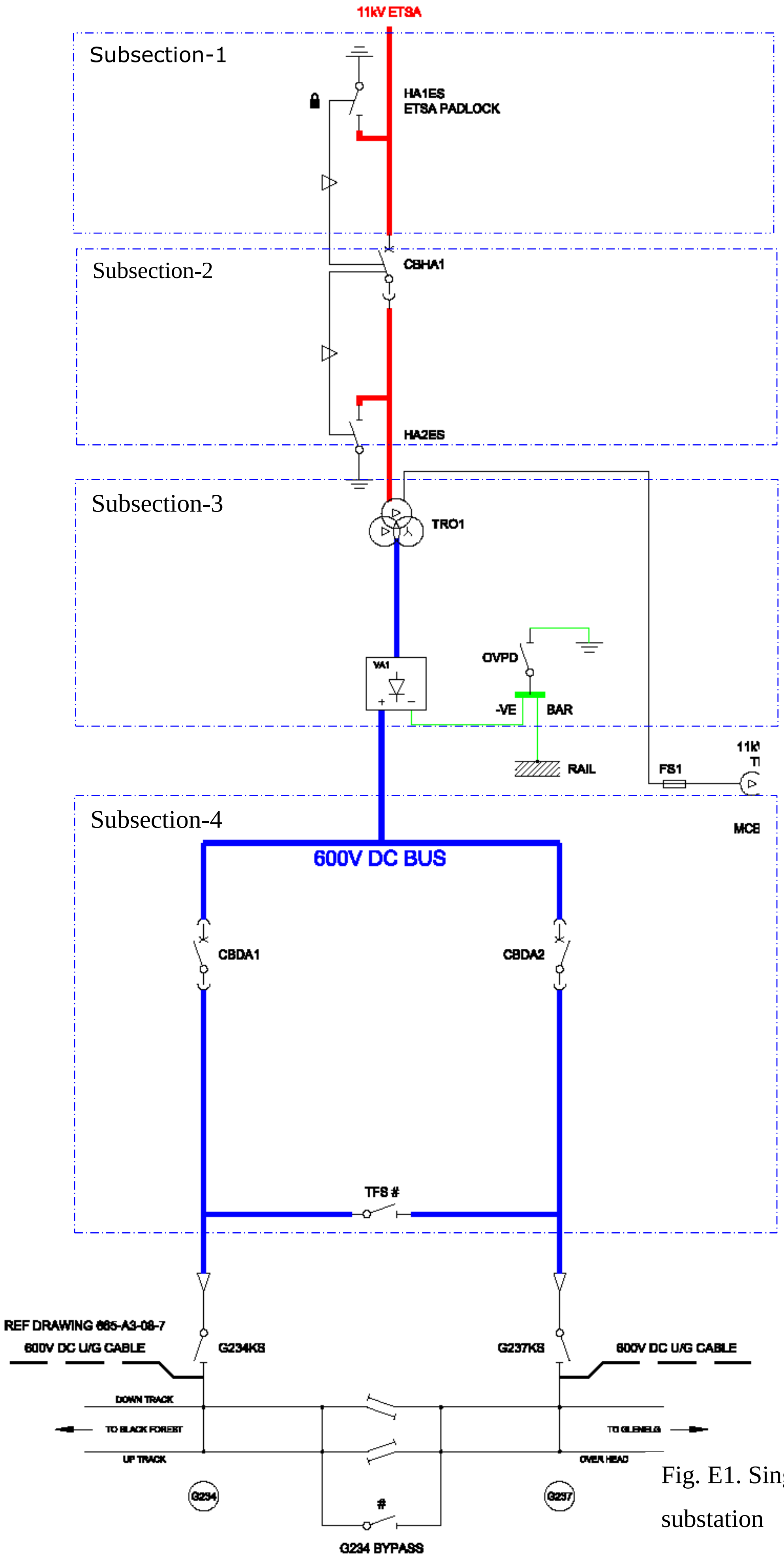


Fig. E1. Single rectifier substation

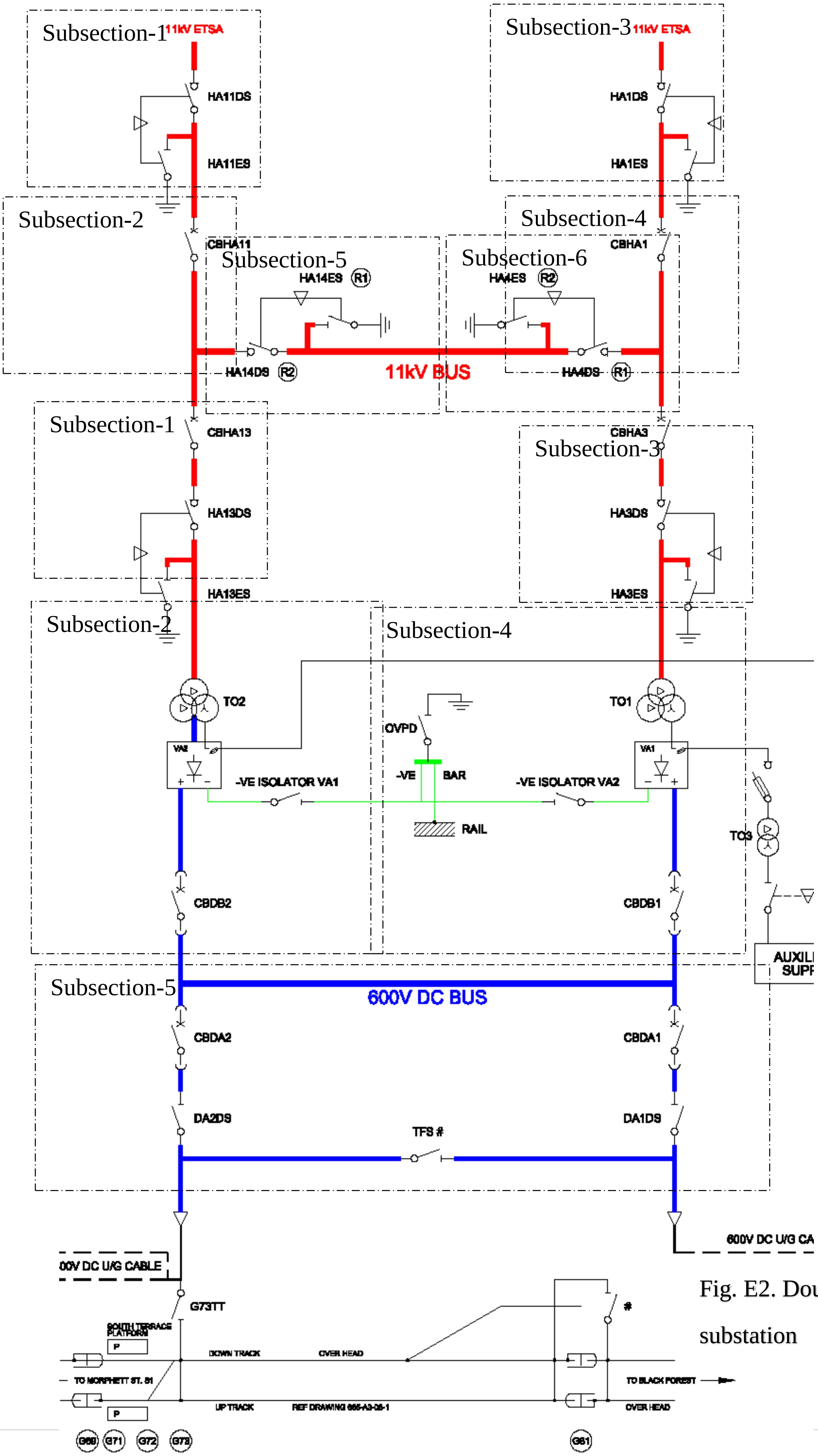
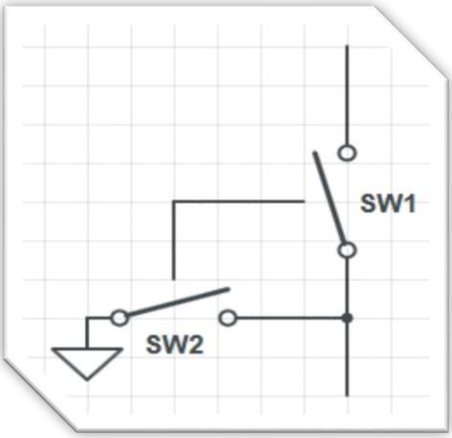
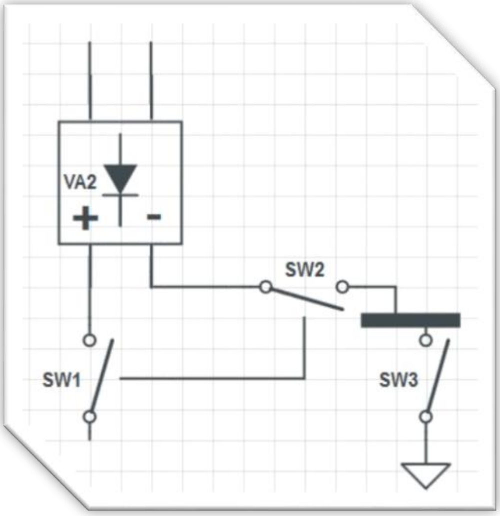


