SVC REFURBISHMENT EXPERIENCE FOR CRITICAL COAL TRAIN HAULAGE NETWORK

Tuan VU
Powerlink Queensland – Australia
tvu@powerlink.com.au

Anthony JOHNSTON
Siemens Limited – Australia
anthony.johnston@siemens.com

ABSTRACT

By June 2009, Powerlink Queensland of Australia will have nineteen (19) Static Var Compensators (SVCs) in service and they provide 3871 MVArs of Dynamic Reactive Power Support to the Queensland transmission network. Ten (10) of these SVCs have been in service since 1987 at substations supplying two phase supply to railway traction loads. Over the last 20 years, these SVCs have provided the critical Negative Phase Sequence (NPS) balance support to the railway electrification network in Central Queensland, Australia. Aging secondary system components have been responsible for some failures and network interruption in recent years. SVC failures causing power transfer limits in the operational network are major concerns and can affect the Australian coal export capability. Recognising the need to refurbish these old SVC components to achieve adequate reliability is an important aspect of Asset Management and Network Operation.

This paper describes in detail the refurbishment process for ten (10) aging SVCs at railway electrification sites. Understanding the critical failure modes and using this information to determine detailed design parameters for different SVC components is a great engineering challenge. The refurbishment processes include study of SVC failure modes, operational network constraints, specification, network modelling, design, testing, implementation, challenges and solutions to overcome challenges. Practical experiences learnt from a difficult yet successful refurbishment project are documented. Over the last 3 years, Powerlink Queensland has worked together with Siemens Limited and successfully refurbished ten (10) SVCs in Central Queensland, Australia, without interruption to the electrified coal train network.

1. INTRODUCTION

The ten (10) SVCs at railway electrification sites are known colloquially throughout Powerlink as the ‘Railway SVCs’ or ‘QR SVCs’. The major function of the these SVCs is to provide critical Negative Phase Sequence (NPS) balance support to the railway electrification network – coal haulage network – in Central Queensland, Australia. The rail traction load is supplied by two phases of a 132kV three phase supply which causes unbalance which can be modeled as NPS. The railway SVCs were built by ASEA (ABB) between 1984 and 1987 and they operate reliably for almost 15 years.

Between 1999 and 2005 Powerlink experienced a high number of SVC failures that resulted in operational network constraints. In 2000, Powerlink launched an investigation into the failures and found that the failures were random and mainly due to aged electronic components.

Since 2005, railway loads in Central Queensland, Australia have been growing strongly and mostly driven by the Queensland coal export. Rapid load growth and high incidents of SVC failures seriously affect the coal export.

It was estimated that network constraints due to SVC failures could cost the coal export industry up to $AUS20M per day. SVC is a highly integrated system from primary plant through to secondary system components. The process and methodology used to decide what components should be refurbished, when and how the refurbishment should be implemented are great challenges to asset management and engineering.

This paper documents the business decision process and the best engineering practices that led to successful refurbishment project. Table 1 shows the basic technical data of the aging railway SVCs.

TABLE 1 - NEBO AND RAILWAY SVCs

SITE NAME	SWING RANGE		COOLING (kW)	TFMR MVA	TCR MVAr	TSC MVAr	FC MVAr	SVC kV
	CAP	IND						
MT MCLAREN	33	-18	100	36	51	0	33	5.7
DINGO	10	-13		40.5	69	0	10	7.7
	10	-13	146				10	
	17	-6					17	
GRANTLEIGH	13	-4		36	51	0	13	5.7
	7	-10	100				7	
	7	-10					7	
OONOOIE	17	-14		60	93	0	17	10.4
	19	-12	167				19	
	16	-15					16	
COPPABELLA	20	-11		60	93	0	20	10.4
	20	-11	167				20	
	18	-13					18	
GREGORY	30	-21	100	36	51	0	30	5.7
MORANBAH	42	-51	167	60	93	0	42	10.4
DYSART	29	-40	146	40.5	69	0	29	7.7
BLACKWATER	18	-33	100	36	51	0	18	5.7
NEBO	260	-80	583	260	170	170	90	17.7

Abbreviations. CAP- capacitive MVar, IND – inductive MVar, TFMR – transformer, TCR – thyristor controlled reactor, TSC- thyristor switched capacitor, FC – filter capacitors.

A single line diagram for a typical railway SVC is shown in Figure 1. The main components are a 60MVA 132/10.4kV transformer, 93Mvar thyristor switched reactor, 3rd and 5th harmonic filter banks. The physical layout of a typical railway SVC site is shown in Figure 2.

2. DECISION TO REFUBISH COMPONENTS

The decision to address the issues of SVC failures causing network constraints that financially affect the coal export industry was urgently required.

