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Investigation of Optimal Location for Series and Shunt Reactive Power Compensation in Distribution Network

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Abstract

Power system is growing massively with rapid increasing load demand by consumer. Load growth and contingency in power system cause an insufficient real power that leads to high-power losses. FACTS device is the latest power electronics controller by which power losses can be reduced and transfer capability can be enhanced. This study is to decide the best location to install these devices in considering to its cost installation which is it quite expensive. The main objective of this study is to determine the optimal location and sizing for TCSC and STATCOM by introducing Loss Sensitivity Factor as analytical method to minimize power losses in the system. Results have been obtained by determining the location of weak lines for TCSC integration and weak buses for STATCOM integration utilizing the proposed technique which aimed to improve overall system's losses in the benchmark system. The proposed approach has been implemented in IEEE 14 Bus test system which is modelled and simulated using DigSILENT PowerFactory 18. This proposed technique has shown a remarkable performance to keep the system at the lowest power losses in different given scenarios

Keywords; *STATCOM, TCSC, contingency, load growth*

I. INTRODUCTION

Power systems are more vulnerable to short-term voltage instability which also resulting in high power losses. It is considered that part of the reason for the North American blackout in August 2003 may be related to short-term voltage instability which is involve with the dynamics of fast acting load components and operating under more stressed situations due to the increasing load demands and electricity exchange between regions that lead to high power losses [1].

Power losses in distribution network have varying of factors depending on system configuration such as the level of losses through transmission and distribution lines. Power losses is happened due to two reasons; resistance of lines that causes the real power losses and reactive elements that causes the reactive power losses. Normally, real power loss draws more attention to the utilities because it reduces the efficiency of transmitting energy to users thus making reactive power flow the need to maintain at a certain level of amount for sufficient voltage level in the power system [2].

Load growth and contingency are two problems that maybe occur in the distribution network due to the demanding of the load use at that time and one of the

elements failed to operate which cause malfunction

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of the electrical system thus create high power losses. This significantly caused other elements such as generator, transmission line, substation, transformer and etc to operate closed to its stability limit which then leads cascading outage and major blackout.

In order to maintain the stability in the power system, reactive power needs to be considered as a required power to meet the balance in the electrical system and also reduce the power quality issue [3]. By introducing reactive power compensation in term to minimize power losses, Flexible Alternating Current Transmission System (FACTS) devices offer fast response in enlarging the safe operating limits of a transmission system without risking stability. This controller is a power electronic based device where the switching technology can be divided in three groups; mechanical switched, thyristor switched and fast switched (IGBT) and the configuration can be classified as shunt, series, series-series, shunt-series connections. [4].

A proper location and sizing of RPC is important to make sure that an adequate investment of this device in the system which helps to reduce the overall system losses, enhance voltage profile at each bus and improve the system voltage stability margin [5-6]. Thus, sensitivity analysis studies are crucial important to ensure that the RPC device is optimally placed at a location which help to mitigate all power system problems.

Numerous researches had been done in past literature to investigate the optimal location and sizing for series and shunt RPC in distribution network to evaluate the most severe buses and lines. These buses and lines are highlighted as the potential location of RPC integration which aimed to provide better performance and protect the network from malfunction with consideration of the cost installation. Most of the studies prefer FACTS device than capacitor bank as reactive power compensation to improve the performance of power system such as voltage stability, voltage profile and power losses under different scenario. This is because the FACTS device offers faster response and enlarge safe operating limits without risking the system. Study done by [7] proposes FACTS device as a medium during heavy load line occur where FACTS device is able to control the power flow in network, which then help to reduce the flow in heavily loaded line, thus increasing load ability and decreasing losses in the system. Under this study, Thyristor Controlled Series Capacitor (TCSC) sensitivity-based approach has been developed and the suitable location of FACTS has been proposed to improve the overall system

performance and reduce the congestion cost under several occasions.

Author in [8] presents method to determine the optimal location and setting the reactive power compensation using Harmony Search Algorithm (HSA). The study has been done in the modified IEEE 30 bus to evaluate optimal setting and location of Static Var Compensator (SVC) and TCSC. In this study, HSA have shown that it produces greater reduction in power loss and voltage deviation by implementing FACTS device and it performs better in finding better solution by accumulating faster response.

