PowerWater

Power and Water Corporation

Preliminary Business Case – Category C

PRK31430

Katherine Voltage Rectification

Proposed:

Jim McKay
A/Chief Engineer
Power Networks
Date: 26/02/2018

Approved:

Djuna Pollard
Executive General Manager
Power Networks
Date: 27/2 /2018

1 RECOMMENDATION

It is recommended that the Chief Executive approve project PRK31430 Katherine Voltage Rectification for an estimated capital cost of [redacted] to be completed by June 2022.

Approval is sought for expenditure of up to $0.1M of the total forecast expenditure to undertake the necessary work to proceed to the next approval gateway (Business Case Approval), including:

- Detailed design; and
- Detailed cost estimate, including by seeking a construction price offer from external contractors through a competitive tender.

The project has a 95% likelihood of being delivered between [redacted]

2 PROJECT SUMMARY

Project Title:	Katherine Voltage Support		
Project No./Ref No:	PRK31430	**SAP Ref:**	
Anticipated Delivery Start Date:	Jul 2021	**Anticipated Delivery End Date:**	Jun 2022
Business Unit:	Power Networks		
Project Owner (GM):	Djuna Pollard	**Phone No:**	8985 8431
Contact Officer:	Peter Kwong	**Phone No:**	8924 5060
Date of Submission:		**File Ref No:**	
Submission Number:		**Priority Score:**	/100
Primary Driver:	Compliance	**Secondary Driver:**	
Project Classification:	Capital Category C		

2.1 Prior Approvals

Document Type	Sub Number	Approved By	Date	Capex Value
BNI		Michael Thomson	/2017	[redacted]

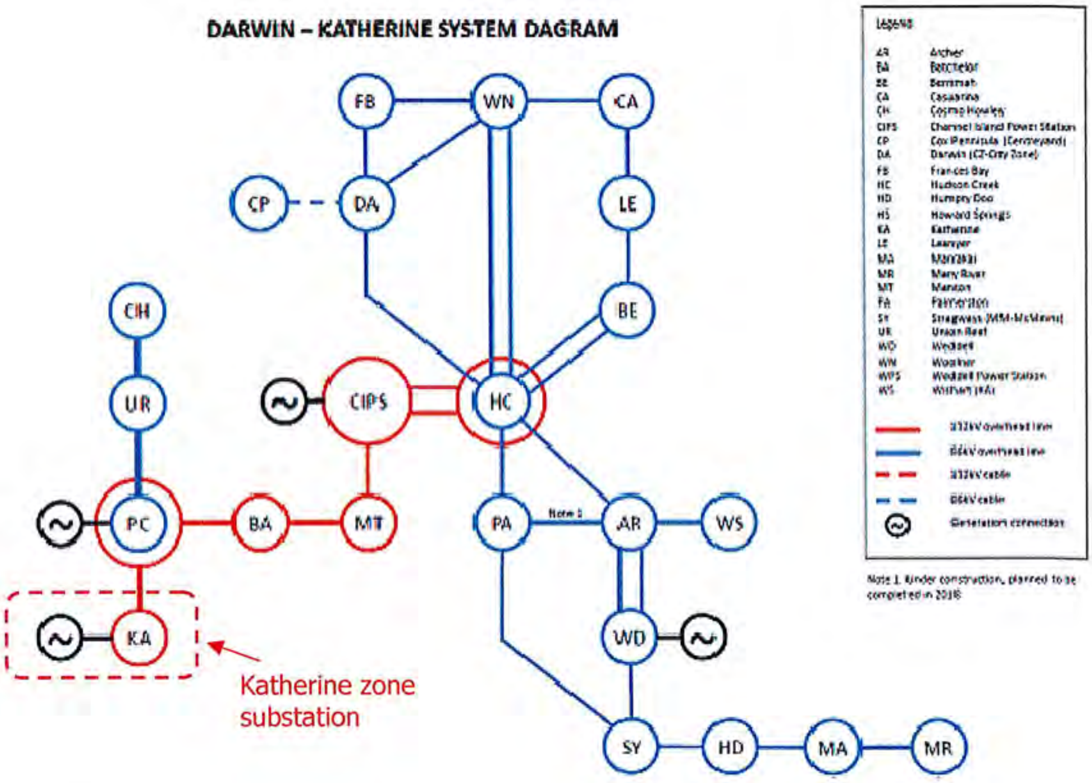
3 INVESTMENT NEED

3.1 Background

The Katherine township is supplied by Katherine Zone Substation. It is connected to the Darwin transmission system via the 132kV Darwin – Katherine Transmission Line (DKTL). The 132kV transmission line is approximately 280km in length and originated at Channel Island Power Station. The DKTL is connected to intermediate substations at Manton, Batchelor, Pine Creek and terminates in Katherine.

There is also power station located in Katherine. It consists of four gas fired generators with a total capacity of 36MW.

Figure 1: System diagram



3.2 LV Network Design

Traditional design assumptions regarding voltage drop in the low voltage network are no longer applicable largely due to the influence of PV systems exporting via the low voltage network.

The higher voltage values being experienced within the low voltage network are evident in the histogram in Figure 3, where almost 50% of voltages are above the preferred range. To address this, Power Networks have been adjusting local transformer tap positions and investigating a broader solution of a significant reduction of the medium voltage at Zone Substations.

Figure 2: Voltage histogram in for LV Distribution

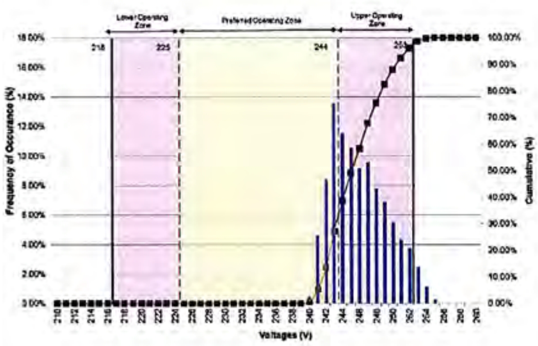


Figure 3– RMS Voltage Distribution Histogram **(Pre-change)**, January 2017 Update

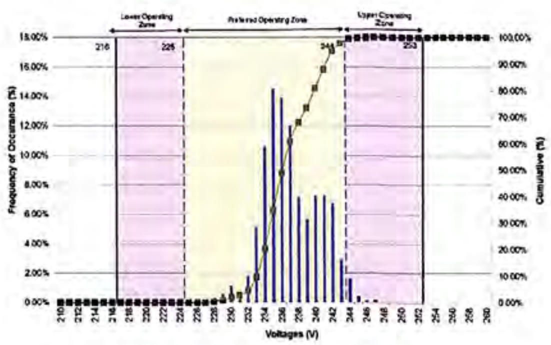


Figure 4 – RMS Voltage Distribution Histogram **(Post-change)**, January 2017 Update

In 2015, Power Networks began to reduce the voltage regulating set points at zone substations across the 11kV network in the Darwin Region. The histograms indicate the success of this approach at a customer's supply point. In this instance, prior to the change less than 40% of sampled voltages were within the preferred range during normal conditions. Subsequent to the change more than 95% of sampled voltages fell within the preferred range. Further work is being conducted for this approach to be applied in the other distribution networks including Katherine.

The 11kV voltage set-points in the Darwin network have been reduced at the transformers from a nominal set point of 11.2 kV to 10.7 kV, resulting in a reduction in the low voltage levels supplied to customer. For Katherine, the equivalent nominal set point will be 21.4kV.

3.3 Steady State Voltages at Katherine

A characteristic of long transmission lines is that the line capacitance values can result in high voltages when the line is lightly loaded (this is termed the Ferranti effect). The DKTL often experiences low load during overnight periods in Katherine that results in high voltages at the Katherine 132kV substation.

In turn, this causes high voltages in the 22kV and 415V networks in Katherine, as the 132/22kV transformers installed have limited tapping range.

The tap changers installed in these transformers are designed to boost voltages rather than lower, and only have three taps to reduce the output voltage.

In addition, Power and Water is aiming to maintain the 22kV busbar voltage below 22.0kV to cater for voltage rise in the low voltage network caused by rooftop solar systems. The tap changers on the low voltage distribution transformers in the Katherine network are primarily designed for boosting voltages and this has resulted in voltages outside of the compliance range on the low voltage network, especially during low load period in the Dry season.