Between 1999 and 2005, numerous SVC failures were recorded. SVC TCR (Thyristor Control Reactor) and TSC (Thyristor Switch Capacitor) valves failed. Various control system electronic boards failed due to aged electronic components. Thyristor valve cooling system failed due to worn out mechanical parts of pump motors, radiators (corrosion), flow meter and pressure meter failures.

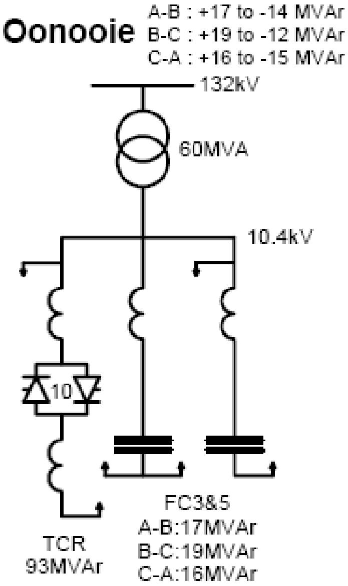

Figure 1 – Electrical diagram of a typical railway SVC

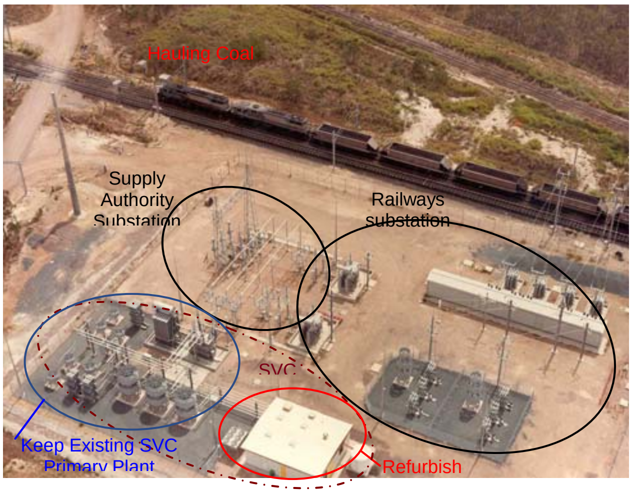

Figure 2 – Railway SVC layout and refurbish decision

There were also some failure incidents related to primary plant such as air cored reactors and capacitors. Primary component failures were mainly due to degraded insulation materials and electrical stresses resulted from the increased system harmonic currents and voltages over the last 15-20 years. When these SVCs were designed in 1984 the system background harmonic currents and voltages were significantly less then what they are today. The designed margins of the equipment in the past may not be sufficient for the condition today. The increased background harmonics is mainly due to the rapid increase of mining and railway electrification loads in the recent years.

The formula below was used to evaluate the relevant rating of primary component such as capacitor and reactors:

$$U_{RATED\_CAP} = U_1 + \sum_{i=2}^{30}\left(U_{i\_TCR} + U_{i\_Background}\right) \qquad (1)$$

$$I_{RATED\_REACT} = \sqrt{I_1^2 + \sum_{i=2}^{30}\left(I_{i\_TCR} + I_{i\_Background}\right)^2}$$

The investigation revealed that replacing all primary components would be a very expensive exercise and not practical. Furthermore, the coal transport network would be interrupted heavily for a long period of time. Therefore, an alternative strategy to address primary component failures is to gradually reduce system background harmonics by installing more harmonic filters closer to harmonic loads , and to purchase a number of standardised spare reactors, capacitors and transformers that can be used at a number of SVC sites.

Solving the failure issues of secondary system component such as thyristor valves, thyristor valve cooling system, control and protection system requires a different approach. The secondary system components are no longer available and these secondary system components are fully integrated. It means that they all have to be compatible with each other. Therefore, Powerlink decided to refurbish the following components: Thyristor valves, Thyristor valves cooling system, control system and protection system for all ten (10) SVCs.

When to refurbish is the next step that needs to be decided. May 2005, Powerlink awarded the refurbishment contract to Siemens Limited to refurbish the ten (10) SVCs. The scope of work includes replacing Thyristor Valves, Thyrsitor Valves Cooling System, Control System and Protection System for ten (10) SVCs.

How to refurbish ten SVCs without interrupting the electrified coal transport network is a great challenge. One of the major challenges in the refurbishment is to limit interruption to the railway electrification network to a maximum of 48 hours.

In order to maintain Negative Phase Sequence support to the coal train network during the refurbishment process, a different approach is required. Powerlink and Siemens Limited together came up with an innovative concept to use a relocatable SVC building as centre solution to the refurbishment strategy. Detailed design of the relocatable SVC building and step-by-step implementation strategy to minimise network interruption represent great challenges .

The relocatable SVC building was designed and constructed by Siemens in Germany. It is a purpose built container specifically designed to house the thyristor valves, thyristor valves cooling system, control system, protection system, AC and DC distribution system. This container is mounted on a trailer that can be conveniently towed to each SVC site. A set of custom made high voltage cables was manufactured and used to connect the high voltage primary plant to the relocatable SVC building.

