

Improvement of Transmission Line Power Transfer Capability, Case Study

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ABSTRACT

This paper investigates different approaches to improve the power transfer capability (PTC) of transmission lines. Study was performed on the Eastern Gold Fields (EGF) area of the Western Power network in Western Australia where power transfer to this area is currently enhanced using four saturable reactor types static var Compensators (SR SVCs) installed in this region. These SR SVCs have reached to the end of operational life and they are scheduled for replacement by different dynamic reactive power devices such as Static Synchronous Compensators (STATCOMs) or Thyristor Controlled SVCs (TSVCs). Another proposed option to enhance the PTC to this area is by upgrading the 220 kV transmission line to 275 kV transmission line and / or using series capacitor compensation. This paper introduces technical and economical study for the aforementioned options and suggests a reliable and cost effective approach to improve the PTC to EGF area.

INDEX TERMS

Transmission Lines, Power transfer, STATCOM, SVC

INTRODUCTION

DUE to the significant power demand increase, the transmission line operators are required to increase transmission line power transfer capability. In this context, they have various options such as building an additional parallel transmission line which is not a cost effective option especially for long transmission lines, using a series-capacitor compensated transmission lines which is a very cost effective option when compared with the former one however, series-capacitor transmission lines may lead to sub-synchronous resonance (SSR) problem or by using a dynamic reactive device. These options are briefly elaborated below.

It is well known that series-capacitor compensation can benefit a power system in several ways such as improving transient stability, increasing power transfer capability, eliminating the need for more parallel and uneconomical transmission lines [1,2]. However, a capacitor compensated transmission line, is not without problems as when the degree of series capacitor compensation is increased, resonance of the generator, transformer, transmission line and capacitor may develop, usually at subsynchronous frequency [3]. If a resonant frequency of the transmission system is complementary to any one of the torsional oscillating frequencies of the turbine generator mass-spring system, they will be mutually excited and the SSR will develop causing serious shaft and other damage to the turbine-generator set [4]. In addition to restoring the load, On Load Tap Changer (OLTC) also may extend the power transfer ability to the load center. However the

OLTC only provides a little benefit to the transient voltage recovery and synchronous stability of the system [5, 6].

The line upgrading techniques will also improve the power transfer capability through the upgraded transmission line however; this is a very expensive option especially for long transmission line [7].

Static Synchronous Compensator (STATCOM) is one of the promising technologies applied to improve power system performance. The advantages of STATCOM include fast response time, better voltage support capability and reactive power support at low voltage levels. Moreover, it does not require thyristor-controlled reactors (TCR) or thyristor-switched capacitors (TCS) and does not produce low harmonic order distortions [8, 9]. STATCOM mainly consists of a pulse width modulation (PWM) voltage source converter (VSC) with a capacitor in the DC side, coupling transformer and control system as shown in Fig. 1. The interaction between the grid voltage and the voltage at the STATCOM ac side provides the control of reactive power flow. The control system enables adapted regulation of bus voltage and the DC voltage levels and hence controlling the reactive power flow according to the system requirements. The VSC consists of 12 pulse IGBT converter station to minimize the harmonics generated from switching operation.

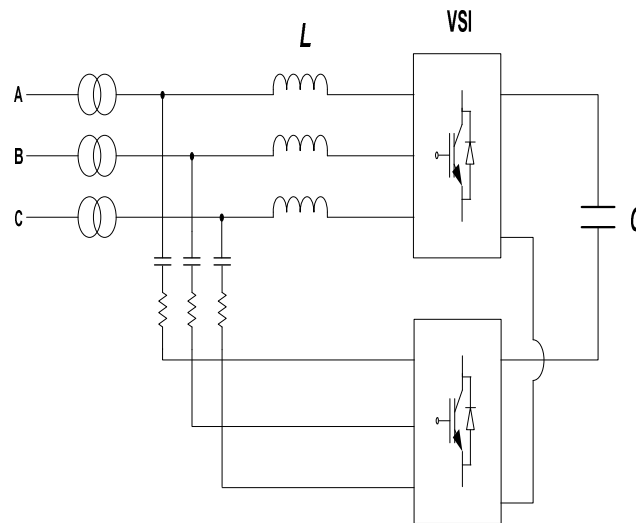


Fig. 1. STATCOM Configuration

The basic principle of STATCOM operation is illustrated in Fig. 2. If the voltage at the STATCOM terminals is higher than the grid voltage (Fig. 2 (a)), reactive power will be injected from STATCOM to the grid and STATCOM will behave as a capacitor. When the voltage at the STATCOM is less than the grid voltage (Fig. 2 (b)), STATCOM will behave as an inductor and reactive power flow will be reversed. Under normal operating conditions, both voltages will be equal and there will be no power exchange between the STATCOM and the grid.