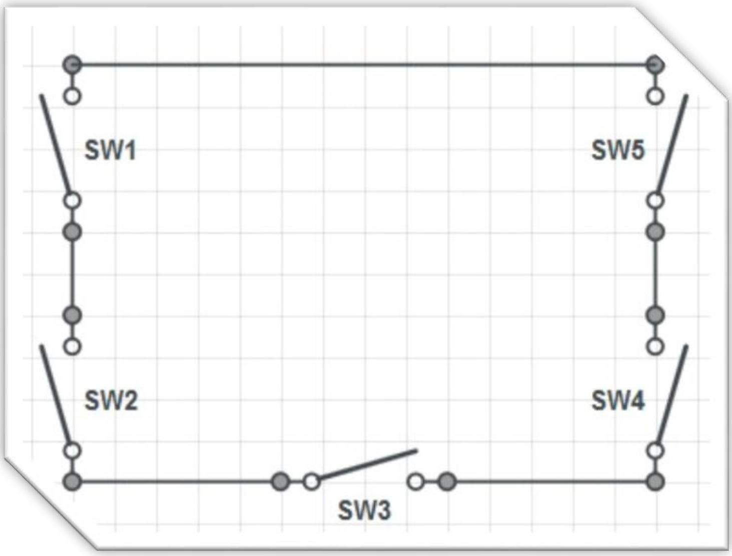
Fig. E2. Double rectifier substation

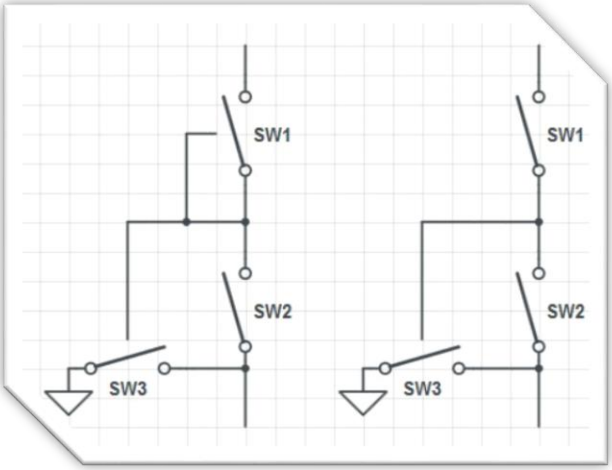
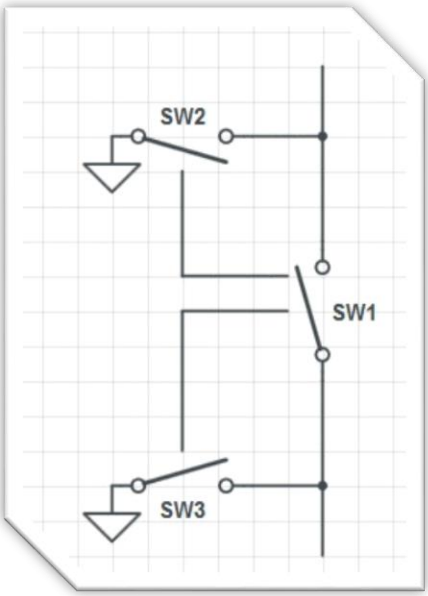
Combinations of switches can be seen in the following table along with the connection matrices for each subsystem. The subsystem is a part of the whole system which is broken into smaller parts, and can be solved individually without any external interference. The purpose of the total system tearing into subsystems, is solving them individually and then putting the subsystems back together to recreate the solution of the true switching representation of the entire traction system.

Table E1: Subsystems and Connection Matrices

Subsystem 1	**subSys1 (Sw1,Sw2)**
 	$\begin{bmatrix} 1 & Sw1 & 0 & 0 & 0 \\ Sw1 & 1 & \overline{Sw1} & Sw2 & 0 \\ 0 & \overline{Sw1} & 1 & \overline{Sw2} & 0 \\ 0 & Sw2 & \overline{Sw2} & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix}$ Construction of the area wise (sample network switch position) matrix has been explained in the appendix B. Possible combination of the subsection (substation switchgear) has been accommodated in the connection matrix as of the sectioned substation schematics.
Subsystem 2	**subSys2(Sw1,Sw2,Sw3)**

	$\begin{bmatrix} 1 & Sw1 & 0 & Sw2 & 0 \\ Sw1 & 1 & \overline{Sw1} & 0 & 0 \\ 0 & \overline{Sw1} & 1 & 0 & 0 \\ Sw2 & 0 & 0 & 1 & Sw3 \\ 0 & 0 & 0 & Sw3 & 1 \end{bmatrix}$

Subsystem 3	**subSys3(Sw1,Sw2,Sw3,Sw4,Sw5)**
	$\begin{bmatrix} 1 & Sw1 & 0 & 0 & Sw5 \\ Sw1 & 1 & Sw2 & 0 & 0 \\ 0 & Sw2 & 1 & Sw3 & 0 \\ 0 & 0 & Sw3 & 1 & Sw4 \\ Sw5 & 0 & 0 & Sw4 & 1 \end{bmatrix}$
Subsystem 4	**subSys4(Sw1,Sw2,Sw3,logical_type)**

	logical_type=1 $\begin{bmatrix} 1 & 0 & Sw1 & 0 & 0 \\ Sw1 & 1 & Sw2 & \overline{Sw2} & Sw3 \\ 1 & Sw2 & 1 & Sw1 & 0 \\ 0 & \overline{Sw2} & \overline{Sw1} & 1 & \overline{Sw3} \\ 0 & Sw3 & 0 & \overline{Sw3} & 1 \end{bmatrix}$ logical_type=0 $\begin{bmatrix} 1 & 0 & Sw1 & 0 & 0 \\ Sw1 & 1 & Sw2 & \overline{Sw2} & Sw3 \\ 0 & Sw2 & 1 & 0 & 0 \\ 0 & \overline{Sw2} & 0 & 1 & \overline{Sw3} \\ 0 & Sw3 & 0 & \overline{Sw3} & 1 \end{bmatrix}$
Subsystem 5	**subSys5(Sw1,Sw2,Sw3)**
	$\begin{bmatrix} 1 & Sw1 & \overline{Sw1} & \overline{Sw1} & Sw2 \\ Sw1 & 1 & 0 & 0 & \overline{Sw3} \\ \overline{Sw1} & 0 & 1 & \overline{Sw1} & \overline{Sw3} \\ \overline{Sw1} & 0 & \overline{Sw1} & 1 & \overline{Sw2} \\ Sw2 & Sw3 & \overline{Sw3} & \overline{Sw2} & 1 \end{bmatrix}$

Combining these subsystems together in different combinations both single and double rectifier feeder substations in the tramline traction tool may be modelled as of Fig. 3E.

