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Reduction of Technical Losses in the National Grid of Sudan Transmission Lines (500KV) Using Static Var Compensator (SVC)

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Abstract: One of the most serious problems in power system is voltage instability and losses. Improving the systems reactive power handling capacity via Flexible AC Transmission system (FACTS) devices is a remedy for prevention of voltage. This paper discusses the use of static var compensators (SVC) for reducing the total losses of a power system. National Grid of Sudan (NGS) transmission lines-500KV is used as case study. Solutions are obtained using Neplan software. The results show that the total losses is about 25.447 MW, which is reduced to 21.551 MW by installing static var compensator in main bus bar of kabashi.

Keywords: Voltage Instability, SVC, technical losses, FACTS.

1. INTRODUCTION

Transmission line losses include conductor losses, radiation losses, dielectric heating losses, coupling losses and corona Conductor losses. They are due to current flows through a transmission line, which has a finite resistance causing the power loss. This is sometimes called conductor loss or conductor heating loss and is simply a power loss .To reduce conductor loss a larger diameter wire is used. Conductor loss depends somewhat on frequency because of a phenomenon called the skin effect. The skin effect is the tendency of an alternating electric current (AC) to distribute itself within a conductor so that the current density near the surface of the conductor is greater than that at its core. A substantial amount of energy is lost in the Transmission and distribution systems, which is well known as Technical and Non-Technical losses.

FACTS devices can be effectively used for power flow control, enhancement of transient stability and mitigation of the system oscillation by giving additional flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating. It employs high speed thyristors for switching in or out transmission line components such as capacitors, reactors or phase shifting transformer for some desirable performance of the systems [1].

2. TECHNICAL LOSSES

Technical losses in power systems are naturally occurring losses, which are caused by actions internal to the power system and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers and measurement systems. Technical losses can involve degrees of turbine efficiency in generation, together with substation, transformer, and line related losses. The most common examples of technical losses include the power dissipated in transmission lines and transformers due to their internal electrical resistance.

These losses are calculated based on the natural properties of components in the power system, which include resistance, reactance, capacitance, voltage, and current. Loads are not included in technical losses because they are actually intended to receive as much energy as possible. Technical losses include resistive losses in the primary feeders (I^2R), distribution transformer losses (resistive losses in windings and core losses), resistive losses in secondary networks, resistive losses in service drops, and losses in kWh metering. Technical losses result from equipment inefficiency, the inherent characteristics of the materials used in the lines and equipment, and the sizes of lines and equipment. The three major contributors are the current squared losses through a resistance, transformer excitation losses, and line and insulation corona or leakage losses [4].

The losses incurred in resistance materials can be reduced by adopting the following means:
1- Reducing the current.
2-.Reducing the resistance and the impedance.
3- Minimizing voltage

Electrical power system losses can be computed using several formulas in consideration of pattern of generation and loads, using one of the following methods:
- Computing transmission losses asI^2R

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- Differential power loss method
- Computing line flows and line losses
- Analyzing system parameters
- Load flow simulation.

3. TECHNICAL LOSSES CALCULATION

Technical losses CAN be simply calculated using load flow method of power system.

3-1 Load Flow Analysis:-

Power flow studies, commonly known as load flow, are an important part of power system analysis. They are necessary for planning, economic scheduling, and control of an existing system as well as planning its future expansion.

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily selected bus that has a generator. This bus is referred to as the Slack Bus.

In the power flow problem, it is assumed that the real power and reactive power at each load bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real power generated and the voltage magnitude |V| is known. For the Slack Bus, it is assumed that the voltage magnitude |V| and voltage phase θ are known. Therefore, for each Load Bus, the voltage magnitude and angle are unknown and must be solved for; for each Generator Bus, the voltage angle must be solved for; there are no variables that must be solved for the Slack Bus. In a system with N buses and R generators, there are then 2(N − 1) − (R − 1) unknowns.

In order to solve for the 2(N − 1) − (R − 1) unknowns, there must be 2(N− 1) − (R − 1) equations that do not introduce any new unknown variables. The possible equations to use are power balance equations, which can be written for real and reactive power for each bus. Equations included are the real and reactive power balance equations for each Load Bus and the real power balance equation for each Generator Bus. Only the real power balance equation is written for a Generator Bus because the net reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the Slack Bus [4].

3-2 Power Flow Equation:

Consider a typical bus of a power system network as shown in figure (1).

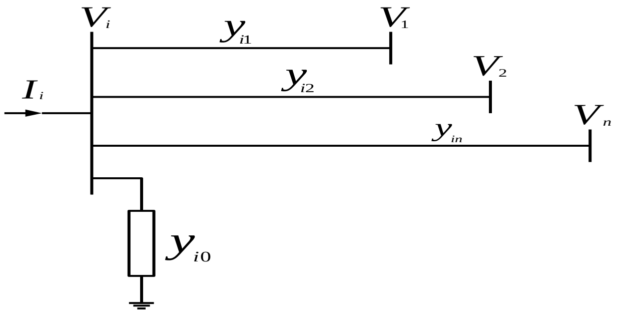

Figure (1) a typical bus of the power system

Transmission lines are represented by their equivalent π models where impedances have been converted to per unit admittances on a common MVA base. Application of KCL to this bus results in.