Studies indicate[1] that the current system design is not capable of reducing cannot reduce the system voltage to below 22.0kV during low load periods in Katherine.

Unless controlled, high network voltages have the potential to cause damage both to Power Networks' and Customers' equipment. It will also reduce the ability for customers to operate rooftop solar systems due to high network voltages. In addition, PWC will not achieve is compliance obligations to maintain system voltage limits.

3.4 Risk Analysis

Figure 3 shows the current rating, inherent rating (in 2024, ie. Is no action is taken in the interim), and the residual (post-treatment) risk ratings associated with power quality issues in Katherine:

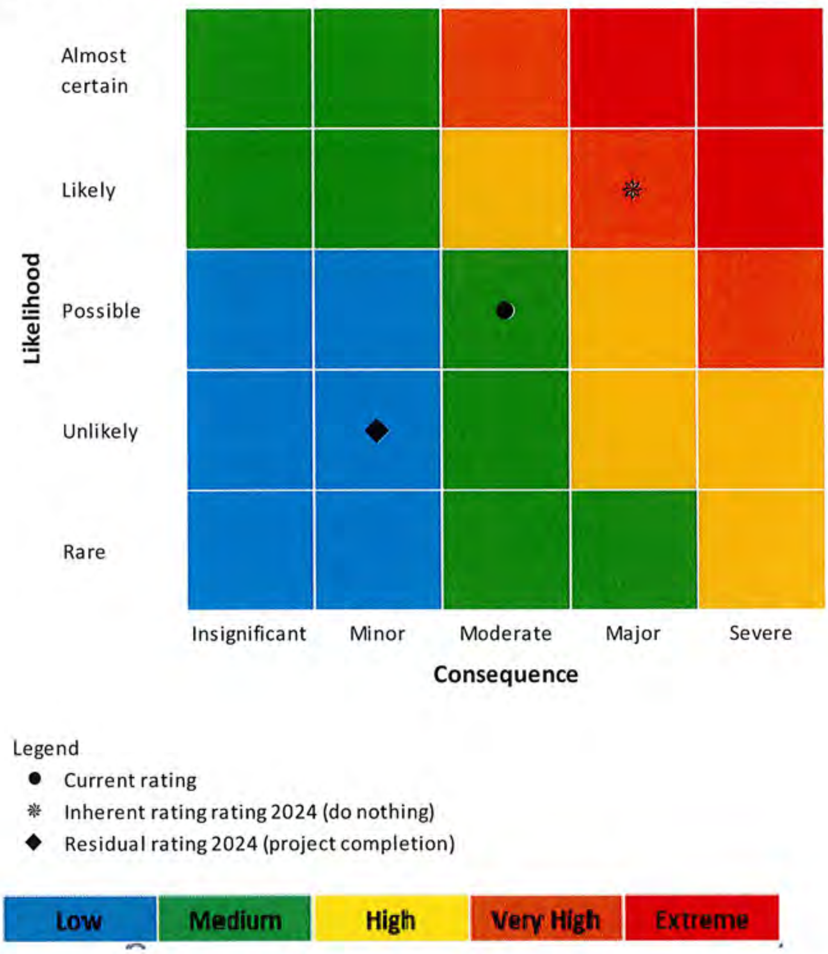
(i) Current rating: The current rating (2017) is assessed to be "Medium" because of the existing voltage profile, voltage excursions outside the defined limits are "Possible". The consequence is classed as "Moderate" as the negative affect to corporate image would be once-off negative media attention and localised community impacts and customer concerns.

(ii) Inherent rating: If nothing is done in the next regulatory period, the probability of significant voltage issues by 2024 is "Likely" due to the increasing number of rooftop solar installations, and the number of unaddressed customer complaints will result in prolonged adverse media attention and customer condemnation weeks. This consequence is classed a "Major". The overall risk rating is therefore "Very High".

(iii)Residual rating: The proposed project will address the probability and consequence of future voltage issues in Katherine. Therefore, the likelihood of an event is "Unlikely" and the impact of the event will be significantly lessened, to a level classified as "Minor". The overall risk rating is therefore "Low".

[1] NPR1701 Katherine Voltage Investigation

Figure 3: Feeder Augmentation Risk Assessment[2]



It is Power and Water's current practice to take action on risks that have an inherent rating of 'HIGH' or above. The PBC summarises the proposed response to this impending risk.

4 STRATEGIC ALIGNMENT

This project aligns with the Corporation's key result areas of operational performance and customer centricity, where the goals are to be an efficient provider of services and delivering on customers' expectations.

This project will allow PWC to safely and reliably operate the distribution system in Katherine.

5 TIMING CONSTRAINTS

The timing for this project is driven by the increased installation of rooftop solar installations in Katherine. It is planned that this issue will be resolved by June 2022 to reduce the risk of significant customer complaints from Katherine residents.

[2] Based on PWC's Risk Assessment Guide

6 EXPECTED BENEFITS

Driver/Objective	Benefit	Current State	Future State
Service Improvement	To maintain voltage levels within acceptable range	The 22kV voltage at Katherine is unable to be maintained below 22.0kV at the lowest transformer tap.	The 22kV voltage at Katherine is able to be maintained at 22.0kV at nominal tap.

7 REQUIREMENTS

The solution selected must cater for the need to reduce the system voltage to below 22.0kV at the 22kV Katherine busbar. It is also preferable to minimise impact on existing operational capabilities and system security during construction.

8 OPTIONS

8.1 Options Development

A number of options were considered for the correction of the system voltages at Katherine 22kV bus. These options are discussed in detailed below:

8.1.1 Option 1 – Base case (continue to operate Katherine Zone Substation under existing conditions and equipment)

This option involves no proactive capital expenditure to install new equipment to improve voltage control at Katherine Zone Substation.

The advantage of this approach is deferment of capital expenditure to address risks associated with system voltages at the 22kV and 415V levels.

However, continuing to operate Katherine Zone Substation under the existing arrangement is not considered prudent given the risk of significant increase in equipment damage and customer complaints regarding high voltage experienced on the 415V network. This risk will continue to grow due to increasing number of rooftop solar installations in Katherine and other areas in the Northern Territory.

There will also be an increase in insurance claims for damaged equipment due to high voltage experienced from customers connected to the electricity network. PWC will not meet its compliance obligations to maintain voltage levels with prescribed limits.

Option 1 is not considered to be technically feasible.

8.1.2 Option 2 – Switched reactive compensation (preferred option)

This option involves the installation of reactive compensation at Katherine 22kV switchboard using mechanically switched reactors to absorb reactive power at an estimated base cost of [redacted].

Sincal studies have shown that 2 x 5 MVAr shunt reactors installed at Katherine 22 kV busbar would be adequate to ensure that steady state busbar voltage can be controlled to maintain a value less than 1.00 per unit of nominal voltage.

The proposed scope includes:

- Procure and install one (1) set of 22kV reactors with two (2) 5MVAr stages
- Connect to the existing 22kV switchboard
- Secondary systems work to protect the equipment and allowing automatic and remote manual operation of the reactors.

The advantage of this solution is that it applies the current design standards and modern technologies to this site, and provides a lower cost and less technically complex solution than option 3.

The disadvantage of this option is that will provide a less precise control of the system voltage, as banks of reactors are switched.

8.1.3 Option 3 – Synchronous condenser

This option involves the installation of 10MVAr synchronous condenser at Katherine at an estimated cost of [redacted].

The rotating machine will continuously absorb or generate reactive power as required. This will have the same effect on steady state voltage as the equivalent rating shunt reactors as discussed in option 2, but the response time will be much shorter.

The proposed scope includes:

- Procure and install one (1) 10MVar, 22kV synchronous condenser.
- Connect to the existing 22kV switchboard
- Secondary systems work for the protection and control of the equipment

The advantage of this solution is that it will provide more detailed control of the system voltage at Katherine. A synchronous condenser would have additional benefits by improving inertia in the system.

The disadvantages of this option include:

(i) The construction personnel will be in close vicinity of live assets;

(ii) This solution is not in the current design standards; and

(iii) There are significant operational maintenance costs.