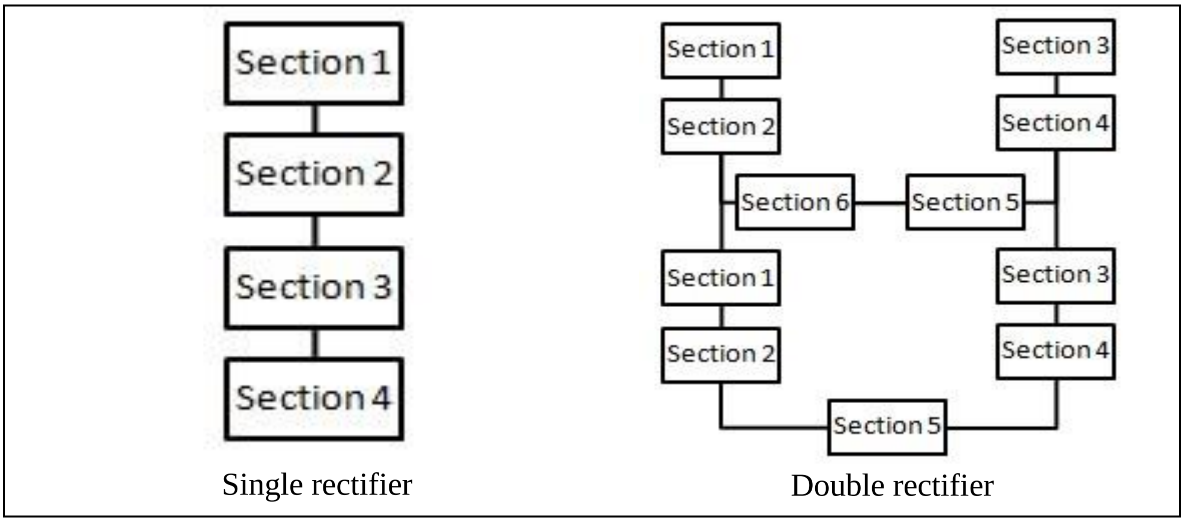


Fig. 3E: Single and double rectifier substation as of subsystems

This has allowed the subsystems functions have to be applied in to all substations. A similar process can be applied to a parallel substation. However, as there are a number of sections in a parallel substation, the function is applied twice to the substation. The results of the first function has determined the initial conditions of the second function. This has allowed a generic function to be applied to any parallel substation in the tramline system simulation development.

As there are significantly less switches on OHW and UFC system (compare to the substation), there were no generic functions required for the subsystems of OHW and UFC systems; only code for each specific OHW and UFC section line have been defined. The point of the connection matrix provided the functions with a picture in Fig. 3E as of how the subsystems are connected. The whole system is divided into 55 subsystems. Then the connection matrix is multiplied with the energization vector. The initial energization vector only shows the 11kV input power supply is energized via the incoming step down transformer. By multiplying the connections and energization matrix until a steady state matrix is reached, this matrix has showed the current switching state of each section as such all subsystems of the entire traction system.

3. **Overall Traction Network (diakoptics implementation)**

The system diakoptical representation is also seen in Fig. 4E. Each boxed area in the Fig. 3E represents a substation which also connect to the OHW and parallel UFC section in the Adelaide traction system. That means:

Subsystems 1-11 represent a dual rectifier substation (Hindmarsh).

Subsystems 13-16, 18-20 represent single rectifier substation (Morphett-St 1 & 2).
Subsystems 23-3 represent a dual rectifier substation (South Tce).
Subsystems 35-37 represents a single rectifier substation (Black Forest).
Subsystems 39-41 represents a single rectifier substation (Plympton).
Subsystems 44-54 represent a dual rectifier substation (Glenelg).
Subsystems 12, 17, 21, 22, 34, 38, 42, 43 and 55 represent OHW and UFC system from the Entertainment Centre, Hindmarsh EOL to Moseley Square, Glenelg EOL.

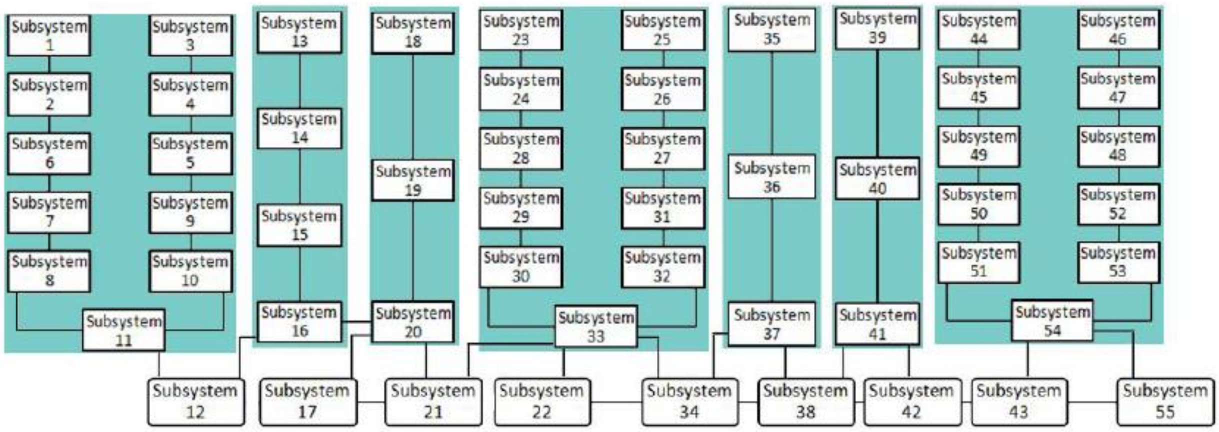


Fig. 4E: Summary of torn network (subsections) of the traction system

Including two new Woodville and Semaphore Substations, the diakoptical representation is seen in Fig. 5E. Each shaded area in the Fig. 5F represents a substation which also connect to the OHW and parallel UFC section in the Adelaide traction system. That means:
Subsystems 1-11 represent a dual rectifier substation (Semaphore).
Subsystems 14-24 represent a dual rectifier substation (Woodville).
Subsystems 26-36 represent a dual rectifier substation (Hindmarsh).
Subsystems 38-41, 43-45 represent single rectifier substation (Morphett-St 1 & 2).
Subsystems 57-57 represent a dual rectifier substation (South Tce).
Subsystems 60-62 represents a single rectifier substation (Black Forest).
Subsystems 64-66 represents a single rectifier substation (Plympton).
Subsystems 68-78 represent a dual rectifier substation (Glenelg).
Subsystems 12, 13, 25, 37, 42, 46, 58, 59, 63, 67, 79 and 80 represent OHW and UFC catenary system from the Semaphore EOL to Moseley Square Glenelg EOL.

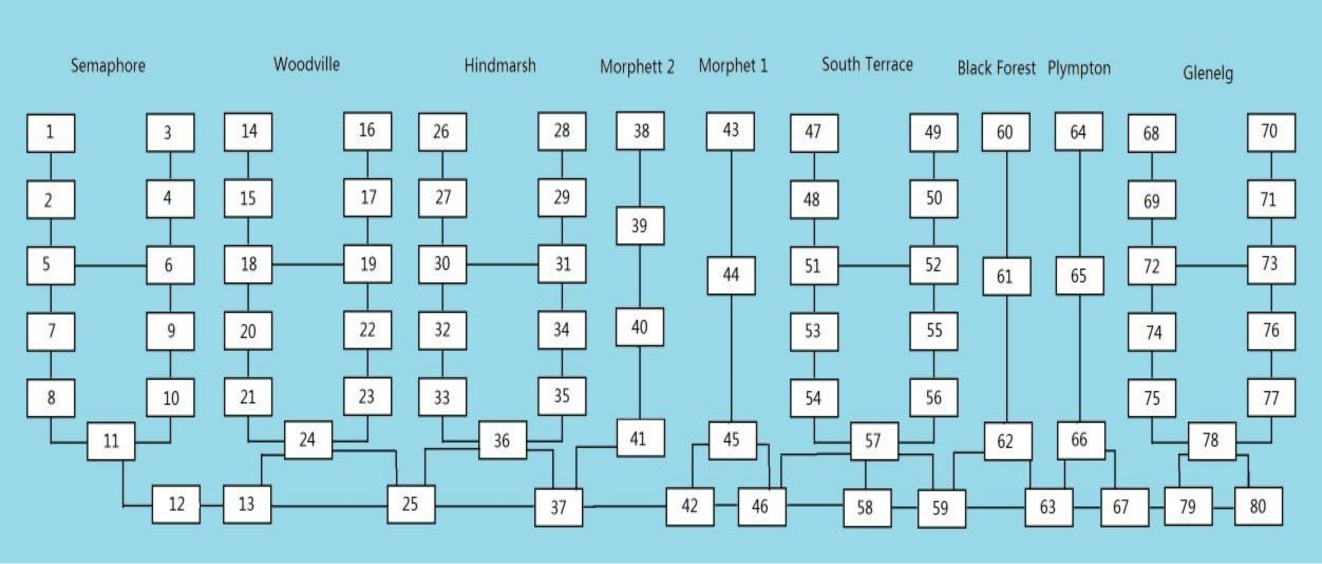


Fig. 5E. Combined extended Subsystems of the Simulation Tool.