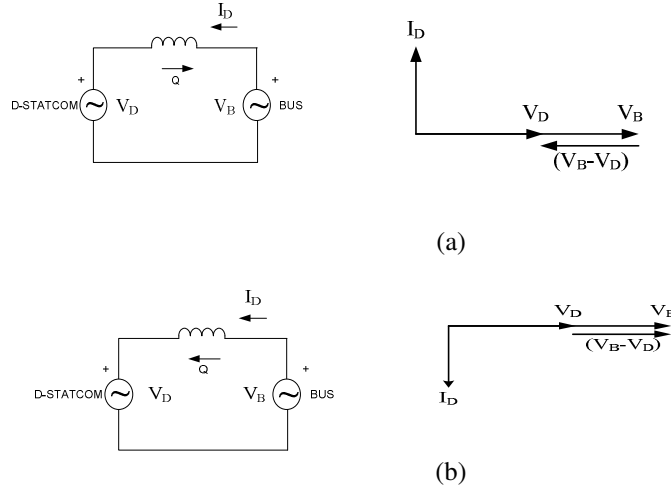


Fig. 2. STATCOM principle of operation [10]

The reactive output power of the compensator is varied to control the voltage at the point of connection to be within the permissible voltage limits. The STATCOM can provide reactive power modulation instantly via controlling the inverter firing angle α and hence improving system transient stability. The detailed control system of the STATCOM is shown in Fig. 3 [10].

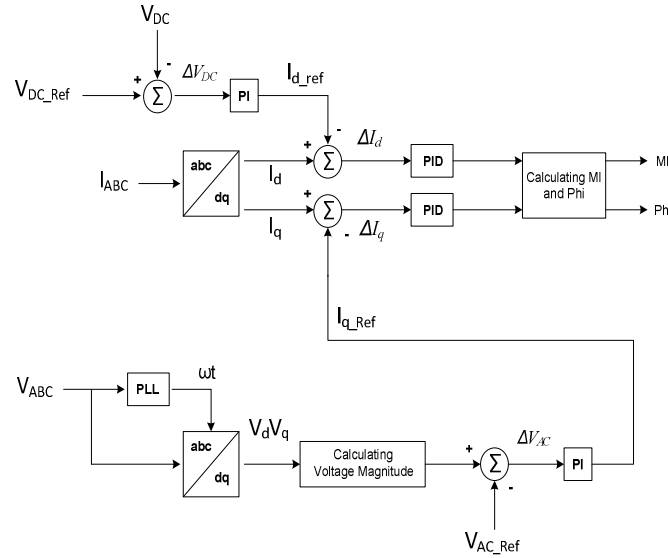


Fig. 3. Control system of STATCOM

In this system, the DC Voltage across the capacitor, the grid three-phase currents and three-phase voltages at a particular bus are sensed and converted to the $d-q$ reference frame to create I_d , I_q , V_d and V_q . These parameters in $d-q$ reference frame are compared with the corresponding nominal values to create error signals (ΔI_d , ΔI_q and ΔV_{AC}) which are fed to PID/PI controllers to create Modulation Index (MI) and phase angle (Phi) required for the voltage source converter (VSC) switching operation.

The SVC is basically representing a shunt connected static var generator/absorber whose output is adjusted to exchange capacitive or inductive current with the power system to maintain or to control specific parameters of the electrical power system, typically bus voltage. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response [11]. There are two types of the SVC namely, fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) and Thyristor Switched Capacitor-Thyristor Controlled Reactor (TSC-TCR) which is more flexible than FC-TCR and it uses smaller rating of reactors and consequently it generates fewer harmonic. Fig. 4 shows a schematic diagram for a TSC-TCR SVC that is consisting of two Thyristors Switched Capacitors (TSC) and one Thyristor Controlled Reactor (TCR).