8.1.4 Option 4 – Running generators at Katherine Power Station

This non-network option involves running generators at Katherine Power Station.

Reactive power control on the generator units at Katherine power station could be set to control the 22 kV busbar voltage to an acceptable bandwidth. If the generator transformers are set on fixed taps it may be possible for the generators to be set to control their own terminal voltage to provide the same outcome.

Territory Generation is reluctant to provide this service due to the low efficiency and high operating costs of running a generator at low load. There will be a significant cost to PWC from Territory Generation to provide this service and will increase over time due to the age of the assets.

It is estimated that it will cost approximately [redacted] per hour to operate one of the 8MW generators. This will equate to an annual cost of [redacted]

Option 4 is not considered to be technically or commercially viable.

8.2 Comparative cost analysis

PWC is currently developing a probabilistic risk-cost methodology which, when completed will be used to compare options and confirm the economically optimum time for investment.

Table 2 summarises the results of a comparative cost analysis, the details of which are included in Appendix A. Of the technically viable options, Option 2 – Switched reactive compensation has the lowest acceptable NPC.

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[3] Assuming $60 megawatt hour for one of 8MW machines

[4] 6 hours a day for 4 months of the year during the Dry season

Table 2: Summary of comparative capital cost analysis

Option	Capital cost ($M)	Net Present Cost ($M)	Comments
1 – Do nothing	[redacted]	[redacted]	Not feasible
2 – Switched reactive compensation	[redacted]	[redacted]	Lowest NPC
3 – Synchronous condenser	[redacted]	[redacted]	
4 – Non network solution	[redacted]	[redacted]	Not feasible

8.2.1 Evaluation Summary

Weighted Scores:

	Project Objectives			Technical & System Risk			Stakeholder Risk			Env. Risk		Commercial
Criteria	Reduced System Voltage	Reduced Customer Complaints	40 Year Design Life	Standard Assets	Constructability	Continuity of Supply	Safety	Community Impact	Approvals	Oil Contamination	Land Clearing	NPV/C
Weighting (%)	10	10	10	5	5	10	10	5	5	5	5	20
Option 1	0.1	0.1	0.1	0.15	0.2	0.4	0.3	0.05	0.2	0.2	0.2	1
Option 2	0.4	0.4	0.4	0.2	0.2	0.4	0.3	0.2	0.15	0.2	0.2	0.8
Option 3	0.4	0.4	0.4	0.1	0.1	0.4	0.3	0.2	0.15	0.2	0.2	0.4
Option 4	0.4	0.4	0.4	0.2	0.2	0.4	0.3	0.2	0.15	0.2	0.2	0.4

Option 1: Deferral	3.00
Option 2: Switched reactive compensation	3.85
Option 3: Synchronous condenser	3.25
Option 4: Non Network Solution	3.45

8.2.2 Preferred Option

The preferred option (Option 2) is the installation of a switched reactive compensation at Katherine Zone Substation.

This option best fulfils the project objectives of lowering the system voltage at Katherine 22kV bus and allows PWC to comply with the "Networks Planning Criteria and Technical Code".

The switched reactive compensation will be connected to the 22kV switchboard and can be automatically or manually controlled by System Control.

There is little risk of public opposition to the construction activity associated with this project as it is located in a rural area.

The new reactive compensation will be designed in consideration to the existing PWC substation standards and will be similar to the capacitive compensation installed in the zone substations. This will maximise constructability and reduce design risk.

9 PROJECT OUTLINE

9.1 Project Description

This project is to install a switched 22kV reactor with two 5MVAr stages at Katherine Zone Substation. The reactor is to be connected to the existing 22kV switchboard.

9.1.1 Scope Inclusions

The scope of the project includes:

- Procure and install a 22kV shunt reactor unit with two 5MVAr stages.
- Install cables from the reactor unit to the spare circuit breaker on the 22kV switchboard.
- Install and commission associated protection and control systems required for the operation of the reactor unit.

9.1.2 Scope Exclusions

- Works not part of the project scope.

9.1.3 Assumptions

- The existing DC and 415V supplies capacity at the substation is adequate for the new shunt reactor.

- Existing cable ductwork and conduits have space for power and control cables from the shunt reactor.

9.1.4 Dependencies

None identified

9.1.5 Key Stakeholders

There is little risk of public opposition to install a new shunt reactor at Katherine. This project will ensure a safe, reliable and high quality power supply for the residents in Katherine and Pine Creek area.

Name	Title / Business Unit
Internal – Governance Stakeholders	Chief Executive
	Investment Review Committee
	Executive General Manager Power Networks
	Chief Engineer
	Group Manager Service Delivery
Internal – Design Stakeholders	Senior Manager Networks Development and Planning
	Manager Major Projects
	Senior Manager Network Assets
	Manager Protection
External – Authorities	Environmental Protection Authority
	Aboriginal Areas Protection Authority
External - Other	Katherine Residents
	Ministers
	Utilities Commission
	Australian Energy Regulator

9.2 Capital Cost

A risk adjusted cost estimate (RACE) was conducted on the preferred option based on latest design, scope and cost information.

Based on the analysis, the project has a 90% likelihood of being delivered between [redacted] The contingency attributable to risk is calculated as P95 – P50 = $0.14M.

[redacted]

9.2.1 Base Capital Cost

Item	**Estimated Cost $'000 ($P_{50}$)**
[redacted]	
	[redacted]
	[redacted]
[redacted]	
	[redacted]
	[redacted]
	[redacted]
	[redacted]
[redacted]	
	[redacted]
[redacted]	

[redacted]

Table 1 – Base Capital Cost Estimate

9.2.2 Risk and Contingency

The current estimate has been developed largely based on PWC and consultant estimates considering previous experience with similar works. The contingency amount, calculated as the P95 value minus the expected P50 value, is currently $ 0.14M.

9.3 Estimated Operating Cost Impact

The ongoing operational costs of the new switched reactors are detailed below.

Item	Annual Incremental Cost
Planned Maintenance	3,044
Preventative Maintenance	6,011
Unplanned Maintenance	890
TOTAL	**9945**

Table 2 – Estimated Operating Cost Impact

9.4 Project Milestones

Project Phase (end)	Investment Planning	Project Development	Commitment	Implementation	Review
Original Plan (BNI)	07/2017	03/2021	06/2021	06/2022	09/2022

Current Forecast	07/2017	07/2021	09/2021	06/2022	09/2022
Actual Completion	072017				

10 RISK MANAGEMENT AND COMPLIANCE

A preliminary risk register has been established to address project risk. This is included in Appendix B. This register will form the basis of the Project Risk Register into the project delivery phase. The register will be regularly reviewed and updated as required to ensure all identified risks are managed as the project progresses.

10.1 Technical and System Issues

The construction work will occur on or adjacent to energised high voltage equipment. PWC has policies and procedures that must be adhered to, such as the Power and Water Access to Apparatus Rules and Access to High Voltage Apparatus Procedure.

11 PROJECT IMPLEMENTATION

This project is to be managed by the Power Networks' Project Management group. It is planned that the project will be delivered using the "Design and Construct" methodology through an external contractor.

Testing and commissioning will be managed by Power Networks' Test and Protection group.

It is expected that the majority of electrical equipment will be procured through the D&C contract, with detailed specifications from PWC.

11.1.1 Resourcing Requirements (to next gateway)

Resource Type/Role	How Many?	Internal/ External?	Anticipated Start Date	Duration Required	Allocation (% time or # hrs/days/ wks/mths)
Project Manager	1	Internal	Jul 2021	6 months	10%
Planning Engineer	1	Internal	Jul 2021	6 months	10%
Design Engineer	1	External	Jul 2021	6 months	50%

12 FINANCIAL IMPACT

12.1 Funding Arrangements

The capital expenditure for this project will need to be approved by the AER's 2019-24 Network Price Determination, which is recovered through standard control network tariffs.

Based on the most up to date information, the project cost estimate has been revised to [redacted] The revised cost is based on the estimated costs provided in the concept design and additional estimates for internal PWC expenditure.