This paper presents the optimal location of Static Synchronous Compensator (STATCOM) for shunt compensation and TCSC for series compensation in IEEE 14 Bus System are proposed by employing the Loss Sensitivity Factor (LSF) method under several events. The whole system was modelled and tested using DigSILENT Power Factory 18 as simulation tool. Based on several analyses conducted, the severe lines and buses were identified and the most suitable locations for TCSC and STATCOM integration were proposed in this study which aimed to reduce the overall system losses.

II. RESEARCH METHODOLOGY

A. System description and modelling

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Based on Fig.1, the basic of IEEE 14 bus system that consist of 11 loads, 16 lines, 5 transformers, and 5 generators is shown. The basic configuration of STATCOM as shunt compensation as shown in Fig. 2 comes with DC source, Voltage Source Inverter and Transformer. For series compensation, the configuration of TSCS shown in Fig. 3 consist of three main components; compensating capacitor, bypass inductance and thyristor. The network and controllers were both modelled according to the technical parameters.

B. Loss Sensitivity Factor (bus)

Electrical power losses in distribution systems vary with numerous factors depending on system configuration such as level losses through transmission and distribution lines, transformers, capacitors, insulators, etc. The main objective power system was to ensure efficient power transfer from power supply to load centre as reliable and economical as possible. One of the common methods for analysing the overall power loss is Loss Sensitivity Factor. The line and bus that consist of high LSF value is selected as candidate for TCSC and STATCOM integration.

LSF is a static analysis which are used to approximately analyze the power losses problem. The index is formulated based on the principle of linearization of nonlinear, exact loss formula which determine the sensitivity of the system loss to the real or reactive power injection at any bus as shown in equation (1).

Extract Loss Formula:

$$P_{L,t} = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij} \left(P_{i,t} P_{j,t} + Q_{i,t} Q_{i,t} \right) + \beta_{ij} \left(Q_{i,t} P_{j,t} - P_{i,t} Q_{j,t} \right) \right] \quad (1)$$

Where,

$$\alpha_{ij} = \frac{R_{ij}}{V_{i,t} V_{j,t}} \cos\left(\delta_{i,t} - \delta_{j,t}\right), \beta_{ij} = \frac{R_{ij}}{V_{i,t} V_{j,t}} \sin\left(\delta_{i,t} - \delta_{j,t}\right)$$

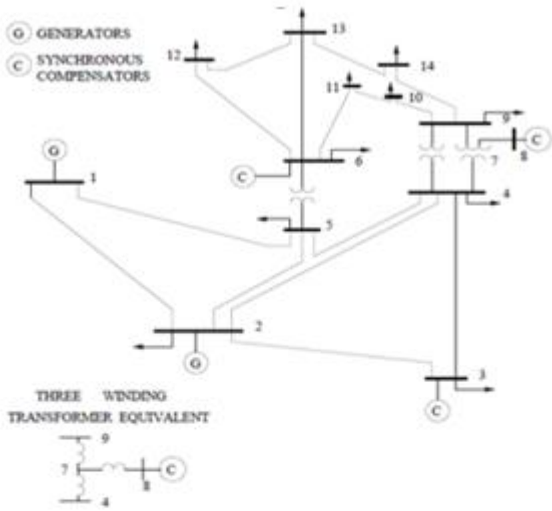

Fig. 1. Single line diagram of IEEE 14 bus system

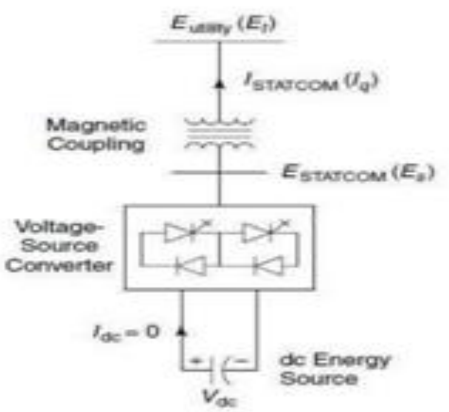

Fig. 2. Configuration of STATCOM

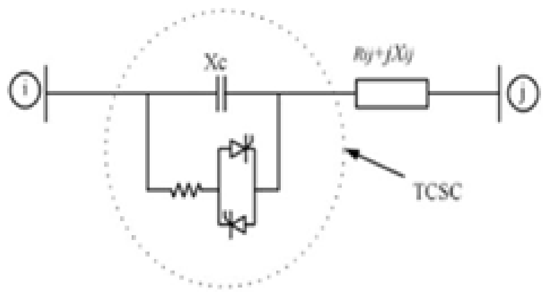

Fig. 3. Configuration of TCSC

R_{ij}, X_{ij} = the line resistance and reactance between bus i (sending end) and bus j (receiving end)