4. Switching state determination (energized or de-energised)

The isolation function is considered two switches as inputs and determined the path of isolation between them. It has achieved this by looking up the switches in the database and determining which subsystem it constructed in. A path-way between the two subsystems has worked out as of example in Fig. 6E.

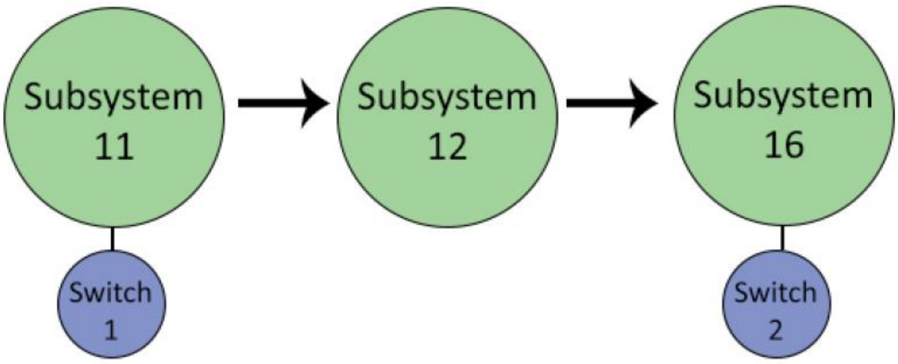


Fig. 6E. Mapping of the isolation procedure

If the given POI are between switch 1 and switch 2, the simulation already has found in what subsystem the switches are connected in. The software would have returned subsystem-11 and subsystem-16. A pathway between these two subsystems is looked up and stored in the array. Each substation is considered as a node in the system and has its connections mapped. The subsystems are numbered such that a series of conditions can provide the function with a clear path to navigate through the system. Once the order of the subsystem has been obtained, the switches that need to be opened are scanned from a database and stored in switch array.

There are a number of key safe operational interlocking to be followed as mapped in as-built electrical & mechanical interlocking of the switchgear. These interlocks and safety principles have been checked in the citectSCADA graphics prior to its chronological open or close operation of the related isolator, bypass switch, TT, KS or substation switchgear.

5. **Automated Switching Sequence**

Diakoptics integration, which is the fundamental technique for the traction simulation tool, is responsible for simplifying the simulation process of the isolation-restoration program. One of the required features to be integrated into the simulation during the development of this project, is the automatic generation of the isolation-restoration switching program. In any given planned or unplanned task in a substation, UFC or OHW, minimum two POIs or work limit switches have to be chosen. The simulation generates required safe switching steps to carry out an isolation- restoration switching on-site for a maintenance work accomplishment.

6. **Overall Safety Integration**

The integration of the Deadman switch into the tram traction simulation incorporates an interface switch though which operators or any authorized attendant in the ECC operates the entire OHW feeding power from all substations to the OHW. On it’s execution (as of the Fig. 7E), the entire traction network OHW is turned off immediately (by opening all outgoing feeder load CBs from all feeding substations). A Deadman switch is required to simulate such an incident to disarm all EMUs in the vicinity by a non-electric network controller, ideally in an unwanted and rare accident (as such fire, dewirement, absolute life threatening condition) or when the regular operator faint or during an extreme emergency when all incoming CBs must be open with a minimal effort.

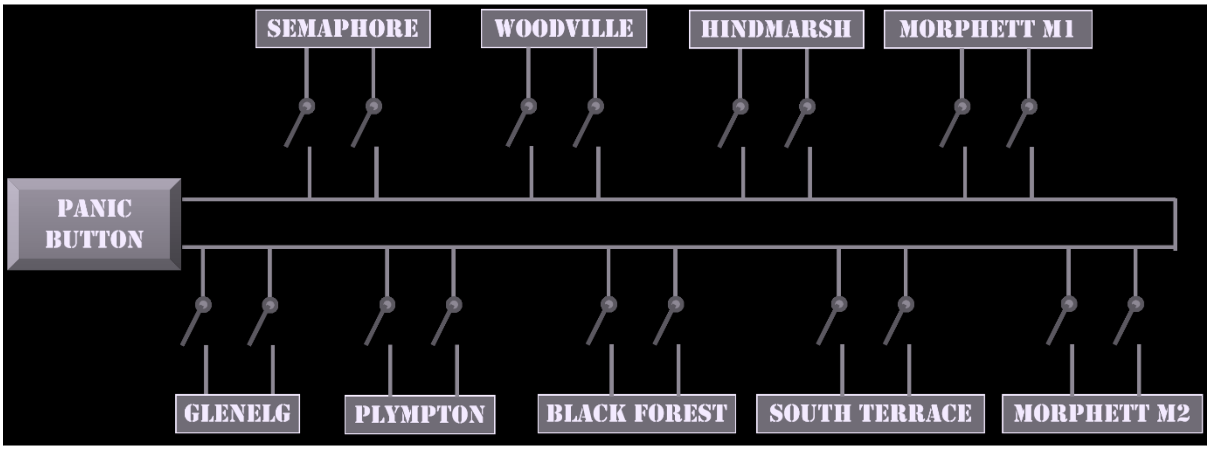


Fig. 7E. Overall safety (panic button)

In the simulation tool, seven existing substations and two additional substations have considered to be covered with the Deadman switch algorithm. Each substation's outgoing two main CBs that need to be controlled by this switch interface. Therefore, total 18 outgoing 600V DC feeder CBs are linked with the control of the Deadman switch. The Cicode function for the Deadman switch is designed with the value of 1 and 0. That means '1' stands for that all the circuit breakers are 'turned on' and '0' stands for that all the circuit breaker are 'turned off'.

7. Graph theory

In mathematical study, graph theory is used to study the pairwise relations between objectives in a system. In late 1840s, Kirchoff initiated graph theory in his literature to illustrate electrical network characteristic. Due to its relatively high efficiency and effective performance, graph theory has been used in electrical network analysis since. Adelaide tram traction system consists of physical devices such as circuit breaker, knife switches, isolator, earth switches and bypass switches. Hence, the tram network could be considered as a tree or graph. To use graph theory in the simulator algorithm, we have to work out the linkage between the traction system and supplication methods. There are two graph theory based measurements which could be used as algorithm for tramline simulation tool. The first method is called Depth First Search (DFS). DFS is a method for traversing the data structure of graphs. It starts at root of data structure or it could start from any vertices as its root, then traversing as long as possible in each branch until it backtracking. The second algorithm called Breadth First Search (BFS). BFS starts at arbitrary root and searches all neighbored nodes before searching next level vertices.

Pseudocode of DFS:

G = (L, Sc); L is the number of lines and Sc is the number of closed switches.

'v' is the line number.

'w' is one not labelled line.

Input: G and v,

Output: All vertices reachable from v labelled as discovered, A recursive implementation of DFS:

- procedure DFS(G,v):

  label v as discovered

  for all edges w in G.adjacentEdges(v) do

  if vertex w is not labeled as discovered then

  and recursively call DFS(G,w)

We will get all labelled lines as a vector which shows the network energised or de-energised state. However, if we use only graph theory, the simulation becomes very slow. Moreover the substation power flow becomes troublesome (due to the transfer switch position and dual outgoing power supply requirements) to direct to the OHW and UFC systems. So we need combine graph theory based approach with the diakoptical tearing method.

