Minimizing Power Losses and Enhancing Voltage Profile of a Multi-machine Power Network using Static Synchronous Compensator (STATCOM) Device

Mbunwe Muncho Josephine, Nwohu Mark Ndubuka and Madueme Victory Chukwuemeka, *Member, IAENG*

Abstract— **This paper discusses a comprehensive review on enhancement of power system stability in multi machine power system network. Modern restructured power systems sometimes operate with heavily loaded lines resulting in power losses and higher voltage deviation, which may lead to mal operation of power system and eventual collapse of the system. It is mainly due to continuous and uncertain growth in demand for electrical power. This paper presents a methodology to solve voltage problem at optimally sited Static Synchronous Compensator (STATCOM) device in order to minimize real power loss (RPL) and to enhance bus voltage profiles. The effectiveness of the proposed method is demonstrated on a 3-machine 9-bus system.**

Index Terms—**STATCOM, Power System losses, Stability, FACTS devices, Transmission lines.**

I. INTRODUCTION

Frequent electrical power outage has been a source of complaints by electricity consumers in some developing countries. This has inevitably led to huge capital investment by large consumers in alternative power standby sources and financial losses to the power industry for energy not supplied. This situation has therefore called for a comprehensive analysis to evaluate the current power system performance and to investigate the effectiveness of new devices for system reliability and stability enhancements.

Flexible Alternating Current Transmission Systems or FACTS as they are generally known are such new devices emanating from recent innovative technologies that promise to enhance the security, capacity and flexibility of existing power transmission systems while maintaining the operating margins necessary for grid stability. FACTS devices are used for the dynamic control of voltage, impedance and phase angle of high voltage ac transmission lines [1].
As a result, more power can reach consumers with a minimal impact on the environment and at a lower investment cost when compared to the alternatives of building new transmission lines or power generation facilities.
However, the use of FACTS devices does not eliminate the occurrence of faults in power systems; rather it has the ability to stabilize the remaining and healthy part of the system while the faulty part is rapidly disconnected. But our focus is on the use of Static Synchronous Compensator (STATCOM) as type of FACTS employed on transmission system to enhance the bus voltage profiles and minimize losses on the transmission lines [2]. Basically, STATCOM is a voltage sourced converter which is connected in shunt with the transmission line through a shunt transformer. It is voltage favourable and generates full capacitive output at low voltage [3].

Many studies have been carried out and reported in literature on the use of STATCOM in improving voltage and transient, stability [4-6]. In his study, [7] discussed the effect of STATCOM on Voltage Stability and evaluated Voltage Stability by Saddle-Node Bifurcation Analysis. Also, Static Voltage Stability Margin Enhancement using STATCOM, TCSC and SSSC is compared [8]. The effectiveness of the STATCOM to control the power system voltage was presented by [9]. However, much has not been reported on minimizing losses on transmission line and enhancing the bus voltage profiles of a power system. Therefore, this paper investigates the possible and effective means of minimizing power losses on transmission line and enhancing the bus voltage profiles of any chosen case study by use of STATCOM. This research work is subdivided into the following: (II) Mathematical modeling of STATCOM and its control system, (III) Proposed approach and case study, (IV) Simulation, results and discussion of results (V) Conclusion.

II. MATHEMATICAL MODELING OF STATCOM AND ITS CONTROL SYSTEM

The Static Synchronous Compensator (STATCOM) [10] is a shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system.
The STATCOM basically consists of a step-down transformer with a leakage reactance, a three-phase GTO or IGBT voltage source inverter (VSI), and a DC capacitor. The AC

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M. J. Mbunwe is with the Department of Electrical Engineering, University of Nigeria, Nsukka. (+2348036675952; e-mail: mamajoe12001@yahoo.com).
M. N. Nwohu is with Federal University of Technology, Minna, Nigeria, as a Lecturer in the Department of Electrical Engineering. He is currently on sabbatical leave with University of Nigeria, Nsukka (e-mail: mnnwohu@futminna.edu.ng).
V. C. Madueme is with the Department of Electrical Engineering, University of Nigeria, Nsukka. (e-mail: victory.madueme@unn.edu.ng).

voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, such that the AC voltage at the bus bar can be regulated to improve the voltage profile of the power system, which is the primary duty of the STATCOM.

The basic structure of a STATCOM with PWM-based voltage controls is depicted in Figure 1 (Canizares, 2000). Eliminating the dc voltage control loop on this figure would yield the basic block diagram of a controller with typical phase angle controls.

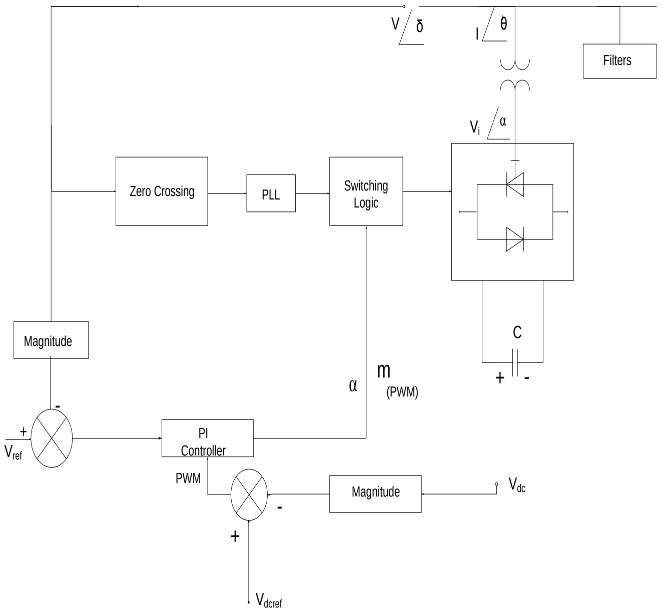

Fig 1. Block diagram of a STATCOM with PWM voltage control

Assuming balanced fundamental frequency voltages, the controller can be accurately represented in transient stability studies using the basic model shown in Figure 2 (Uzunovic, et al, 1997; Canizares, et al, 1998; Koseterev, 1997).