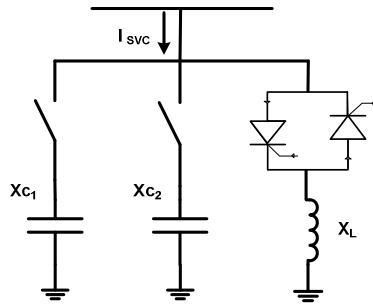


Fig. 4 TSC-TCR SVC structure.

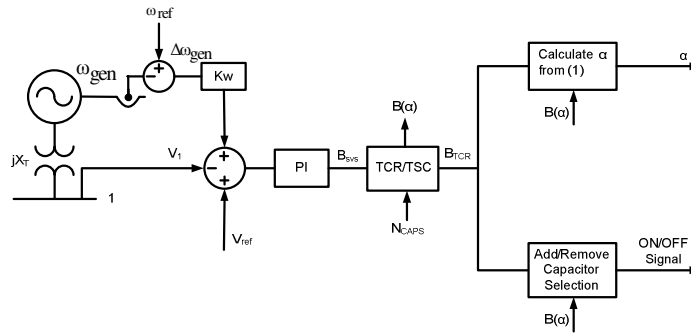


Fig. 5 Proposed control system scheme.

The control scheme for TSC-TCR SVC is shown in Fig. 5. The voltage deviation at the machine terminals ΔV_1 and the generator shaft speed deviation $\Delta \omega_{gen}$ are used as input signals to the proposed controller. The controller provides three outputs; capacitor bank switching signal that determines the number of capacitor banks needed to be on, thyristor firing angle α that is required to control the TCR and the TCR susceptance $B(\alpha)$. As shown in Fig. 5, the voltage and speed deviations are used as input signal to the PI controller that is used to generate an SVC susceptance reference value B_{svc} which is used as an input to a non-linear susceptance characteristic for TSC and TCR along with the number of TSC in use N_{CAPS} to generate the TCR susceptance $B(\alpha)$ and the non-linear TCR susceptance B_{TCR} which are used to create the on/off signal and the thyristor firing angle α .

The power transfer to the Eastern Gold Fields (EGF) area (Fig. 6) of the Western Power network (WP) in Western Australia is limited due to synchronous and voltage stability issues in this area. Power transfer to this area was improved by installing four Saturable Reactor (SR) type Static Var Compensators (SVC) [12]. Two of them were installed at West Kalgoorlie Terminal (WKT) in the year 1985 and the other two were installed at Meredin Terminal (MRT) during the years 1985 and 1990.

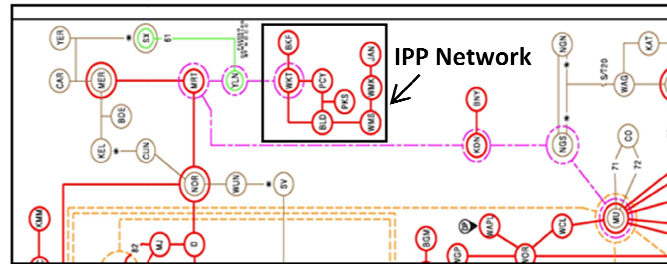


Fig. 6. Single Line Diagram of the EGF Network

Under contingency conditions, these SR SVCs help to maintain the system voltage within acceptable margin and consequently maintains the system dynamic stability. These SR SVCs were manufactured based on an old technology and they are considered to be obsolete nowadays. Moreover, the production cost of these SR SVCs is very high as it comprises heavy materials. The majority of loads in this area include mining and other industrial loads that are working on full capacity over the entire period of the year. With the increase in the load growth in the region, the western power network is not in a position to accommodate the additional loads due to the power transfer limitation of the existing transmission line. Meanwhile, operating regional generators are not economical as these generators are fossil fuel based that incur a very high operational cost. To increase the transmission lines power transfer capability to this area, some options were suggested by the transmission line operator (TLO). These options include, upgrading the transmission line and / or using capacitor series compensation, replacing the currently installed SR SVCs by either Static Synchronous Compensators (STATCOMs) or Thyristor Controlled SVCs (TSVCs) [13].

This paper investigates the technical and economic feasibility of these options to help the TLO in selecting the most suitable solution to this issue. Simulation studies were carried out using Power System Simulation Engineering (PSS/e) software package [14].