P_i, Q_i = real and reactive power at bus i (sending end)

P_j, Q_j = real and reactive power at bus j (receiving end)

$V_i \angle \delta_i$ = voltage and voltage phase at

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bus i (sending end)

$V_j\angle\delta_j$ = voltage and voltage phase at bus j (receiving end) The analytical expression of the exact loss formula with respect to reactive power injections at sending bus is formulated in equation (2). This index is employed to determine the candidate bus for STATCOM integration.

C. Loss Sensitivity Factor (line)

LSF line is employed in this study to determine the candidate line for TCSC integration. The index is formulated using the equation real and reactive power loss in transmission line as shown in equation (3) and (4).

$$P_{line\,loss}[j] = \frac{(P_j^2 + Q_j^2)R_{ij}}{(V_j)^2} \quad (3)$$

$$Q_{lineloss}[j] = \frac{(P_j^2 + Q_j^2)X_{ij}}{(V_j)^2} \quad (4)$$

LSF line can be given as,

$$\frac{\partial P_{lineloss}}{\partial Q} = \frac{(2 * Q_j * R_{ij})}{(V_j)^2} \quad (5)$$

$$\frac{\partial Q_{lineloss}}{\partial Q} = \frac{(2 * Q_j * X_{ij})}{(V_j)^2} \quad (6)$$

D. Case Study

Several case studies were proposed to evaluate the system's performance with TCSC and STATCOM integration in IEEE 14 Bus System in determining the optimal location and sizing in distribution network which aimed to minimize the power losses under load growth and contingency occurrence. Fig. 4 illustrates the flowchart of the proposed techniques to determine the optimal location of shunt and series compensation. The simulations were carried out in two different scenarios as follow.

a) Case 1 : Identification of Critical line and bus. Studies on the normal operation, load growth and line contingency in IEEE 14 bus system (without RPC Integration).

b) Case 2 : Identification of optimal placement of RPC under load growth occurrence

Considering loading factor (50% load growth) in IEEE 14 bus system by analysing the power flow and loss Sensitivity Factor (LSF) with TCSC and STATCOM integration.

c) Case 3 : Identification of optimal placement of RPC under line contingency occurrence

Considering line and transformer tripping in IEEE 14 bus system by analysing the power flow and Loss Sensitivity Factor (LSF) with TCSC and STATCOM integration.

III. RESULTS AND DISCUSSION

In this section, the simulation was conducted in three cases. The study was conducted using IEEE 14 Bus System

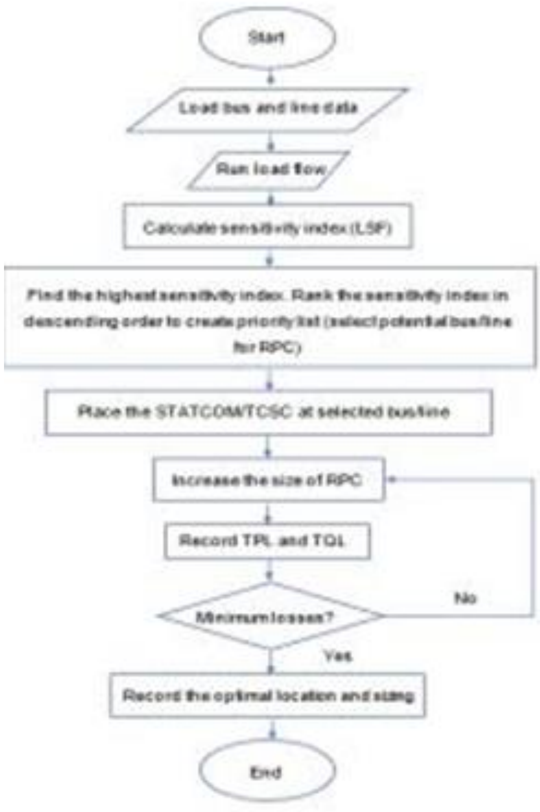

Fig. 4. Flowchart of proposed technique

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and simulated using DigSILENT PowerFactory 18. In Case 1, the base case study was conducted using analytical method by evaluating the performance of system under several occasions to in. In Case 2, the load growth study was conducted to evaluate the system's performance with RPC integration to propose the optimal location of RPC in distribution network using LSF. Next, Case 3 was conducted to determine the optimal location of RPC in distribution network using the same analytical approach.