12.2 Capital Expenditure

The capex in the table below is in $2017-18, and is excluding capitalised overheads and cost escalation

Year	2019-20 ($'000)	2020-21 ($'000)	2021-22 ($'000)	2022-23 ($'000)	2023-24 ($'000)	Total ($'000)
[redacted]			[redacted]			[redacted]
[redacted]			[redacted]			[redacted]

12.2.1 Variance Coverage

The reduction in the project amount from the approved BNI [redacted] is due to a better understanding of the requirements and budget costing from suppliers.

12.3 Incremental Operating Expenditure

An operating expenditure of approximately $9,945 per annum is expected for the maintenance of the new reactor and associated equipment. Upon completion of the project, the operational cost of the new reactor will be included in the operational budget and forecasted in regulatory processes.

APPENDIX A

DETAILED FINANCIAL ANALYSIS

Introduction

The purpose of this Appendix is to provide details of the options analysis for Katherine Voltage Support.

Table A1 below outlines the estimated capital expenditure for the options 2, 3 and 4. The operational cost of each option is also detailed in the table and will be used in the analysis. This is reflected in the operational cash flows below.

Commercial analysis of option1 (deferral) was not undertaken as it is not considered to be a viable alternative due to the risk of an increase in the significant number of customer complaints and insurance claims.

Table A1 – Estimated Capital & Operating Expenditure

Option	Capex – Base Costs ($M)	Opex – Base Costs ($000's)
Option 2 – Switched shunt reactor	[redacted]	[redacted]
Option 3 – Synchronous condenser	[redacted]	[redacted]
Option 4 – Non Network Solution	[redacted]	[redacted]

Assumptions

In modelling the options, technical, economic and cost parameters were included. The technical and cost data was provided by Power Networks and the economic data was sourced from Pricing and Economic Analysis (PEA). Base cost capital expenditure was based on the consultant's feasibility study.

In the assumptions, all costs exclude GST or other government charges.

The common variables employed in the Discounted Cash Flow (DCF) model are presented in Table A2 below. These variables are consistent with the 2019-24 Regulatory Proposal to the AER and are considered appropriate for use in the detailed commercial analysis.

Table A2 – Common Variables

Variables	
Nominal Pre-Tax WACC	6.96%
CPI – 2017/18	2.42%
CPI after 2017/18	2.42%

Time Horizon of Project	40 years

Option 1 – Do Nothing

Commercial analysis of Option 1 (deferral) was not undertaken as it is not considered to be a viable alternative due to the risk of an increase in the number of customer complaints and insurance claims.

Option 2 – Switched reactive compensation

The analysis for this option includes capital expenditure [redacted] is estimated to be the base cost with ongoing operational costs of $9,945 per annum.

Option 3 – Synchronous Condenser

The analysis for this option includes capital expenditure of [redacted] is estimated to be the base cost with ongoing operational costs of $50,000 per annum.

Option 4 – Non Network Solution (Running Katherine Generator)

The analysis of this option does not require any capital expenditure but it will incur ongoing operational costs [redacted] per annum.

Least cost analysis

Based on the DCF analysis undertaken, the least cost option is Option 2 (switched reactive compensation). This is summarised in Table A3 below.

Table A3 – Net Present Cost of Options

Option	NPC ($M)
Option 2 – Switched reactive compensation	[redacted]
Option 3 – Synchronous condenser	[redacted]
Option 3 – Non Network Solution	[redacted]

Tariff cover

This project capex (2021/22 expenditure) will be submitted as part of the 2019 Regulatory Proposal to the AER. The AER's Final Determination will provide the approved level of net capital expenditure for the 2019-24 period. In so far as the Regulated Networks annual capital expenditure program remains at this level (or lower), Networks will earn a guaranteed rate of return through standard control service charges until the commencement of the next regulatory control period in 2024-25.

APPENDIX B

DETAILED RISK REGISTER

Refer:

PRK31430 Risk Analysis Katherine Voltage Support

PWC Ref: D2018/17687

APPENDIX C

SUMMARY PROJECT PROGRAM

Task	Baseline			2021				2022				2023			
	Plan Start	Plan Duration	Percent Complete	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Options Study	Jul 17	6 wks	100%												
Concept Design	Jul 17	6 wks	20%												
Planning and Permits	Jul 21	10 wks													
Detailed Design	Sep 21	10 wks													
Procurement	Oct 21	16 wks													
Civil Construction	Jan 22	4 wks													
Cable Installation	Feb 22	4 wks													
Electrical Construction	Jan 22	16 wks													
Commissioning and Energisation	Mar 22	12 wks													
Cutover Existing Services	Jun 22	2 wks													

APPENDIX D

PLANNING REPORT

Refer:

NPR1701 Katherine Voltage Investigation

PWC Ref: D2017/365443

PowerWater

Report No: NPR1701 File No: D2017/365443

Date: 28 November 2017 Container No: F2005/13996

Author: Craig Owens

Approved by: Tat Au-Yeung - Senior Manager Network Development and Planning

Title: Katherine Voltage Investigation

Report Circulation:

The following staff members are on the circulation list for this report:

Christina Camilleri	Peter Kwong	
Goutham Maddirala	Jim McKay	Santos Sukumaran

13 Executive Summary

This report documents a study to investigate voltage issues that have been reported at Katherine. .

This report discusses the following options to ensure that network voltage remains within Network Planning Criteria limits. The particular issue addressed in this report is the higher than nominal voltage observed on the Katherine 132 kV busbar during periods of light load, and the fact that these higher voltages are reflected in supply voltages supplied to customers connected to the distribution network supplied from Katherine zone substation.

1. Do Nothing
2. Installation of reactive plant
3. Installation of synchronous condenser
4. Contract Katherine Power Station to provide voltage control services.

Option 4 is the preferred option, as it requires no capital investment. Negotiations will be required to come to technical and commercial arrangements with one or both of the power station operators.

Detailed technical study will be required to determine the precise control strategy which should be employed. Preliminary load flow studies have shown that voltage control services provided by Katherine Power Station would be sufficient to maintain Katherine 22 kV busbar steady state within the required range.

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15 List of Figures

16 List of Tables

No table of figures entries found.

17 Network Planning Criteria

The relevant clauses in the Power Networks Network Technical Code and Network Planning Criteria, July 2012 that apply to this study are:

Part A – Legislative Requirements

Part B – Network Technical Code

1.7 Obligations

2.3 Power frequency voltage levels

3 Technical requirements for equipment connected to the network

4.2 Power system security principles

4.3 Power system security obligations and responsibilities

4.5 Control of network voltages

8 Disconnection and reconnection of plant and equipment

Part C – Network Planning Criteria

The purpose of Network Planning Criteria is to strike a balance between each User's need for a safe, secure, reliable, high quality electricity supply and the desire for this service to be provided at minimal cost. At the same time, environmental and social considerations shall be taken into account.

13 Introduction

14 Supply contingency criteria

15 Steady state criteria

18 Construction standards criteria

19 Environmental criteria

Of particular importance for this study is chapter 3 of the Network Technical Code, 'Technical requirements for equipment connected to the network', and chapter 15 of the Network Planning Criteria 'Steady state criteria'. Clause 15.2 of the Network Planning Criteria specifies the steady state power frequency voltage limits that apply to the Power and Water network.

Clause 3.3.2.1 discusses the reactive power capability requirements for generation units connected to the network.

18 Introduction

18.1 Background

Electricity supply to Katherine and surround areas is via a single radial overhead 132 kV line, originating at Channel Island Power Station (CIPS), and connected via Manton, Batchelor and Pine Creek.

Figure 1 below is extracted from the Network Management Plan[5], and shows a simplified single line diagram of the network.