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{\substack{j=1 \\ j\neq i}}^{n} y_{ij} V_j \qquad (3.1)$$

Where
V_i = voltage at bus i.
I_i= current for bus i.
V_j = voltage at bus j.
y_{ij} = per unit admittances between bus i and j.
The active and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^* \qquad (3.2)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (3.3)$$

Substituting for I_i in (3-2) yield

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=1}^{n} y_{ij} - \sum_{\substack{j=1 \\ j\neq i}} y_{ij} V_j \qquad (3.4)$$

From the above relation, the mathematical formulation of the power flow problem results in a system of algebraic nonlinear equations which must be solved by iterative techniques. [5].

4. STATIC VAR COMPENSATOR (SVC)

The SVC today is considered a very mature technology, which has been used for reactive power compensation since the 1970s. A SVC is a shunt connected FACTS device whose output can be adjusted to exchange either capacitive or inductive currents to the connected system. This current is controlled to regulate specific parameters of the electrical power system [2].

The thyristor has been an integral part in realizing the SVC and to enable control of its reactive power flow. It is used either as a switch or as a continuously controlled valve by controlling the firing angle. It should be noted that the SVC current will contain some harmonic content, something that needs attention in the design process [2].

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5. SVC MODELING

SVC is a Shunt FACTS device which is considered a variable impedance type device. The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Figure (2), which consists of a fixed Capacitor (C) and a thyristor-controlled reactor (L). The firing angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system [3].

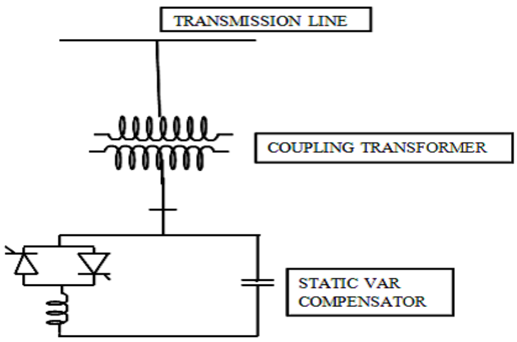

Figure (2) SVC connected to a transmission line

$$I_{SVC} = j\, B_{SVC}\, V_m \qquad (5\text{-}1)$$

The reactive power injected at bus m is

$$Q_{SVC} = Q_m = I_{SVC} V_m = -V_m^2 B_{SVC} \qquad (5.2)$$

Where

$$B_{SCC} = \frac{1}{X_L X_C} \frac{X_L - X_C}{\Pi} \begin{bmatrix} 2(\Pi - \alpha_{SVC}) \\ + \sin \alpha_{SVC} \end{bmatrix} \quad (5\text{-}3)$$

A Jacobian matrix for the SVC is given by the following equation:

$$\begin{bmatrix} \Delta P_m \\ \Delta P_k \\ \Delta Q_m \\ \Delta Q_k \end{bmatrix} = \begin{bmatrix} \frac{\partial P_m}{\partial \delta_m} & \frac{\partial P_m}{\partial \delta_k} & 0 & V_k \frac{\partial P_m}{\partial V_K} \\ \frac{\partial P_k}{\partial \delta_m} & \frac{\partial P_k}{\partial \delta_k} & 0 & V_k \frac{\partial P_k}{\partial V_K} \\ \frac{\partial Q_m}{\partial \delta_m} & \frac{\partial Q_m}{\partial \delta_k} & \frac{\partial Q_m}{\partial \alpha_{svc}} & V_k \frac{\partial Q_m}{\partial V_K} \\ \frac{\partial Q_k}{\partial \delta_m} & \frac{\partial Q_k}{\partial \delta_k} & 0 & V_k \frac{\partial Q_n}{\partial V_K} \end{bmatrix} \begin{bmatrix} \Delta \delta_m \\ \Delta \delta_k \\ \Delta \alpha_{svc} \\ \frac{\Delta |V_k|}{|V_k|} \end{bmatrix} \quad (5\text{-}4)$$

Where;

$$\frac{\partial Q_m}{\partial \alpha_{svc}} = \frac{2V_k^2}{\pi X_L} [\cos(2\alpha_{svc}) - 1] \qquad (5\text{-}5)$$

$\Delta\alpha_{svc}$ is found from inversion of the Jacobian matrix. The variable is then updated by the following equation:

$$\alpha_{svc}{}^{n+1} = \alpha_{svc}{}^{n} + \Delta\alpha_{svc}{}^{n} \qquad (5\text{-}6)$$

The control strategy of SVC is considered as:

$$B_{SVC} = \begin{bmatrix} B_{svc}^{MAX}, if\, \omega \geq -\beta\omega_{max} & : during\ the\ first\ swing \\ K\omega, B_{svc}^{Min} \leq K\omega \leq B_{svc}^{MAX} & : IN\ Sub\ sequent\ swing \end{bmatrix}$$

Were ω_{max} is the maximum speed of the machine and it is usually at fault clearing and β is a small positive constant. K is a positive gain and its value depends on SVC rating [3].