A. Case 1: Base Case Study: Identification of Critical line and bus

In this case, three different events were conducted to evaluate performance of the benchmark test system under normal condition (base case), load growth occurrence (50% PQ loading) and line contingency occurrence. For load growth event, the PQ load was increased up to 50% on each of the load buses simultaneously. The reason for this case is to evaluate the condition of the existing network under future load growth occurrence as the peak demand is expected to be double from the current value in 2050 [9]. Next, the line contingency events were also tested in the network to predict the effect of line outage on the overall system losses. This event helps to identify the most severe lines and buses that will be the potential candidates for RPC integration.

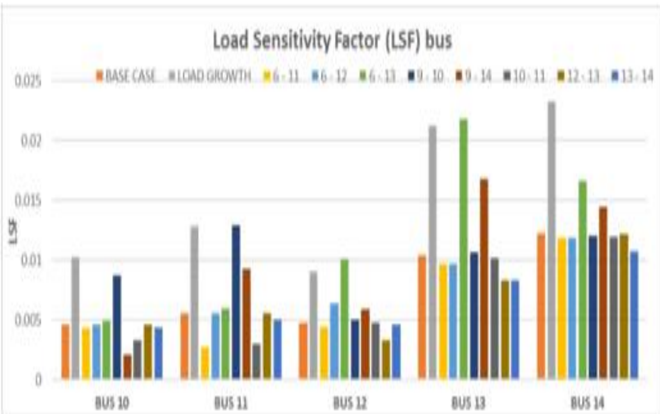

Fig. 5. LSF index of all distribution buses for IEEE 14 bus system under normal, load growth and line contingency conditions.

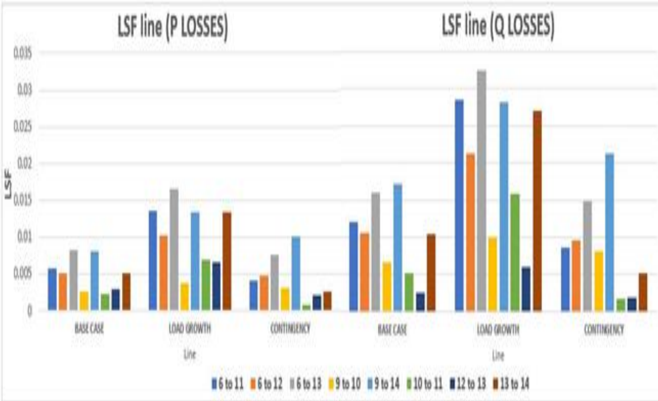

Fig. 6. LSF index (P and Q losses) of all distribution line for IEEE 14 bus system under normal, load growth and line contingency conditions.

A clear bar graph presentation illustrated in Fig. 5 is used for highlighting the three different occasions; normal condition (base case), 50% PQ loading and line contingencies at all distribution networks for LSF bus. Based on the results obtained for in all events, Bus 14 measures the highest index followed by Bus 13 and Bus 11. This clearly shows that Bus 14 is the most sensitive bus in the distribution network due to the location itself which is situated far from the main source. Next, by evaluating the index for all given scenarios, the most severe event is during the load growth occurrence as the index in all buses were appeared among the highest values. However, in term of the line severity, line 6 – 13 and 9 – 14 were appeared as the most critical lines in distribution network. This can be seen when these lines are temporarily disconnected due to fault occurrence or maintenance purposed, the neighboring buses were affected.

Similarly as for LSF line, the most severe event is during the load growth occurrence. Fig. 6 clearly shows that all lines in the distribution system provide the highest index for both real and reactive power losses during load growth event. By evaluating the index for each scenario, line 9 – 14 and 6 – 13 appear as the most severe lines, followed by line 13 – 14 and 6 – 11. It can be observed that the lines or buses which located at bus with the largest loads in distribution system; bus 9 and bus 14 are appeared as critical line and bus. Besides, line 9 - 14 and line 6 - 13 carry a large amount of real and reactive power flow thus significantly caused these two lines to contribute the highest amount of power losses. The critical buses from line 9 - 14 and line 13 – 14 which referred to Bus 14 have the highest power losses compared to Bus 13 and Bus 11 because the line to carry its power are far from the main source to the next source which then caused current to increase, real power and reactive power increase and eventually losses increase.