PROBLEM AND PROPOSED SOLUTION

Rotor angle stability refers to the ability of synchronous machines in an interconnected network to be remained in synchronism after being subjected to a disturbance. The transient rotor angle stability criterion for WP is defined in the WP's Technical Rules [13]. Fig. 7 shows the rotor angle behaviour of two generators at Eastern Goldfields (IPP generators) and Collie Power Station (CPS) after a 3 phase short circuit at the 220 kV line connecting Muja (MU) and WKT bus bars. The 3-phase short circuit fault is applied at the middle of the transmission line connecting Yilgarn (YLN) and WKT bus bars at $t = 0.25$ s and is assumed to last for 5 cycles.

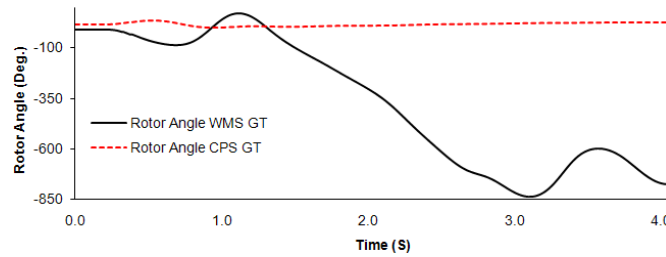


Fig. 7 Rotor angle changes of EGF and other generators

Fig. 7 shows that for such a fault, the two generators become out of synchronism. For the same 3-phase short circuit fault, the voltage profile at the WKT bus bar was observed as shown in Fig. 8 from which one can observe that the voltage at the WKT 220 kV bus cannot be recovered after fault clearance.

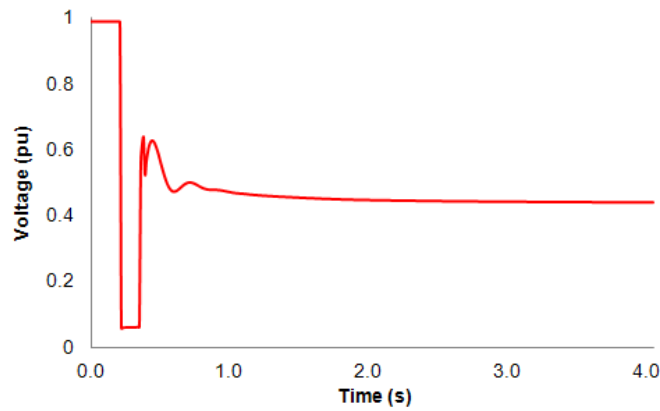


Fig. 8 Voltage profile at WKT 220 kV bus bar

Voltage stability creates a serious problem in the ability of a transmission line to transfer maximum power, particularly with high VAR demand [13]. It is essential to improve the voltage stability under contingency and normal operating conditions. Dynamic reactive devices such as STATCOM and TSVC can improve the voltage stability of the network and enhance the power transfer capability of the transmission line.

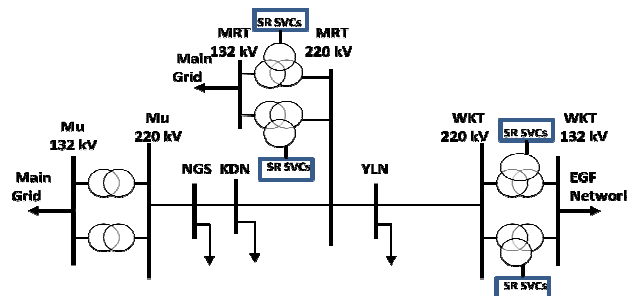


Fig. 9 Proposed locations for the new reactive compensation devices

The above discussion shows that there is an essential need to increase the power transfer capability to the EGF area meanwhile, improving the dynamic performance of the overall EGF network. The considered proposed options are:

Option 1: Replacing each of the SR SVCs at MRT and WKT (as shown in Fig. 9) with a SVC connected to the tertiary winding of the existing 220/132/29.5 kV transformers at MRT and WKT.

Option 2: Replacing each of the SR SVCs at MRT and WKT with a STATCOM connected to the tertiary winding of the existing 220/132/29.5 kV transformers at MRT and WKT.

Option 3: Upgrading the 650 km, 220 kV transmission line between MU and WKT to 275 kV line and / or using series capacitor compensation.

SIMULATION RESULTS

STATCOMs and SVCs are used to improve the overall system performance during steady state and transient conditions. Fig. 10 shows the size of the reactive power compensation required for different power transfer levels to WKT and MRT. For 145 MW power transfer level, the reactive power compensation required is 45 MVar for WKT and 23 MVar for MRT.