3. ENGINEERING SOLUTIONS

3.1 Cooling System and Thyristor Valves New Ratings

Powerlink and Siemens together studied the network condition of each SVC site. Network background Harmonic impedances, harmonic currents and voltages on the network were collected and evaluated. The results from network evaluation were used to recalculate the operational ratings of the existing primary components such as power transformer, capacitors and reactors. The new operational ratings of the existing primary equipment are used as the limits to derive the safety margin and to redesign the secondary system components. Refer to equation (1), in simple terms, U_{RATED} and I_{REATED} of the existing primary components are unchanged while $U_{BACKGROUND}$ and $I_{BACKGROUND}$ increased. Hence, U_{TCR_RATED} and $I_{TCR\ RATED}$ must be optimised. This can be achieved by redesigning the control system schemes and logics.

Due to the increased background harmonics, the new thyristor valves were designed with an additional level of thyristors in series to give an increased safety margin. Refer to column "Level" in Table 2. Consequently, cooling capacity also needs to be increased by a factor of 20%.

TABLE 2
THYRISTOR VALVES AND COOLING SYSTEM RATING

	Cooling Flow (L/m)			Power	TCR Thyristor Valve		
SITE	MIN	RATED	MAX	kW	Level	V (kV)	Irms (A)
MT MCLAREN	187	196	205	120	3+1	5.81	3300
DINGO	270	283	296	175	5+1	7.5	3300
GRANTLEIGH	187	196	205	120	3+1	5.64	3300
OONOOIE	311	327	342	200	6+1	10.67	3300
COPPABELLA	311	327	342	200	6+1	10.67	3300
GREGORY	187	196	205	120	3+1	5.7	3300
MORANBAH	311	327	342	200	6+1	10.67	3300
DYSART	270	283	296	175	5+1	7.5	3300
BLACKWATER	187	196	205	120	3+1	5.64	3300
NEBO	TCR						
	395	415	433	336.78	8+1	19.7	3529
	TSC						
	426	447	467	363.22	12+1	22.302	3580

The new rated Thyrsitor Valves and Thyristor Valve Cooling System were also redesigned with higher rating and margins to tolerate the additional system background harmonic stresses. Table 2 shows the new ratings for Thyristor valves and valves' cooling systems.

3.2 Control and Protection System Redesign

The old protection systems of these SVCs are no longer non-compliant with the current Australian Electricity Codes. The new protection system will use modern numerical relays and duplicated protection schemes (main and backup). Table 3 shows the new protection schemes that comply with the current Australian Electricity Codes.

The SCADA (Supervisory Control And Data Acquisition) system or remote control capability of the old railway SVCs were very primitive and virtually non-existent. These SVCs are located in the remote locations that could take up to 4 hours drive from the nearest maintenance depots. The need to upgrade the SCADA system and improve the remote control capability is essential. The SCADA system is redesigned using modern proven control system equipment and latest telecommunication technology. The new SCADA system uses Remote Terminal Units (RTU), protocol converters, serial communication using DNP3.0 protocol and fibre optic communication.

Table 3 – New Relay schemes

Relay	ANSI Device No.	Relay Type	Mai n Prot.	Backup Prot.	Protection Function
-F01	87T 87BB 50/51 50N/51N 50BF	7UT613	x		Transformer differential protection Busbar / TCR differential protection Overcurrent protection Earth fault overcurrent protection Breaker fail protection
-F02	87T 50/51 50N/51N	7UT612		X	Transformer differential protection Overcurrent protection Earthfault overcurrent protection
-F03	59G	7RW600	X		LV-side Displacement ovevoltage protection
-F04	59	7RW600	X		Phase-phase overvoltage protection
-F05	50/51N	7SJ602		X	Earth fault overcurrent protection
-F11	50/51 50N/51N 49	7SJ602		X	TCR overcurrent protection TCR ground fault overcurrent protection TCR overload protection
-F21	50/51 50N/51N	7SJ602		X	Filter 1 overcurrent protection Filter 1 earthfual overcurrent protection
-F22	60C 50/51 49 59	CPR04	X		Filter 1 unbalance protection Filter 1 overcurrent protection Filter 1 overload protection Filter 1 overvoltage protection
-F31	50/51 50N/51N	7SJ602		x	Filter 2 overcurrent protection Filter 2 earth fault overcurrent protection
-F32	60C	CPR04	X		Filter 2 unbalance protection

The new SVC control functions include Negative Phase Sequence / Steinmetz load balance control (priority 1), Positive Phase Sequence control (Voltage Setpoint – priority 2), Susceptance control and Droop / Slope settings. All settings can be dynamically controlled and adjusted from Powerlink's control centre.
The SVC start-up sequence was redesigned to limit unnecessary voltage stresses to the existing capacitors.