By evaluating the results in this case, an appropriate power system planning such as adding generating capacity and expanding or reinforcing the transmission facilities is essential especially for load growth event to ensure that electrical power transmitted from source to load side via the transmission network is reliable, secure and economical [10-11]. Installing reactive power compensation is much lower cost than building a new transmission line and with a proper location of RPC integration will additionally improve the system's performance especially in reducing the power loss. Therefore, the next case studies were proposed to investigate the optimal location of RPC under two different occasions.

B. Case 2: Load growth occurrence: Identification of optimal placement of RPC under load growth occurrence

Based on results in Case 1, Bus 14, Bus 13 and Bus 11 were the most sensitive buses while line 9 – 14, 6 – 13, 13 – 14 and 6 – 11 were the most severe lines in the distribution network by considering power losses. These buses and lines were highlighted as the suitable candidates for locations of RPC. Hence, this study is aimed to propose the most optimal location of STATCOM and TCSC with considering load growth occurrence (50% PQ loading).

Fig. 7 illustrates the results of LSF bus when STATCOM have been integrated at the selected critical bus under 50% load growth occurrence. Based on the results, Bus 14 appears as the most optimal location since the overall system losses had been reduced the most when STATCOM is located at this particular bus compared to other locations; Bus 13 and Bus 11. This is because the location of the bus itself is located far from the main source. By introducing reactive power compensation at this bus, the amount of reactive power which is imported from grid can be reduced as the nearest buses are able to receive the reactive power directly from STATCOM which this significantly helps to reduce the overall system losses. [5]

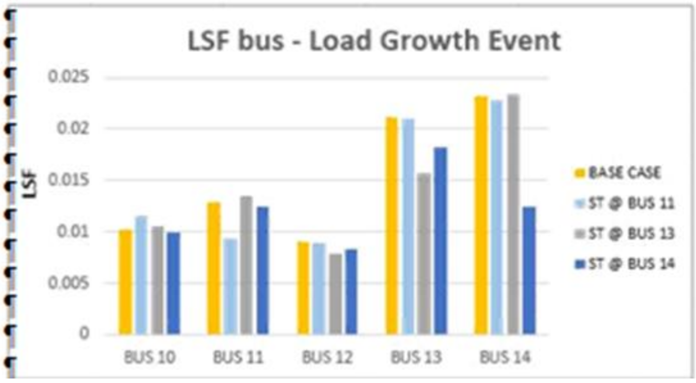

Fig. 7: LSF index of all distribution buses under load growth event with STATCOM integration.

Fig. 9 presents the results of LSF index with TCSC implementation at distribution lines under load growth event. For TCSC locations, line 9 – 14 and 13 – 14 appear as the optimal location for TCSC integration as both of real and reactive power losses were decreases in most distribution lines when TCSC is placed at these lines. However, in some cases, when TCSC is located at line 6 – 13, both of real and reactive power losses in line (line 6 -13, 12 – 13 and 9 – 14) were increased more than without TCSC integration. This is because these lines carry a large amount of real and reactive power flow and with the additional reactive power provided by TCSC significantly contribute the highest amount of power losses in these lines.

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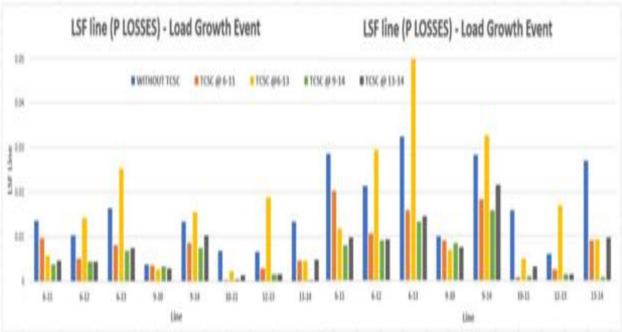

Fig. 8. LSF index (P and Q losses) of all distribution lines under load growth event with TCSC integration.