[5] D2017/263214 - Network_Management_Plan_2013-14_to_2018-19

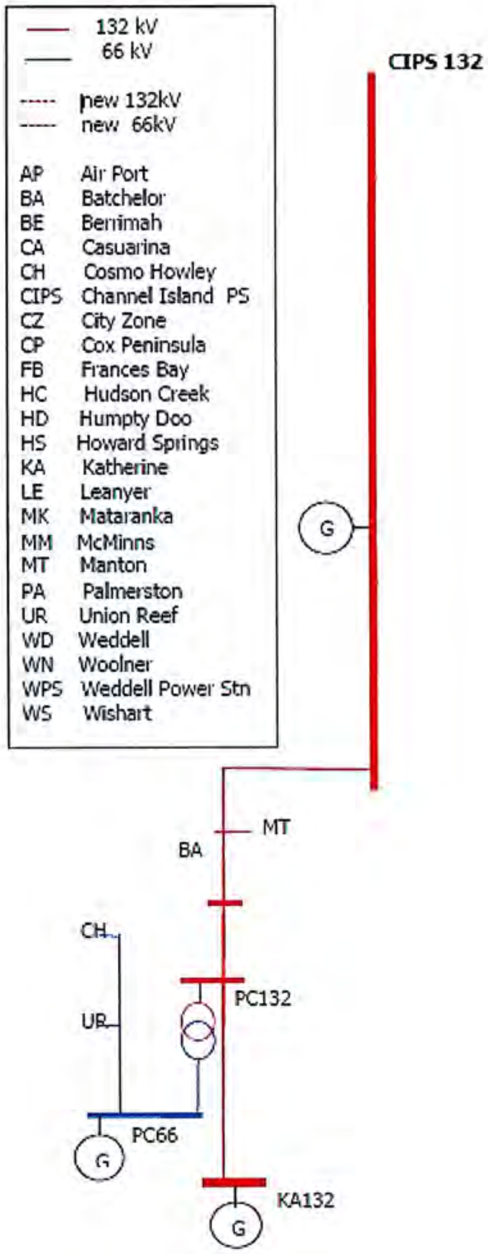

Figure 1 - CIPS to KA Transmission Network

The issue that has led to this investigation is that voltage at the Katherine 22 kV busbar can sometimes rise above the upper limit of the acceptable range. There are two primary causes of this issue, the Ferranti effect on the long 132 kV line from Channel Island to Katherine, and the limited tapping range of the 132/22 kV transformers at Katherine.

The transformers have only three taps reducing output voltage. This means that 22 kV voltage can be no more than approximately 2 % of nominal below the 132 kV voltage.

In addition Power and Water is seeking to keep 22 kV busbar voltage below 22.0 kV in order to allow for voltage rise in the low voltage network cause by rooftop solar systems.

Figure 2 below shows recent voltage recordings at CIPS, Pine Creek and Katherine 132 kV busbars.

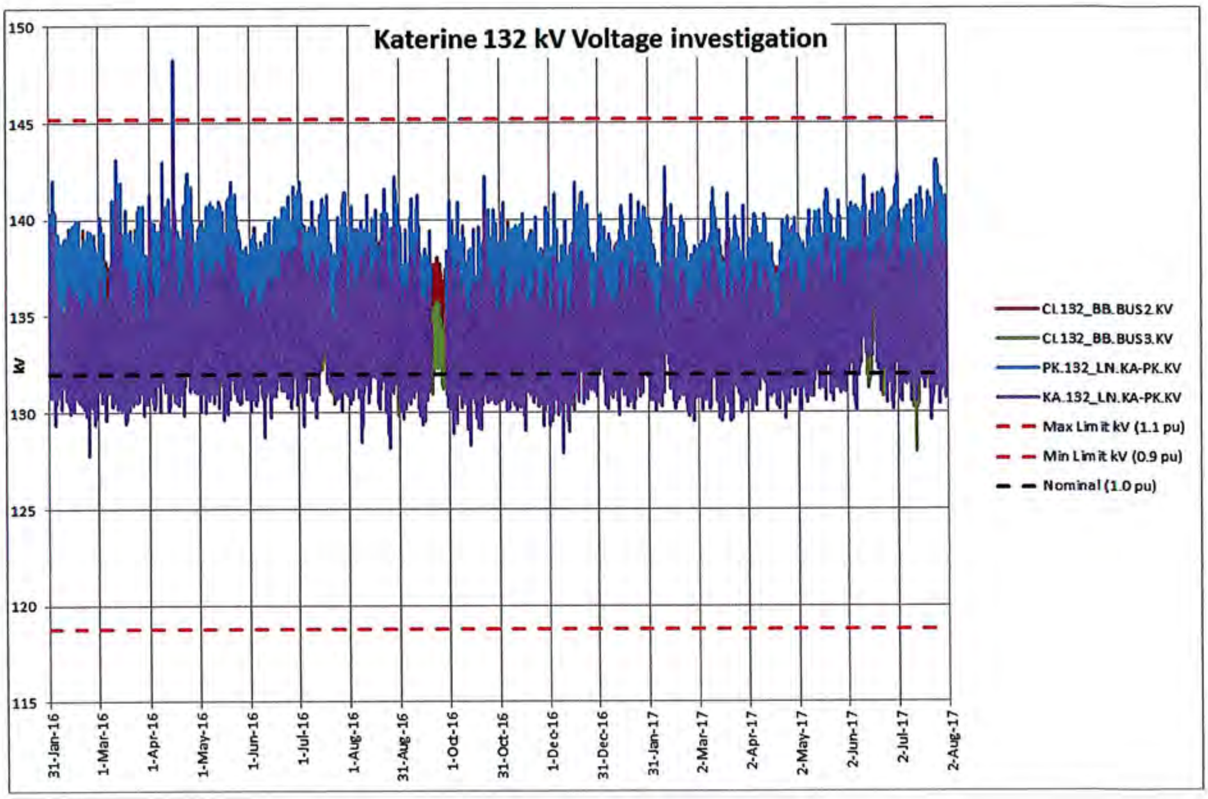

Figure 2 - SCADA voltage

The allowable steady state voltages are defined as:

> For *voltages* of 11 kV or more, the *network* shall be planned and designed to maintain a continuous *network voltage* at a *User's connection* not exceeding the design limit of 110% of nominal *voltage* and not falling below 90% of nominal *voltage* during normal and maintenance conditions. [6]

These limits are shown as red dotted lines on the chart. As can be seen from the chart there are no instances in the recent 18 month period where recorded voltage at the Katherine 132 kV busbar has exceeded the Network Planning Criteria upper limit. The one instance where voltage exceeded the limit occurred at Pine Creek for a period of one hour. During this period the Katherine 132 kV busbar voltage rose to approximately 109% of nominal voltage.

[6] D2017/263214 - Network_Management_Plan_2013-14_to_2018-19, Clause 15.2(a).

While the 132 kV voltage at Katherine remains within the acceptable range, it is likely that voltages seen by customers may be above the acceptable range when the 132 kV voltage is above nominal, due to the limited tapping range of the 132/22 kV and the voltage rise effect of rooftop solar systems in the low voltage network. Appendix A contains voltage logs in the distribution system with confirmed cases of high voltages.