6. NGS TRANSMISSION LINES-500KV (CASE STUDY)

NGS Transmission lines-500kv that used throughout the study are shown in table (1) below and in the single line diagram in figure (3):

Table (1): NGS Transmission lines-500kv

Name	Length **km**	R (1) **Ohm / km**	X (1) **Ohm/ km**	C (1) **uF/km**
Marwi-Mrkhiat 1	345	0.028	0.276	0.013079
Marwi-Mrkhiat 2	345	0.028	0.276	0.013079
Mrkhiat-Kabashi	36.8	0.03	0.276	1.3083e-005
Marwi-Atbra	236.7	0.028	0.276	0.013079

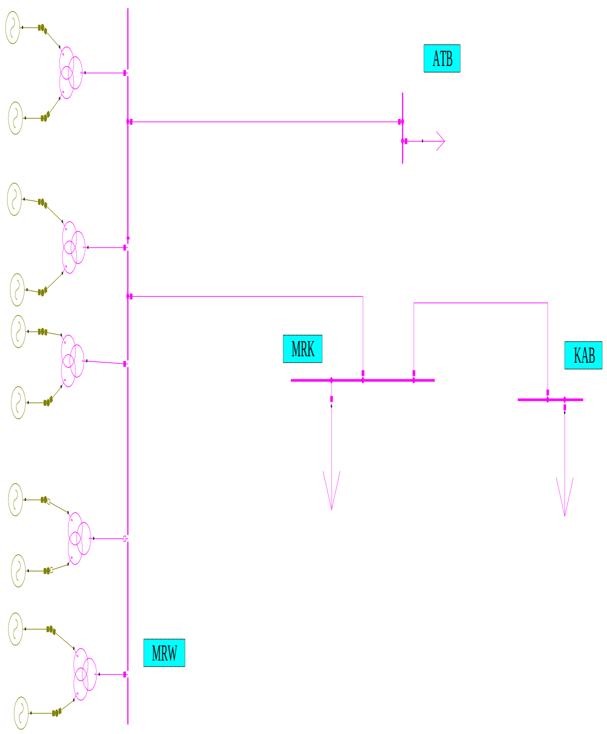

Figure (3): Single line diagram Sudan transmission line - 500KV test system

7. SIMULATION RESULTS

Simulation for the case study is done using NEPLAN software with loading point (λ) equal 1.2 the total connected load. The total losses for the active and reactive power are calculated without SVC and with it. The results are obtained by installing SVC in two different places (Kabashi busbar and Markhiat busbar) as shown in tables 2 and 3. The results show SVC can be used to minimize the transmission losses.

Table (2): Active and Reactive Power Losses before & after installing SVC at Kabashi busbar

From bus	To bus	Without SVC		With SVC	
		P_{Loss} MW	**Q_{Loss} MVar**	**P_{Loss} MW**	**Q_{Loss} MVar**
Marwi	Markhiat1	11.353	-219.358	9.563	-266.926
Marwi	Markhiat2	11.353	-219.358	9.563	-266.926
Markhiat	Kabashi	0.687	6.739	0.487	4.760
Marwi	Atbara	2.054	-216.054	1.938	-230.787

Table (3): Active and Reactive Power Losses before & after installing SVC at Markhiat busbar

From bus	To bus	Without SVC		With SVC	
		P_{Loss} MW	**Q_{Loss} MVar**	**P_{Loss} MW**	**Q_{Loss} MVar**
Marwi	Markhiat1	11.353	-219.358	9.727	-262.005
Marwi	Markhiat2	11.353	-219.358	9.727	-262.005
Markhiat	Kabashi	0.687	6.739	0.613	6.005
Marwi	Atbara	2.054	-216.054	1.950	-229.185

SVC injects 90.392 MVAr to kabashi busbar in order to reduce losses from 25.447 to 21.551, Where SVC injects 91.409MVAr to markhiat busbar in order to reduce losses from 25.447 to 22.017.

8. CONCLUSION

This paper discusses the use of SVC to reduce the transmission lines technical losses. Application of SVC to NGS Transmission lines-500kv presents that the best result is obtained by installing SVC in kabashi busbar. Where the real power loss is reduced from 25.447 to 21.551 and Reactive power loss is reduced from -648.031 MVAr to -759.879 MVAr. In general the losses are reduced by 2.3% with SVC. To get good results the optimum placement of SVC is of great importance.

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