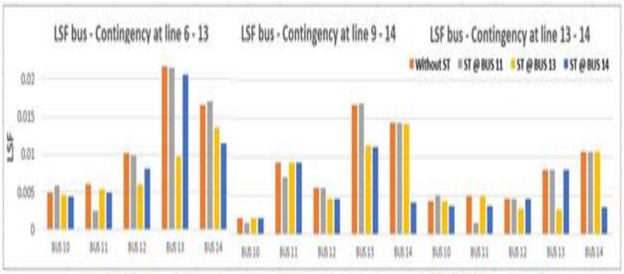

Fig. 9. LSF index of all distribution line under line contingency event with STATCOM integration.

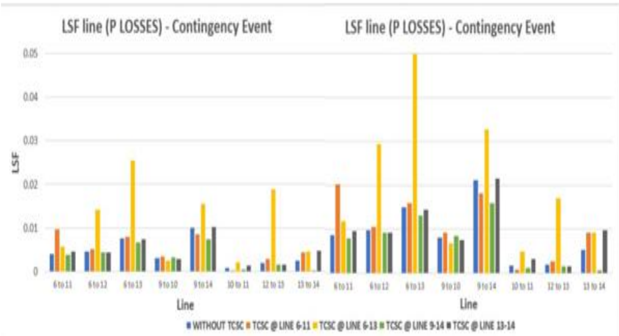

Fig. 10. LSF index (P and Q losses) of all distribution lines under contingency event with TCSC integration.

C. Case 3: Contingency occurrence: Identification of optimal placement of RPC under contingency occurrence

In this case, the study aimed to propose the method for optimal location of STATCOM and TCSC in distribution system similarly as done in Case 2 by considering contingency. As mentioned in Case 1, the most severity case is when contingency transformer 4 - 9. By considering line and transformer tripping event, the optimal location of STATCOM and TCSC were proposed which reduced the overall system losses. Fig. 9 presents the result of LSF bus when STATCOM have been integrated at the candidate bus under several line contingencies occurrence. The candidate buses; Bus 11, Bus 13 and Bus 14 and the severity lines for contingency study; line 9 – 14, 13 – 14 and 6 – 13 were nominated in Case 1.

In all contingency events, when line 6 – 13, 9 – 14 and 13 - 14 was disconnected, Bus 14 is the most optimal location for STATCOM as the reduction of overall system

losses is the highest compared to other locations, followed by Bus 13 and Bus 11. This is again due to the distance of bus itself which is located far from the main source as the load connected at this bus is one the largest load in distribution network. Hence, power travel from main source to Bus 14 is higher compared to other neighboring buses that caused higher overall system losses. By reducing the amount of reactive power travel to this bus, it significantly reduces the power losses. In few cases, the indices for case with STATCOM integration were higher than without STATCOM as shown in Fig. 9 due to inappropriate sizing of 3MVAR STATCOM which is too large to be carried in lines which increase power losses in lines.

Fig. 10 illustrates the results of LSF index with TCSC integration at distribution lines under contingency event. The results clearly show that the line 9 – 14 is the most optimal location for TCSC integration due to both of real and reactive power losses were recorded the lowest, followed by line 13 – 14 and 6 – 13. This shows the overall system losses are reduced compared to without TCSC integration. However, in some cases, when TCSC is located at certain lines, both of real and reactive power losses in line were increased higher than without TCSC integration. This is because these lines carry a large amount of real and reactive power flow and with the additional reactive power

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provided by TCSC significantly contribute the highest amount of power losses in these lines as described in pervious case.

V. CONCLUSION

This paper proposes an approach for optimal location of RPC in power system network which aimed to minimize the real and reactive power losses in distribution network. In order to determine the appropriate locations of series and shunt RPC using TCSC and STATCOM, an analytical approach using Loss Sensitivity Factor had been implemented in this study by considering the impact of load growth and contingency events. Both events provide the same results whereby Bus 14 is the most optimal bus for STATCOM and line 9 – 14 is the most optimal line for TCSC integration. The implementation of STATCOM at bus and TCSC at line were successfully modelled and integrated in the IEEE 14 bus test system using DigSILENT Power Factory 18. In order to reduce the overall system losses effectively, the optimal sizing of RPC should be adopted in future works to ensure an adequate sizing of STATCOM and TCSC are injected to the network.

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