Standard SVC START-UP Sequence: Close High Voltage Breaker => Wait approximately 30 seconds for transformer inrush to decay => Close filter circuit breaker and at the same time release the TCR firing pulses to achieve 0MVARs at energisation, then regulate Negative Phase Sequence.

The QR SVCs do not have filter circuit breaker. Using the standard start-up sequence will effectively energise the coupling transformer and harmonic filters at the same time, hence SVC is ernergised at maximum capacitive limit. During energisation, SVC secondary bus bar voltage rises up to 29kV peak (nominal system voltage of 10.4kV RMS) and caused additional stresses to harmonic filter capacitors and excessive capacitor failures were observed during energisation. Refer to Figure 3.

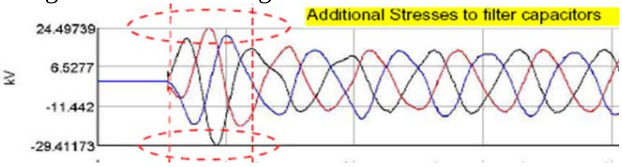

Figure 3 – Secondary bus bar voltage Increased

New SVC START-UP Sequence: Prior to breaker closing, the control system sends starting pulses to the TCR Valve Base Electronics (VBE) to start TCR Thyristor valves in TSR (Thyristor Switch Reactor) mode. Transformer, filter capacitors and reactors are energised at the same time and SVC is energised at maximum inductive limit. Shortly after transformer inrush has decayed, the control system starts to regulate TCR firing pulses and switch the TCR thyristor valves back to Thyristor Control Reactor mode. By using this energisation method, the SVC secondary bus bar voltage reduced to 16.9kV peak during energisation. Refer to Figure 4.

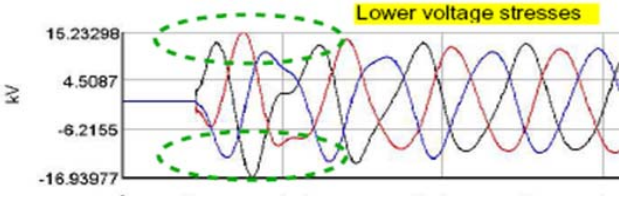

Figure 4 – Secondary bus bar voltage Decreased

4. IMPLEMENTATION CHALLENGGES

4.1 48 Hours Outage Constraints:

The greatest challenge of the implementation phase was the 48 hours outage constraints. The refurbishment process utilised the relocatable SVC building and 48 hours Cut-in and 48 hours Cut-out procedures for each SVC site.

4.2 48 Hours Cut-In: The SVC site is shutdown, yard primary equipment (e.g. Transformers, reactors, capacitors, CTs, VTs) are disconnected from the old SVC building and reconnected to the relocatable SVC building using the custom made high voltage cables. The old secondary system equipment are disconnected and field cables are redirected from the old control building to the relocatable SVC building. Full commissioning test procedures were carried out. At the end of the 48 hours period, the SVC is fully operational using the relocatable SVC building.

At this time, all equipment in the old SVC building are removed and disposed and new equipment are installed and tested offline. This period takes approximately 4-6 weeks. Once the new equipment are fully installed and tested offline, the 48 hours Cut-Out starts.

4.3 48 Hours Cut-Out: The SVC using the relocatable building is again shutdown for 48 hours. The process occurred during the Cut-In is now reversed. All cables and wirings are redirectedfrom the relocatable SVC building to the permanent building. Once all commissioning testing completed, the SVC is energised with the new equipment in the permanent building and relocatable SVC building is transported to the next refurbishment site.

5. CONCLUSIONS

Recognising the need to refurbish aging SVCs at the time when the system equipment approaching their end of service life was a critical business decision of asset management. The most innovative aspects were standardising on primary components, designing the secondary system as a complete demountable module and using a demountable secondary system to ensure cut ins and outs were limited to 48hours.

It took almost three (3) years to gradually refurbish ten (10) SVCs. During the three (3) year refurbishment process, the coal transport network has never been constrained. The key success to this difficult refurbishment project is the combined efforts and effective cooperation of Powerlink Queensland's Asset Management, Planning, Operation and Engineering departments, and Siemens Limited.

6. ACKNOWLEDGEMENT

This project could not have been successfully completed without the great efforts and support from the project team members of Powerlink Queensland and Siemens Limited. Special thanks to Mr. Alwyn Janke and Mr. Tony Gillespie for their valuable supports.

REFERENCES

[1] Narain G. Hingorani, Laszlo Gyugyi, 1999, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems

[2] Jos Arrillaga, Neville R. Watson, 2003 "Power System Harmonics, 2nd Edition"

[2] Siemens Limited, 2005-2008 "Railway SVC thyristor valves design reports".