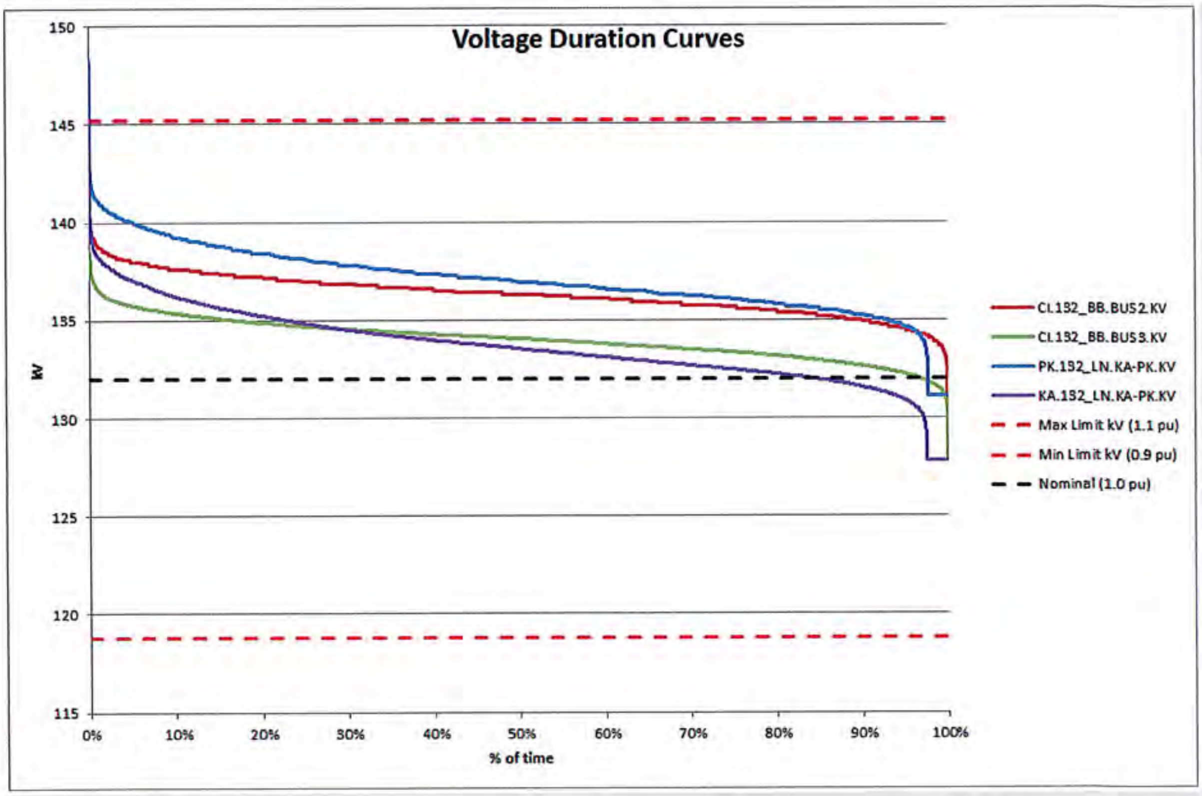

Figure 3 -132 kV voltage duration curves

Figure 3 above represents the same data as shown in Figure 2. It is interesting to note from this chart that Pine Creek which is at a midpoint of the network is often the highest voltage point.

The accuracy of the VTs used to measure voltages in the data has not been determined, so firm conclusions about voltage levels should not be reached from this data.

18.2 Existing Network

The 132 kV network from Channel Island Power Station to Katherine is approximately 290 km long. This represents a charging reactance of approximately 13 MVAr. Network modelling results show that this line will generate a voltage rise of approximately 6 % when no load or generation is connected.

18.3 Scope of Study

The scope of study is to determine the required actions to be able to meet the steady state voltage requirements of section 15.2 of the Network Planning Criteria in the Katherine area under all load conditions.

The study will consider possible options to delay capital expenditure and operational measures to maintain acceptable voltage levels.

19 Network modelling results

A Sincal model[7] of the network from Channel Island Power station CIPS to Katherine was used to analyse the likely outcomes of various voltage control strategies. The model represents CIPS as an infinite busbar.

Network conditions were analysed for load conditions as tabulated below. Data is based on recorded SCADA data from January 2016 to August 2017.[8]

Load Case	System load (MVA)
Maximum Load	45.9
Minimum Load	9.3
Average Load	25.4

The full detail of the network modelling is available in a spreadsheet[9].

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[7] H:\Power Network Management\Network Planning\Transmission system studies\NPR1701 Katherine Voltage\Katherine Voltage Investigation.sin

[8] H:\Power Network Management\Network Planning\Transmission system studies\NPR1701 Katherine Voltage\Darwin Katherine SCADA Analysis.xlsm

[9] D2017/526712 - NPR1701 Supporting Document - Katherine Voltage Sincal Results.xlsx

The key results in this investigation were the voltage at Katherine 22 kV busbar and the tap position of the Katherine 132/22 kV. The aim was to have the busbar voltage at or below 100% of nominal while the transformer tap changers were not at their limiting tap position. The table below shows voltage and tap position at minimum load conditions, which is the most onerous case. Tap 3 on the Katherine 132/22 kV transformers is the limiting tap which produces the lowest possible 22 kV voltage.

	Description	KA 22 kV voltage %	KA 132/22 Tap Position
1	Base Case	102.2	3
2	PCPS voltage control @132 kV. (18 MW @0.8PF)	100.5	3
3	KA 2 x 2.5 MVAr reactors	99.6	1
4	KA 2 x 5 MVAr reactors	99.6	1
5	KA 5 MVAr synchronous condenser	99.6	1
6	KPS voltage control @ 22 kV. (7 MW @ 0.8 PF)	100.0	2

Note that one tap position is equivalent to approximately 1.1 % of nominal voltage. By observation cases 3, 4, 5 and 6 in the above table meet the requirement of achieving a maximum of 100 % of nominal voltage while not being on limiting tap position.

Cases 3, 4 and 5 show identical voltage and tap position, since in each case a total of 5 MVAr of shunt reactance is switched in.

. Case 2 is slightly outside the required outcome, and obviously Case 1 with no additional voltage control measures is not acceptable.

Further study will be required to finalise the rating required prior to implementation of the options. The MVAr and MW ratings selected are the minimum required in the modelling to achieve acceptable outcomes.

It will be prudent to confirm that modelling results match real world voltage measurements prior to committing to any solution.

The results indicate that three options for voltage control at Katherine busbar are likely to be feasible:

1. Switched Shunt Reactors
2. Katherine synchronous condensor
3. Katherine Power Station voltage control

Note that the model was setup with CIPS busbar voltage set at 102.5% of nominal voltage.

20 Options Considered

20.1 Do Nothing

This option is not considered reasonable since voltages above limits have been experienced in the Katherine network.

20.2 Installation of reactive plant

Sincal studies have shown that 2 x 2.5 MVAr shunt reactors installed at Katherine 22 kV busbar would be adequate to ensure that steady state busbar voltage does can be controlled to maintain a value less than 1.00 per unit of nominal voltage.

20.3 Installation of a synchronous condenser

The installation of a synchronous condenser at Katherine of 10 MVAr would have the same effect on steady state voltage as the equivalent rating shunt reactors as discussed in section 20.2 above.

A synchronous condenser would have additional benefits by improving inertia in the system. Issues of system inertia and stability are beyond the scope of this study. This is likely to be the most expensive of the options considered

20.4 Contract with Pine Creek or Katherine Power Stations to provide voltage control services

20.4.1.1 Current use of generator voltage control

In order to control overvoltage at Katherine 22 kV busbar, Katherine Power station is occasionally requested by System Control to provide voltage control services by running generation when it would not normally be in operation. This has been an ad-hoc process in the past with no financial compensation to the power station operator.

Voltage control services are required by Power Networks, and will likely be most cheaply obtained by contracting with the power station operator. This arrangement should be added to the connection agreement between the power station operator and Power Networks.

20.4.1.2 Proposed scheme

Reactive power control on the generator units at Katherine power station should be set to control the 22 kV busbar voltage to an acceptable bandwidth. If the generator transformers are set on fixed taps it may be possible for the generators to be set to control their own terminal voltage to provide the same outcome. It is important to note that it is good electricity industry practice for these control changes to be implemented using automatic settings that do not require manual intervention.

20.4.1.3 Technical investigations required

As part of the technical investigation into implementing this option, it will be necessary to investigate in detail the interaction between the automatic voltage regulation (AVR) control of the 132/22 kV transformers at Katherine substation, with the proposed generator voltage control settings. It will be preferable to rely on transformer AVRs as the primary voltage control system, and the generators to provide additional control, when the transformer tap changers are at or near their limiting tap position.

Note that the proposed arrangement does not mean that generation must be constantly running at Katherine power station. It may be possible to implement a system which automatically brings units online when the 132/22 kV transformers approach their maximum or minimum tapping position. Such a system would then send an 'enable voltage control' signal to the power station. The total time that this control signal is asserted could be used as a basis for paying a fee for voltage control services.

20.4.1.4 Possible Commercial arrangements

Power Networks should consider a commercial arrangement with a monthly payment to the power station operator for having the voltage control facility available, and an hourly rate for when voltage control is enabled.

20.4.1.5 Alternative scheme using Pine Creek Power station

If negotiations with Katherine Power Station are cannot be concluded, a similar scheme may be possible at Pine Creek power station, although the present analysis has shown that more than 18 MW of generation with a minimum power factor capability of 0.8 would be required.

21 Recommended Strategy

A business case should be prepared detailing an NPV analysis of the options which have been identified as possible. The NPV should identify the maximum commercial rates at which option 20.4, contracting for voltage control services is the most attractive option. This analysis will be used as a basis for negotiations with the power station operator.