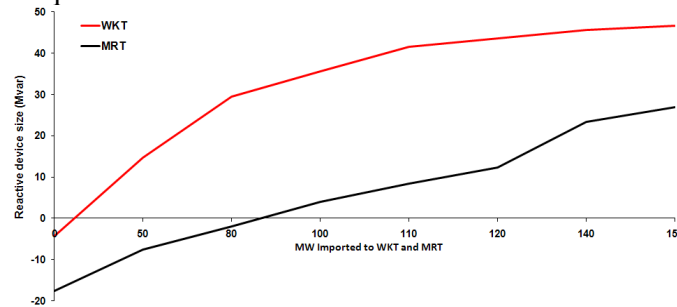


Fig. 10 Reactive device size against power transfer level

To optimise the size of the reactive power compensator, the existing 5 MVar capacitor bank that is installed at EGF area can be used for the steady state conditions while the proposed STATCOMs or SVCs can support the capacitor banks during transient conditions. The size of the proposed reactive power device could be reduced to 40 MVar rather than 45 MVar as shown in Fig. 11 which is drawn according to the daily load profile in the EGF area.

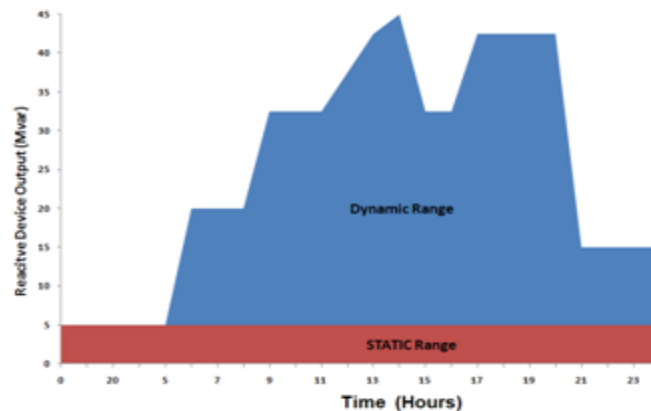


Fig. 11. Reactive power Static and Dynamic ranges

The TL power transfer capability was evaluated for the aforementioned options and the exported power from the Independent Power Producer (IPP) to WKT was plotted as shown in Fig. 12 which shows that the highest transfer capability is achieved when the SR SVCs are replaced with STATCOMs. However the performance of TSVCs is better than that of the STATCOMs after 120 MW power transfer to WKT.

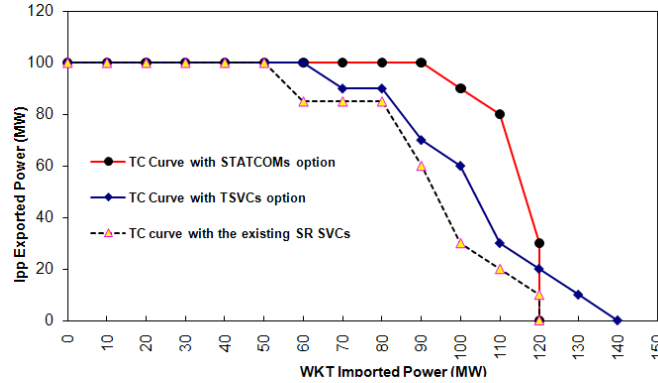


Fig. 12 TL Power transfer capability for different options

For low WKT import levels, both IPP can produce the maximum export to the network. With the increase of the transfer level to WKT, the power transfer from the IPP generators will be reduced due to the transmission line power transfer capability. A 3-phase short circuit fault within the IPP network will island the IPP network, as a result of that WP supply will be increased via the 220 kV line to cover the load demand at ECF region. Therefore the pre-contingency transfer via the 220 kV line should be limited to ensure that the system is stable under contingency conditions.

A 3-phase short circuit fault at the middle of the transmission line connecting Yilgarn (YLN) and WKT bus bars was applied at $t = 0.2$ s and is assumed to be cleared after 5 cycles. Fig. 13 shows the voltage profile at WKT generator terminal during the fault for the three different proposed options at the same power transfer level. As shown in the Fig. 13, the STATCOM provides the fastest voltage recovery among the other options considered in this study.