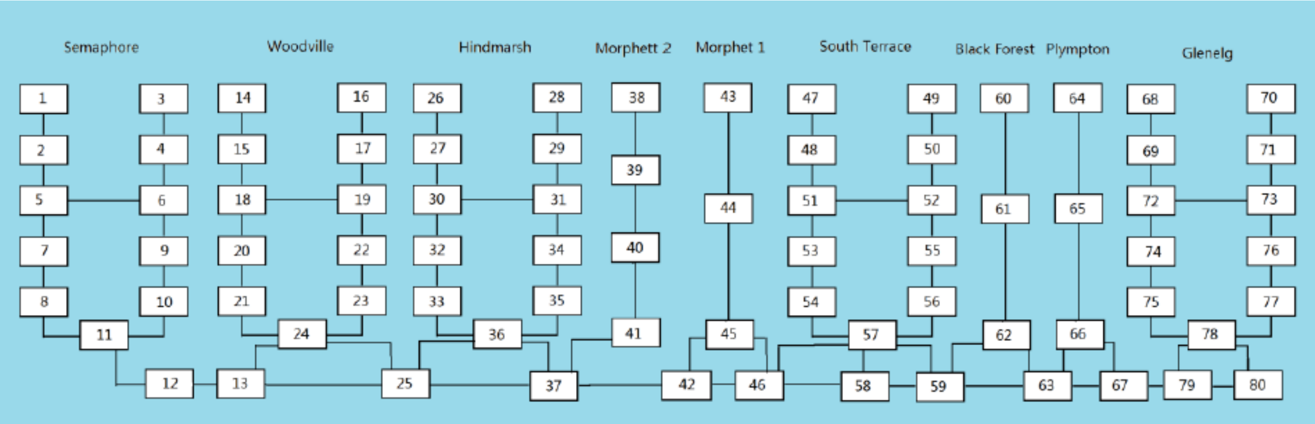


Fig. 8E. Extended network subsystem representation.

At a glance, the simulation consists of 80 diakoptics matrixes. In combination algorithm, we consider each matrix instead of a line as a node and serve lines which connect with matrix as edges. For simplification, we set an illusion matrix which connect all sources (1, 3, 14, 16, 26, 28, 38, 43, 47, 49, 60, 64, 68, and 70) together as the root. Then we could use DFS or BFS for the simulation outcome.

The pseudocode of DFS:

G = (M, ln); M is the number of matrixes

ln is the number of connection lines in above graph.

'v' is the matrix number.

'w' is one not labelled matrix.

Input: G and v

Output: All matrix reachable from v.

recursive implementation of DFS:

procedure DFS(G,v):

imply diakoptics to get line energy in this matrix

label v as discovered

for all edges w in G.adjacentEdges (v) do

if matrix w is not labeled as discovered then

recursively call DFS(G,w)

Finally, we get all labelled lines as a vector which shows the switching state (energised and de-energised) status of the entire network.

API and Description of Functions

The following descriptions explain how each function used in the simulation is constructed and what information each function takes in and gives to the other areas of the simulation.

blackforest()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Blackforest substation 1x5 integer matrices for all energy states in the Blackforest substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Blackforest graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the Blackforest substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Blackforest substations for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the three subsystems in the Blackforest substation are connected.

define()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	Integer variables representing all switches in the system.

OUTPUTS CALCULATED:	5x5 integer matrices for all system connections
USE OF FUNCTION:	Called before the diakoptics function is called for each subsystem.
DESCRIPTION:	Defines all of the connections matrices (global variables) in the system. Information is gathered from the switch TAGS in the graphics and inputs them into the connections matrix.

diakoptics()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrix 'system' 1x5 integer matrix 'energy'
OUTPUTS CALCULATED:	1x5 integer matrix 'energy'
USE OF FUNCTION:	Called in each substation and line function.
DESCRIPTION:	Multiplies the connections matrix with the energisation matrix, until a steady state solution is reached.
NOTES:	Allows up to 5x5 matrices to be multiplied out.

glenelg()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Glenelg substation 1x5 integer matrices for all energy states in the Glenelg substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Glenelg graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the Glenelg substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Glenelg substations for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the eleven subsystems in the Glenelg substation are connected.

hindmarsh()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Hindmarsh substation 1x5 integer matrices for all energy states in the Hindmarsh substation

OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Hindmarsh graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the Hindmarsh substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Hindmarsh substations for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the eleven subsystems in the Hindmarsh substation are connected.

initialiseSimulation()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS CALCULATED:	1x150 digital matrix ‘switchVal’ displaying the initial (normal operating) state of all switches in the system
USE OF FUNCTION:	Used when program is first run and when the RESET button is pressed
DESCRIPTION:	Defines the value for all of the switches in the system in the case of normal operation.

interlockSwitch(INT switchVar, INT interlock1, INT interlock2)

TYPE:	Void
INPUT VARIABLES:	Integer ‘switchVar’ Integer ‘interlock1’ Integer ‘interlock2’
OUTPUT:	Integer ‘LOCK’
USE OF FUNCTION:	Used in genie ‘switch2’, representing an interlock switch.
DESCRIPTION:	Checks the three inputs and if switchVar is open (0) and both interlock1 and interlock2 are closed (1). If so LOCK=0 and an error message appears.

isolateAreaOrder(INT area1, INT area2)

TYPE:	Void
INPUT VARIABLES:	Integer ‘area1’ Integer ‘area2’
OUTPUT:	Integer 1x55 matrix and exended to 1x80 matrix with two new substations ‘area_order’
USE OF FUNCTION:	Used in order to generate the switching schedule outlining the isolation procedure. Called when switches are inputted into the Isolation GUI.

DESCRIPTION:	This function takes in 2 areas and works out what areas are between area1 and area2. It stores the list of areas in the matrix area_order[].The matrix is then re-arranged so that the substation areas are listed first then line areas. The matrix area_order is then given as the output.
NOTES:	This only outlines the areas in the isolation order, not the switches. The output area_order[] is then used in the function isolateSwitchOrder() to determine the correct order for the switches.

isolateDemo(INT isoNo)

TYPE:	Void
INPUT VARIABLES:	Integer 'isoNo'
OUTPUT:	None
USE OF FUNCTION:	Used in the demos, accessed from the main menu.
DESCRIPTION:	This function contains two cases that demonstrate how to isolate a certain area of the track. The function manually goes through and calls specific functions that would normally be automatically called from the graphics. This function allows an automatic procedure to be shown, without any input from the user.
NOTES:	

isolatePoint1()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS CALCULATED:	
USE OF FUNCTION:	Used in the popup isolation graphic.
DESCRIPTION:	Used to Select the line or substation that the first point of isolation is from.

isolatePoint2()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS CALCULATED:	
USE OF FUNCTION:	Used in the popup isolation graphic.

DESCRIPTION:	Used to Select the line or substation that the second point of isolation is from.

isolateSwitchOrder(INT area1, INT area2)

TYPE:	Void
PARAMETERS USED IN FUNCTION:	Integer 1x80 matrix ‘area_order’
OUTPUTS CALCULATED:	Integer 1x200 matrix ‘switch’ Integer 1x200 matrix ‘switchName’ Integer 1x200 matrix ‘areaName’
USE OF FUNCTION:	Used in order to generate the switching schedule outlining the isolation procedure. Called when switches are input into the Isolation GUI.
DESCRIPTION:	This function takes in the matrix area_order and from the area numbers determines which switches need to toggled to isolate that area. The function stores the switch number (switch[]), switch name (switchName[]) and the area name (areaName[])

isolateSwitchSelect1()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS	

CALCULATED:	
USE OF FUNCTION:	Used in the popup isolation graphic.
DESCRIPTION:	Used to Select the switch, from the line or substation previously selected, for the first point of isolation.

isolateSwitchSelect2()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS CALCULATED:	
USE OF FUNCTION:	Used in the popup isolation graphic.
DESCRIPTION:	Used to Select the switch, from the line or substation previously selected, for the second point of isolation.

jumpToPage(STRING pageName)

TYPE:	Void
INPUT VARIABLES:	String ‘pageName’
OUTPUT:	None

USE OF FUNCTION:	Called when a new page is required to be opened.
DESCRIPTION:	Calls the simulate function to calculate the current page energy status and displays the page, 'pageName'

lines()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the lines 1x5 integer matrices for all energy states in the lines
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the lines graphics pages. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the lines. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for lines for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the four subsystems in the lines are connected.

morphettM1()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the M1 substation 1x5 integer matrices for all energy states in the M1 substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the M1 substation graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the M1 substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for M1 substation for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the three subsystems in the M1 substation are connected.

morphettM2()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the M2 substation 1x5 integer matrices for all energy states in the M2 substation
OUTPUTS	1x5 integer matrices calculated to the current state

CALCULATED:	
USE OF FUNCTION:	Called to simulate the M2 substation graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the M2 substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for M2 substation for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the four subsystems in the M2 substation are connected.

outputMessage()

TYPE:	STRING
INPUTS:	
OUTPUT:	String 'outputMess'
USE OF FUNCTION:	Function to return current output message
DESCRIPTION:	To display string property of a text object we must have a function, which returns the output message string, this function allows this to occur.
NOTES:	

setOutputMessage(INT switchVar, STRING switchName)

TYPE:	Void
INPUTS:	Integer ‘switchVar’ String ‘switchName’
OUTPUT:	String ‘outputMess’
USE OF FUNCTION:	Function display the switch that has just been opened or closed
DESCRIPTION:	Function sets the outputMess to either “opened” or “closed” switchName, depending on the value of the switch.
NOTES:	

setIsolateSwitchMessage(INT switchVar, STRING switchName, STRING pageName, INT isolate)

TYPE:	STRING
INPUTS:	Integer ‘switchVar’ String ‘switchName’ String ‘pageName’ Integer ‘isolate’
OUTPUT:	String ‘outputMess’
USE OF FUNCTION:	Function display an instruction for the switch in the isolation or reenergise procedure.
DESCRIPTION:	Function sets the outputMess to an instruction to either open or close a particular switch on a particular page.