Commercial rates to be considered in the NPV analysis are:

- Capital contribution to the power station operator for the design and installation of the scheme

- Monthly fee for the availability of the scheme
- Hourly fee for the operation of the scheme

22 PSS Sincal Load Flow Model

A detailed Sincal network model[10] is available which was used to analyse the issues discussed in this report.

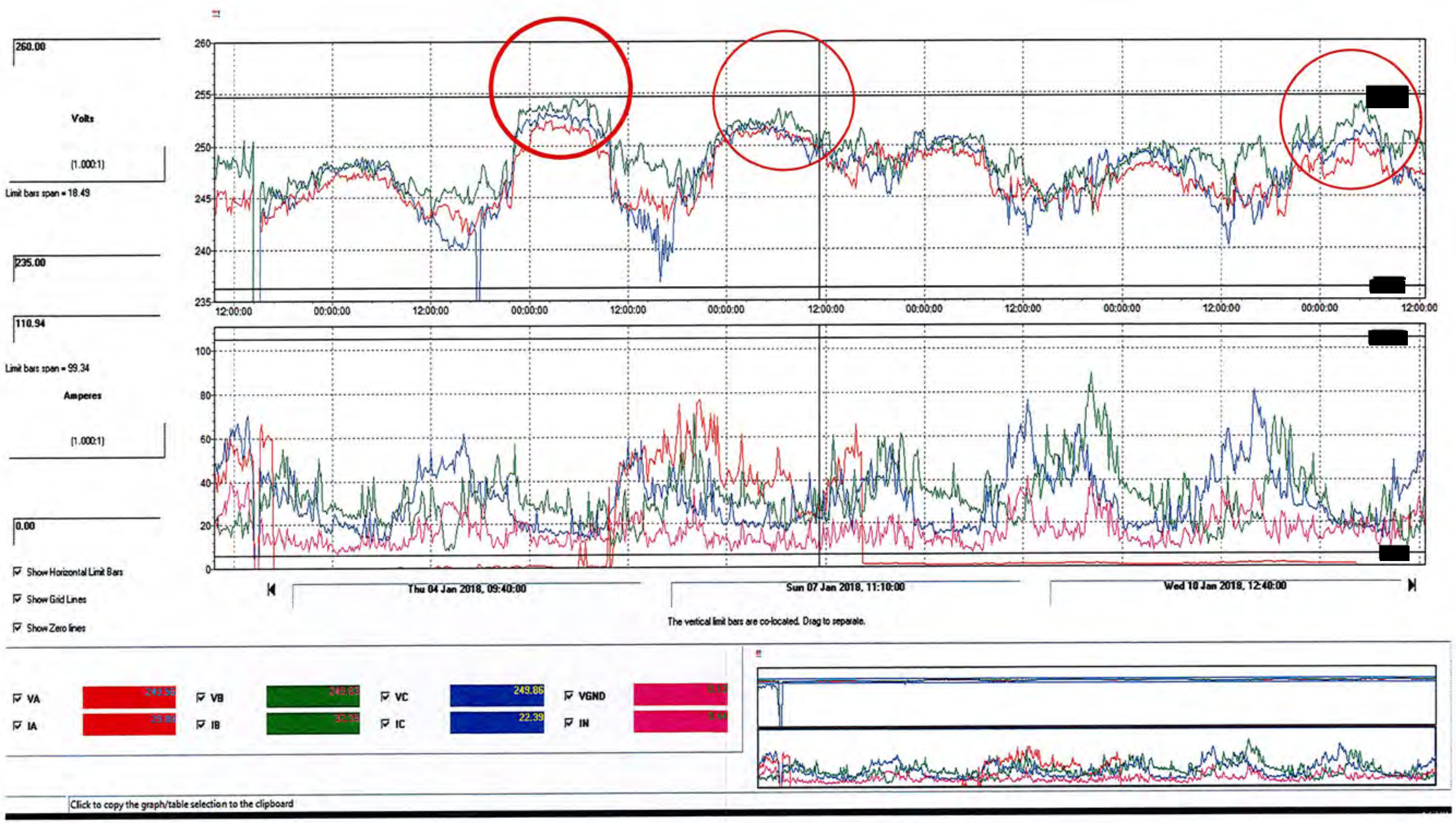
23 Conclusions and Recommendations

A business case should be prepared to analyse the options which have been identified as possible.

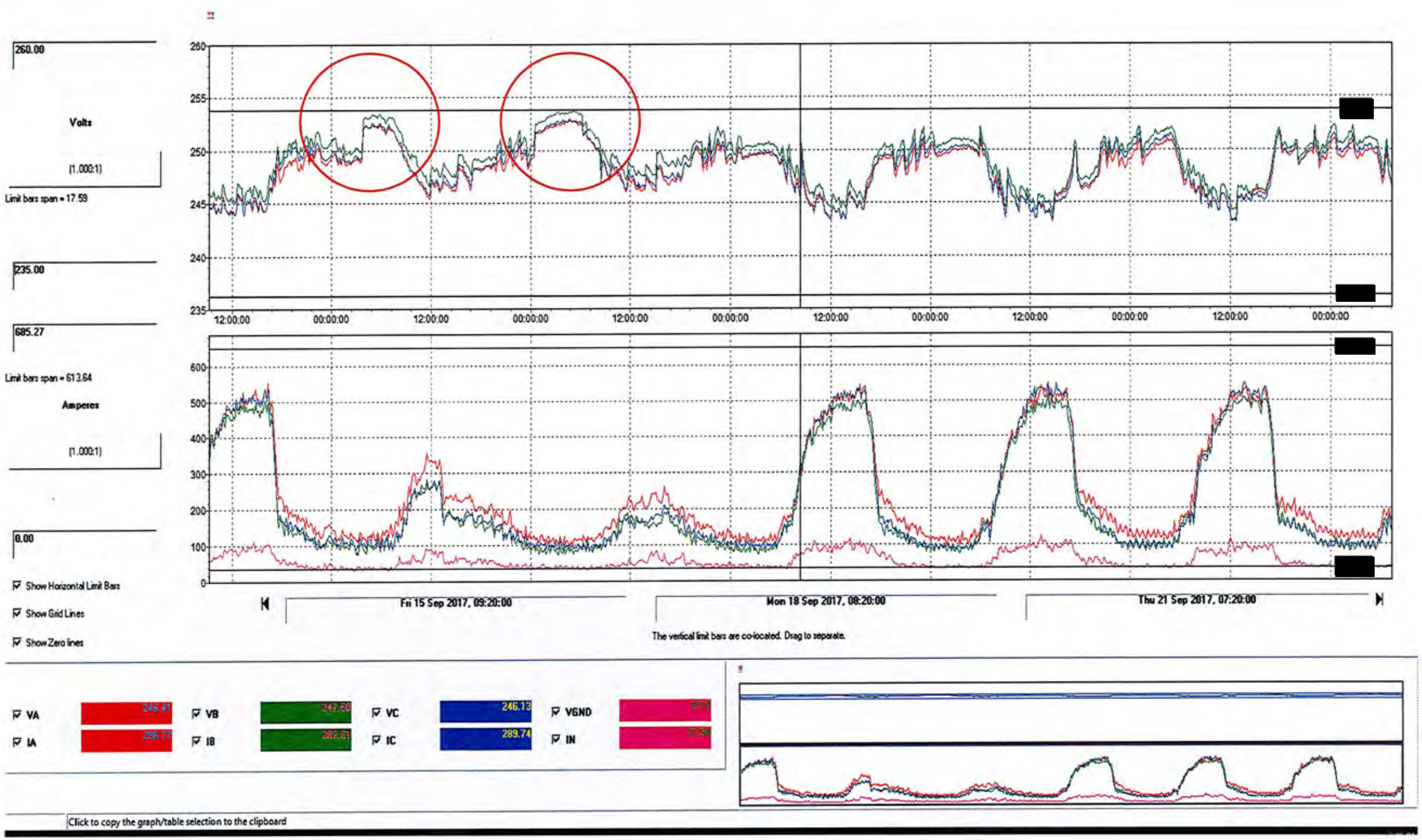
[10] H:\Power Network Management\Network Planning\Transmission system studies\NPR1701 Katherine Voltage\Katherine Voltage Investigation.sin