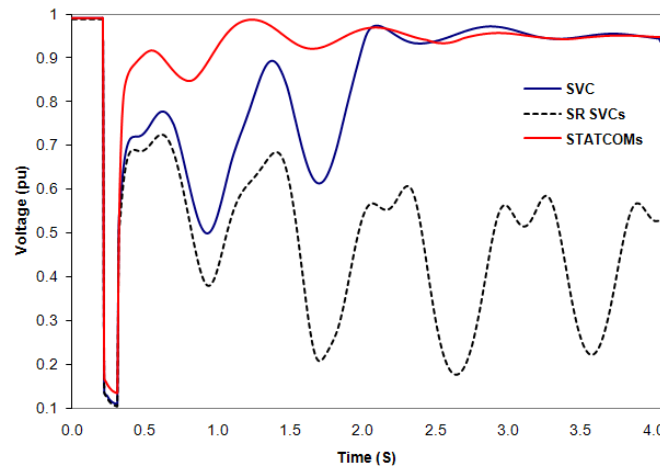


Fig. 13. Voltage profile at WKT 220 kV bus-bar during a 3-phase fault

Nowadays, STATCOMs are available in 4 Mvar size blocks, which makes it flexible for future expansion. Moreover, the dynamic over loading capability is another feature that enhances the STATCOMs performance during transient events.

Fig. 14 shows the power transfer to WKT with the connection of STATCOM only, with the connection of STATCOM and in the same time upgrading the 220 kV transmission line connecting WKT and MU to 275 kV and when the existing 220 kV transmission line is compensated using a series capacitor in addition to the connection of STATCOM. It can be shown from Fig. 14 that, upgrading the line with STATCOM will extend the maximum power transfer to WKT to 190 MW while series capacitor transmission line with STATCOM has better performance than the connection of STATCOM only after 120 MW power transfer to WKT.

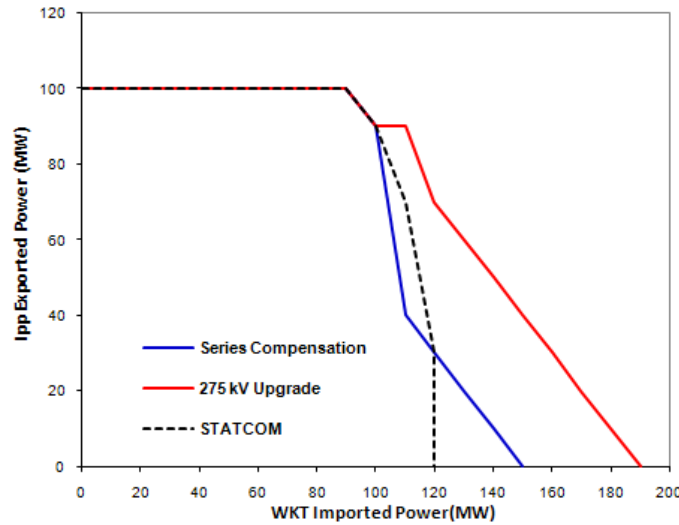


Fig. 14. TL Power transfer capability using series compensation and line upgrading

COST STUDY

Capital cost of all options discussed above is given in Table I [16].

Table I. CAPITAL COST FOR DIFFERENT OPTIONS

Option	AUD Million
TSVC	44
STATCOM	55
Series Compensation and STATCOM	66
220 kV Line Upgrade and STATCOM	459

Table I shows that TSVC option has the lowest capital cost. The cost of series compensation option does not include the additional cost that may be required to resolve the SSR and power quality issues that may arise due to series compensation. Upgrading the line has the highest capital cost as was expected due to the length of the transmission line (650 km). Although the capital cost of the STATCOMs option is higher than TSVC, STATCOM option remains preferable due to its better dynamic response as previously shown in Fig. 13.

CONCLUSIONS

This paper investigates various options to increase the power transfer to the EFG network in Western Australia. Options considered include the use of TSVC, use of STATCOM, using series capacitor compensation and upgrading the transmission line. Results show that both STATCOM and TSVC can increase the transmission line power transfer capability. However, STATCOM has better dynamic performance and can help in recovering system voltage faster than TSVC. This helps to shift the boundary points of the stability limits, as a result of that power transfer capability can be improved. Upgrading the existing line is not a cost effective solution. Although the cost of TSVCs is less than STATCOMs, STATCOMs option, however, remains preferable option due to its better dynamic performance during disturbance events.

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