NOTES:	

setIsolatePageMessage()

TYPE:	STRING
INPUTS:	String ‘pageName’
OUTPUT:	String ‘outputMess’
USE OF FUNCTION:	Function to return an instruction to what page needs to be opened.
DESCRIPTION:	The function displays an instruction to what page needs to be opened in order to find a switch in the isolation and restoration procedures.
NOTES:	Not currently used, replace by setIsolateSwitchMessage().

plympton()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Plympton substation 1x5 integer matrices for all energy states in the Plympton substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Plympton substation graphics page. Called from the simulate() function upon entry of all pages.

DESCRIPTION:	Used to define energy matrices for the Plympton substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Plympton substation for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the three subsystems in the Plympton substation are connected.

restoreSwitchOrder()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	Integer 1x200 matrix 'switch' Integer 1x200 matrix 'switchName' Integer 1x200 matrix 'areaName'
OUTPUTS CALCULATED:	Integer 1x200 matrix 'restoreSwitch' Integer 1x200 matrix 'restoreSwitchName' Integer 1x200 matrix 'restoreAreaName'
USE OF FUNCTION:	Called to create the procedure used to restore the system after isolation.
DESCRIPTION:	Takes in the information from the isolation procedure and stores it in reverse order in the restore arrays.
NOTES:	

simulate()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	
OUTPUTS CALCULATED:	
USE OF FUNCTION:	Called on the entry of each page, including when switches are toggled.
DESCRIPTION:	Calls all of the substation and line functions, in order to refresh the energy state of all areas.
NOTES:	

southTerrace()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the South Terrace substation 1x5 integer matrices for all energy states in the South Terrace substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state

USE OF FUNCTION:	Called to simulate the South Terrace substation graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the South Terrace substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for South Terrace substation for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the eleven subsystems in the South Terrace substation are connected.

woodville()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Woodville substation 1x5 integer matrices for all energy states in the Woodville substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Woodville substation graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the South Terrace substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Woodville substation for the current states of the switches.

NOTES:	Contains the information that allows the program to know how the eleven subsystems in the Woodville substation are connected.

semaphore()

TYPE:	Void
PARAMETERS USED IN FUNCTION:	5x5 integer matrices for all subsystems in the Semaphore substation 1x5 integer matrices for all energy states in the Semaphore substation
OUTPUTS CALCULATED:	1x5 integer matrices calculated to the current state
USE OF FUNCTION:	Called to simulate the Semaphore substation graphics page. Called from the simulate() function upon entry of all pages.
DESCRIPTION:	Used to define energy matrices for the Semaphore substation. From this function the diakoptics function is called, multiplying the connections matrix with the energisation matrix, giving the energy matrices for Semaphore substation for the current states of the switches.
NOTES:	Contains the information that allows the program to know how the eleven subsystems in the Semaphore substation are connected.

switchNameToVariable()

TYPE:	Void
PARAMETERS	String ‘switchNameString1’

USED IN FUNCTION:	String ‘switchNameString2’
OUTPUTS CALCULATED:	Integer 1x55 matrix ‘area_order’
USE OF FUNCTION:	Used to find the switch number from the switch name, called when isolation procedure is called.
DESCRIPTION:	The two points of isolation are inputted and the area number corresponding to those switch names is found, the function isolateAreaOrder() is then called, returning the area_order matrix.
NOTES:	Purely a lookup table to find the area number for the switches.

ToggleSwitch(INT switchVar)

TYPE:	Void
PARAMETERS USED IN FUNCTION:	Integer ‘switchVar’
OUTPUTS CALCULATED:	Integer ‘switchVar’
USE OF FUNCTION:	Used when switch genie is pressed to change the state of the switch.
DESCRIPTION:	Reverses the value stored at switchVar.

NOTES:	

Wait(INT cycles)

TYPE:	Void
PARAMETERS USED IN FUNCTION:	Integer ‘cycles’
OUTPUTS CALCULATED:	
USE OF FUNCTION:	Used during the demos to delay the calling of functions
DESCRIPTION:	The wait function simply executes 0 to cycles loops while doing nothing

TAGS

Tag Name	Data Type	Array Size	TAG’s use in Simulation
HINDMARSH_ENERGY	DIGITAL	55	Used to store the energy state of each area of the substation Hindmarsh. If the array element is 1 then the area of the substation is energized. For

			a value of 0 the area is de-energised.
SOUTHTERRACE_ENERGY	DIGITAL	55	Used to store the energy state of each area of the substation South Terrace. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.
GLENELG_ENERGY	DIGITAL	55	Used to store the energy state of each area of the substation Glenelg. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.
MORPHETTM1_ENERGY	DIGITAL	15	Used to store the energy state of each area of the substation Morphett M1. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.
MORPHETTM2_ENERGY	DIGITAL	20	Used to store the energy state of each area of the substation Morphett M2. If the array element is 1 then the area of the substation is energized. For a

			value of 0 the area is de-energised.
PLYMPTON_ENERGY	DIGITAL	15	Used to store the energy state of each area of the substation Plympton. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.
WOODVILLE_ENERGY	DIGITAL	55	Used to store the energy state of each area of the substation Woodville. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.
SEMAPHORE_ENERGY	DIGITAL	55	Used to store the energy state of each area of the substation Semaphore. If the array element is 1 then the area of the substation is energized. For a value of 0 the area is de-energised.

Tag Name	Data Type	Array Size	TAG's use in Simulation
BLACKFOREST_ENERGY	DIGITAL	15	Used to store the energy state of each area of the substation Blackforest. If the array element is 1 then the area of the substation is energized. For a

			value of 0 the area is deenergised.
LINE_ENERGY	DIGITAL	21	Used to store the energy state of each area of the Lines. If the array element is 1 then the area of the line is energized. For a value of 0 the area is de-energised.
LOCK	DIGITAL	1	Used with interlock switches (Switch2 genie), The value determines if a switch can be opened or closed. If LOCK=1 then the switch can be toggled. If LOCK=0 then a error message is printed and the switch cannot be toggled.
area_order	INT	20	Used in the isolation code. The array stores the area numbers in the order that they need to be isolated.
switch	INT	200	Used in the isolation code. Stores the switch numbers in the correct order that they need to be isolated.
switchName	STRING	200	Used in the isolation code. Stores the switch names in the