24 Appendix A – Katherine Distribution Voltage Logs

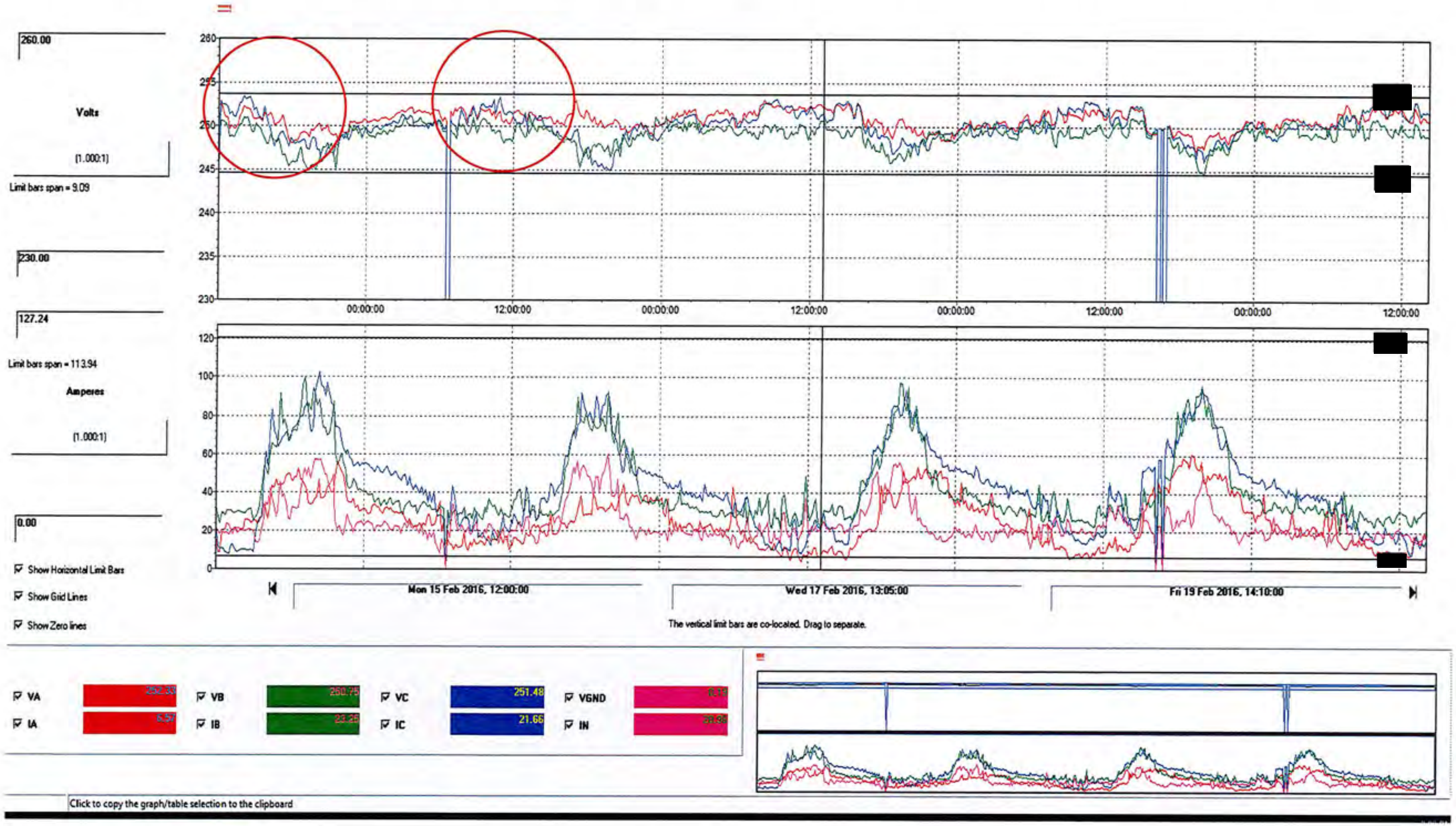
Fourth Street Katherine Voltage complaint Jan 2018: Voltage above 253 volts



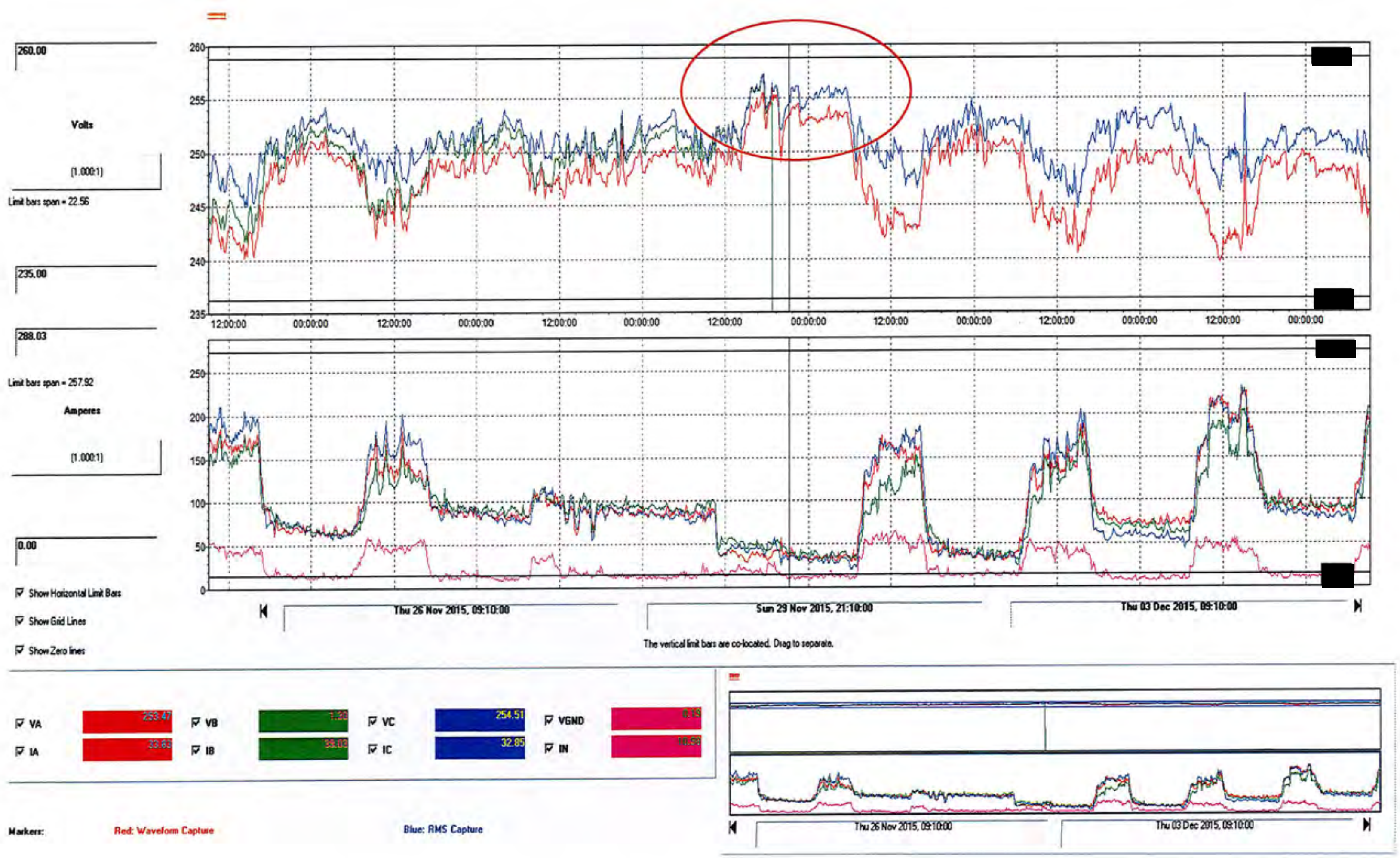
Railway Tce Katherine – 2017 High Voltage- No tap positions left at TF



Bray Road Katherine Voltage Complaint 2016: Voltage above 253 volts no more tap positions at transformer.



Crawford Street Katherine 2015 – high voltage complaint



Martin Tce Katherine Voltage Complaint 2015: Voltage above 253 volts