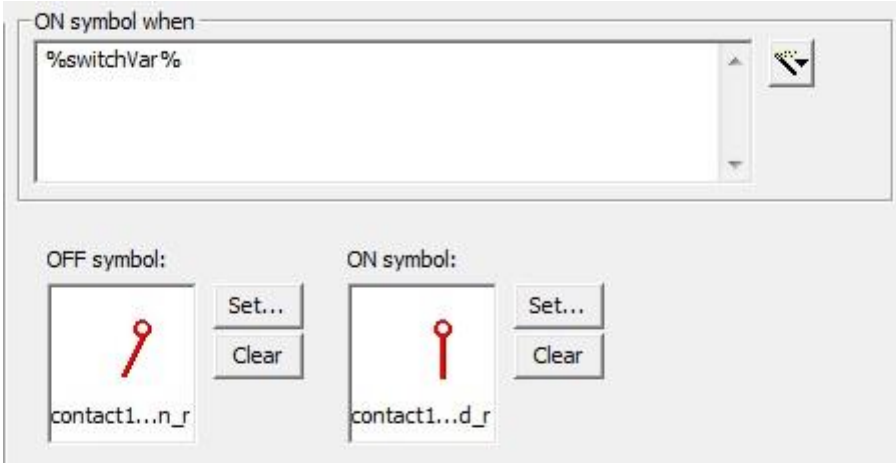
			correct order that they need to be isolated.
areaName	STRING	200	Used in the isolation code. Stores the area name corresponding to the switch, in the correct order that they need to be isolated.
switchSelected1	STRING	1	Used to store the name of the switch that user selects as a point of isolation.
switchSelected2	STRING	1	Used to store the name of the switch that user selects as a point of isolation.
switchSubsys	INT	2	Used to store the switch number, once it has been translated from the string name the user has inputted.
Tag Name	**Data Type**	**Array Size**	**TAG's use in Simulation**
areaSelect1	STRING	1	Used to store the name of the area that user selects as a point of isolation.
areaSelect2	STRING	1	Used to store the name of the area that user selects as a point of isolation.
restoreSwitch	INT	200	Used in the restoration code. Stores the switch numbers in the

			correct order that they need to be restored.
restoreAreaName	STRING	200	Used in the restoration code. Stores the area name corresponding to the switch, in the correct order that they need to be restored.
restoreSwitchName	STRING	200	Used in the restoration code. Stores the switch names in the correct order that they need to be restored.
isoDemo	DIGITAL	10	Used to store the number of the isolation demo. Up to 10 isolation demos can be inputted, at this time only 2 are used.
switchVal	INT	200	Stores the value of the each switch in the system. The array element displays 1 if the switch is closed and 0 if the switch is open.
temp_line	INT	10	Used as temporary storage in order to rearrange the area orders, to ensure that lines are isolated before substations.
temp_substation	INT	25	Used as temporary storage in order to rearrange the area

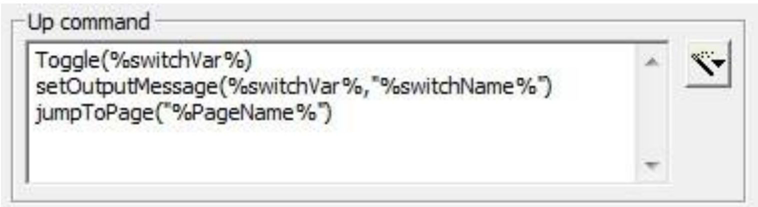
			orders, to ensure that lines are isolated before substations.

Genies

1. Switch1

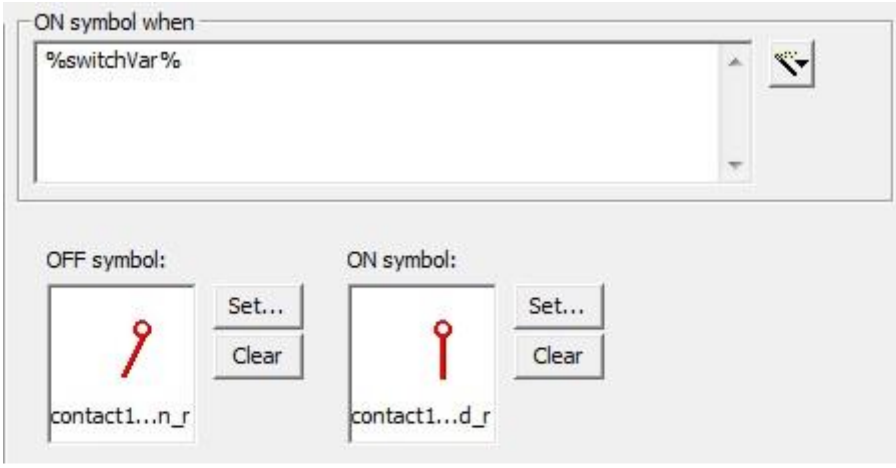


1.1. Input

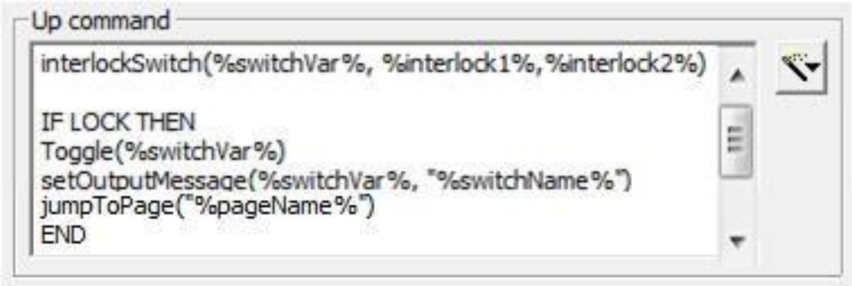


2. Switch2

2.1 Appearance



2.2 Input



Switch Information

pageName	swName	swValue	swNumber	Area Number
Hindmarsh	CBHA1	switchVal [1]	1	1
Hindmarsh	HA1ES	switchVal [2]	2	1
Hindmarsh	HA3DS	switchVal [3]	3	2

Hindmarsh	HA3ES	switchVal [4]	4	2
Hindmarsh	CBHA11	switchVal [5]	5	3
Hindmarsh	HA11ES	switchVal [6]	6	3
Hindmarsh	HA13DS	switchVal [7]	7	4
Hindmarsh	HA13ES	switchVal [8]	8	4
Hindmarsh	HA15DS	switchVal [9]	9	5
Hindmarsh	HA15ES	switchVal [10]	10	5
Hindmarsh	HA5DS	switchVal [11]	11	6
Hindmarsh	HA5ES	switchVal [12]	12	6
Hindmarsh	CBHA4	switchVal [13]	13	7
Hindmarsh	HA4DS	switchVal [14]	14	7
Hindmarsh	HA4ES	switchVal [15]	15	7
Hindmarsh	CBDB1	switchVal [16]	16	8
Hindmarsh	-VEVA1	switchVal [17]	17	8
Hindmarsh	OVPD	switchVal [18]	18	8
Hindmarsh	CBHA14	switchVal [19]	19	9
Hindmarsh	HA14DS	switchVal [20]	20	9
Hindmarsh	HA14ES	switchVal [21]	21	9
Hindmarsh	CBDB2	switchVal [22]	22	10
Hindmarsh	-VEVA2	switchVal [23]	23	10

Hindmarsh	CBDA2	switchVal [24]	24	11
Hindmarsh	DA2DS	switchVal [25]	25	11
Hindmarsh	TFS	switchVal [26]	26	11
Hindmarsh	DA1DS	switchVal [27]	27	11
Hindmarsh	CBDA1	switchVal [28]	28	11
Line1	H95KS	switchVal [29]	29	12
Line2	H83KS	switchVal [30]	30	12
Line3	H73KS	switchVal [31]	31	12
Line4	H62KS	switchVal [32]	32	12
Line5	H51KS	switchVal [33]	33	12
Line6	H48KS	switchVal [34]	34	12
Line7	H37KS	switchVal [35]	35	12
Line8	H23KS	switchVal [36]	36	12
Morphett_M2	HA1DS_M2	switchVal [37]	37	13
Morphett_M2	HA1ES_M2	switchVal [38]	38	13
Morphett_M2	CBHA1_M2	switchVal [39]	39	14
Morphett_M2	HA3DS_M2	switchVal [40]	40	14
Morphett_M2	HA3ES_M2	switchVal [41]	41	14
Morphett_M2	POSVA1_M2	switchVal [42]	42	15

pageName	swName	swValue	swNumber	Area Number
Morphett_M2	NEGVA1_M2	switchVal [43]	43	15
Morphett_M2	OVPD_M2	switchVal [44]	44	15
Morphett_M2	CBDA2_M2	switchVal [45]	45	16
Morphett_M2	DA2DS_M2	switchVal [46]	46	16
Morphett_M2	TFS_M2	switchVal [47]	47	16
Morphett_M2	DA1DS_M2	switchVal [48]	48	16
Morphett_M2	CBDA1_M2	switchVal [49]	49	16
Line2	H14KS	switchVal [50]	50	17
Line2	H7KS	switchVal [51]	51	17
Morphett_M1	CBHA2_M1	switchVal [52]	52	18
Morphett_M1	HA2ES_M1	switchVal [53]	53	18
Morphett_M1	POSVA1_M1	switchVal [54]	54	19
Morphett_M1	NEGVA1_M1	switchVal [55]	55	19
Morphett_M1	OVPD_M1	switchVal [56]	56	19
Morphett_M1	CBDA1_M1	switchVal [57]	57	20
Morphett_M1	DA1DS_M1	switchVal [58]	58	20
Morphett_M1	TFS_M1	switchVal [59]	59	20
Morphett_M1	DA2DS_M1	switchVal [60]	60	20
Morphett_M1	CBDA2_M1	switchVal [61]	61	20

Line2	G11KS	switchVal [62]	62	21
Line2	G27KS	switchVal [63]	63	21
Line2	G41KS	switchVal [64]	64	21
Line2	G42KS	switchVal [65]	65	21
Line2	G55KS	switchVal [66]	66	21
Line2	G87KS	switchVal [67]	67	21
Line2	G73KS	switchVal [68]	68	22
Line2	G81KS	switchVal [69]	69	22
South_Terrace	HA11DS	switchVal [70]	70	23
South_Terrace	HA11ES	switchVal [71]	71	23
South_Terrace	CBHA11	switchVal [72]	72	24
South_Terrace	HA1DS	switchVal [73]	73	25
South_Terrace	HA1ES	switchVal [74]	74	25
South_Terrace	CBHA1	switchVal [75]	75	26
South_Terrace	HA4DS	switchVal [76]	76	27
South_Terrace	HA4ES	switchVal [77]	77	27
South_Terrace	HA14DS	switchVal [78]	78	28
South_Terrace	HA14ES	switchVal [79]	79	28
South_Terrace	CBHA13	switchVal [80]	80	29
South_Terrace	HA13DS	switchVal [81]	81	29

South_Terrace	HA13ES	switchVal [82]	82	29
South_Terrace	CBDB2	switchVal [83]	83	30
South_Terrace	-VEVA1	switchVal [84]	84	30
South_Terrace	OVPD	switchVal [85]	85	30

pageName	**swName**	**swValue**	**swNumber**	**Area Number**
South_Terrace	CBHA3	switchVal [86]	86	31
South_Terrace	HA3DS	switchVal [87]	87	31
South_Terrace	HA3ES	switchVal [88]	88	31
South_Terrace	CBDB1	switchVal [89]	89	32
South_Terrace	-VEVA2	switchVal [90]	90	32
South_Terrace	CBDA2	switchVal [91]	91	33
South_Terrace	DA2DS	switchVal [92]	92	33
South_Terrace	TFS	switchVal [93]	93	33
South_Terrace	DA1DS	switchVal [94]	94	33
South_Terrace	CBDA1	switchVal [95]	95	33
Line3	G91KS	switchVal [96]	96	34
Line5	G153KS	switchVal [97]	97	34
Line5	G154KS	switchVal [98]	98	34

Black_Forest	CBHA1_BF	switchVal [99]	99	35
Black_Forest	HA1ES_BF	switchVal [100]	100	35
Black_Forest	HA2ES_BF	switchVal [101]	101	35
Black_Forest	OVPD_BF	switchVal [102]	102	36
Black_Forest	CBDA1_BF	switchVal [103]	103	37
Black_Forest	TFS_BF	switchVal [104]	104	37
Black_Forest	CBDA2_BF	switchVal [105]	105	37
Line5	G155KS	switchVal [106]	106	38
Line6	G234KS	switchVal [107]	107	38
Line6	G234 BYPASS	switchVal [108]	108	38
Plympton	CBHA1_P	switchVal [109]	109	39
Plympton	HA1ES_P	switchVal [110]	110	39
Plympton	HA2ES_P	switchVal [111]	111	39
Plympton	OVPD_P	switchVal [112]	112	40
Plympton	CBDA1_P	switchVal [113]	113	41
Plympton	TFS_P	switchVal [114]	114	41
Plympton	CBDA2_P	switchVal [115]	115	41
Line6	G237KS	switchVal [116]	116	42
Line7	G275KS	switchVal [117]	117	42
Line7	G281KS	switchVal [118]	118	42

Line7	G282KS	switchVal [119]	119	42
Line8	G315KS	switchVal [120]	120	43
Line8	G316KS	switchVal [121]	121	43
Glenelg	HA1DS	switchVal [122]	122	44
Glenelg	HA1ES	switchVal [123]	123	44
Glenelg	CBHA1	switchVal [124]	124	45
Glenelg	HA11DS	switchVal [125]	125	46
Glenelg	HA11ES	switchVal [126]	126	46
Glenelg	CBHA11	switchVal [127]	127	47
Glenelg	HA14DS	switchVal [128]	128	48
pageName	**swName**	**swValue**	**swNumber**	**Area Number**
Glenelg	HA14ES	switchVal [129]	129	48
Glenelg	HA4DS	switchVal [130]	130	49
Glenelg	HA4ES	switchVal [131]	131	49
Glenelg	CBHA3	switchVal [132]	132	50
Glenelg	HA3DS	switchVal [133]	133	50
Glenelg	HA3ES	switchVal [134]	134	50
Glenelg	CBDB1	switchVal [135]	135	51
Glenelg	-VEVA1	switchVal [136]	136	51
Glenelg	OVPD	switchVal [137]	137	51

Glenelg	CBHA13	switchVal [138]	138	52
Glenelg	HA13DS	switchVal [139]	139	52
Glenelg	HA13ES	switchVal [140]	140	52
Glenelg	CBDB2	switchVal [141]	141	53
Glenelg	-VEVA2	switchVal [142]	142	53
Glenelg	CBDA1	switchVal [143]	143	54
Glenelg	DA1DS	switchVal [144]	144	54
Glenelg	TFS	switchVal [145]	145	54
Glenelg	DA2DS	switchVal [146]	146	54
Glenelg	CB2DS	switchVal [147]	147	54
Line8	G317KS	switchVal [148]	148	55
Line8	G317TT	switchVal [149]	149	55
Woodville	WA14ES	switchVal [150]	150	56
Woodville	WA4DS	switchVal [151]	151	57
Woodville	WA4ES	switchVal [152]	152	58
Woodville	CBHA3	switchVal [153]	153	59
Woodville	HA3DS	switchVal [154]	154	59
Woodville	HA3ES	switchVal [155]	155	60
Woodville	CBDB1	switchVal [156]	156	61
Woodville	-VEVA1	switchVal [157]	157	62

Woodville	OVPD	switchVal [158]	158	63
Woodville	CBHA13	switchVal [159]	159	64
Woodville	WA13DS	switchVal [160]	160	65
Woodville	WA13ES	switchVal [161]	161	65
Woodville	CBDB2	switchVal [162]	162	66
Woodville	-VEVA2	switchVal [163]	163	66
Woodville	CBDA1	switchVal [164]	164	67
Woodville	DA1DS	switchVal [165]	165	67
Woodville	TFS	switchVal [166]	166	68
Woodville	DA2DS	switchVal [167]	167	68
Woodville	CB2DS	switchVal [168]	168	69
Line9	W96KS	switchVal [169]	169	69
Line9	W97KS	switchVal [170]	170	70
Semaphore	SA14ES	switchVal [171]	171	70
Semaphore	SA4DS	switchVal [172]	172	71
Semaphore	SA4ES	switchVal [173]	173	71
Semaphore	CBHA3	switchVal [174]	174	72
Semaphore	SA3DS	switchVal [175]	175	72
Semaphore	SA3ES	switchVal [176]	176	73
Semaphore	CBDB1	switchVal [177]	177	73

Semaphore	-VEVA1	switchVal [178]	178	74
Semaphore	OVPD	switchVal [179]	179	74
Semaphore	CBHA13	switchVal [180]	180	75
Semaphore	SA13DS	switchVal [181]	181	75
Semaphore	SA13ES	switchVal [182]	182	76
Semaphore	CBDB2	switchVal [183]	183	76
Semaphore	-VEVA2	switchVal [184]	184	77
Semaphore	CBDA1	switchVal [185]	185	77
Semaphore	DA1DS	switchVal [186]	186	78
Semaphore	TFS	switchVal [187]	187	78
Semaphore	DA2DS	switchVal [188]	188	79
Semaphore	CB2DS	switchVal [189]	189	79
Line10	S98KS	switchVal [190]	190	80
Line10	S99KS	switchVal [191]	191	80