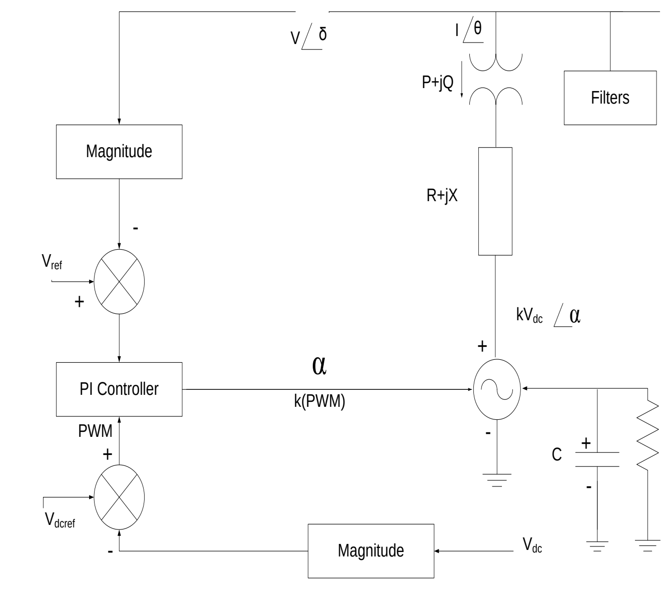

Fig 2. Transient stability model of a STATCOM with PWM voltage control

The per-unit differential- algebraic equations corresponding to this model are:

$$\begin{bmatrix} \dot{x}_c \\ \dot{\alpha} \\ \dot{m} \end{bmatrix} = f\left(x_c, \alpha, m, V, V_{dc} V_{ref}, V_{dc_{ref}}\right) \qquad (1)$$

$$\dot{V}_{dc} = \frac{VI}{CV_{dc}}\cos(\delta - \theta) - \frac{1}{R_c C} V_{dc} - \frac{RI^2}{CV_{dc}} \qquad (2)$$

$$0 = \begin{bmatrix} P - VIcos(\delta - \theta) \\ Q - VIsin(\delta - \theta) \\ P - V^2 G + kV_{dc}VGcos(\delta - \alpha) + kV_{dc}VBsin(\delta - \alpha) \\ Q - V^2 B + kV_{dc}VBcos(\delta - \alpha) + kV_{dc}VGsin(\delta - \alpha) \end{bmatrix}$$

$$0 = g(\alpha, k, V, V_{dc}, \delta, I, \theta, P, Q) \qquad (3)$$

Where the admittance $G + jB = (R + jX)^{-1}$ is used to represent the transformer impedance, any ac series filters, and the "switching inertia" of the inverter due to its high frequency switching. The constant $k = \sqrt{3/8}\, m$, is directly proportional to the pulse width modulation index m and x_c represents the internal control system variables.

The ac bus voltage magnitude is controlled through the modulation index m, since this has a direct effect on the ac side voltage source inverter (VSI) voltage magnitude. But the phase angle, α which basically determines the active power P flowing into the controller is used to directly control the dc voltage magnitude since the power flowing into the controller charges and discharges the capacitor. The controller limits are defined in terms of the controller current limits which are directly related to the switching device current limits, as these are the basic limiting factor in VSI-based controllers. In simulations, these limits can be directly defined in terms of the maximum and minimum converter currents, I_{max} (I_{Lmax}) and I_{min} (I_{Cmax}) respectively.

However, the steady state model can be obtained from equation (1) by replacing the differential equations with the steady state equations of the dc voltage and the voltage control characteristics of the STATCOM, thus,

$$0 = \begin{bmatrix} V - V_{ref} + X_{SL} I \\ V_{dc} - V_{dc_{ref}} \\ P - V_{dc}^2 / R_c - RI^2 \\ g(\alpha, k, V, V_{dc}, \delta, I, \theta, P, Q) \end{bmatrix} \qquad (4)$$

So, a phase control technique can be readily modeled by simply replacing the dc voltage control equation in (4) with an equation for k that is, 0 = [k – 0.9]. In this case, the dc voltage changes as α change, thus charging and discharging the capacitor to control the inverter voltage magnitude.

The voltage sourced converter technology using power transistors (IGBTs) operates at a frequency in the kHz range,

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giving possibilities to implement advanced algorithms in the control system. A comparison with Static Var Compensator yields that the capacitors and reactors are replaced with intelligent switching of semiconductors and can generate full capacitive output at low voltage [11]. By connecting DC capacitors on one side of the converter, the STATCOM is able to vary its output with respect to magnitude, frequency and phase angle, thus providing voltage and transient stability.

III. PROPOSED APPROACH AND CASE STUDY

Several methods have been developed for decision on optimal placement of STATCOM [7- 8, 12-16]. But a simple heuristic approach was adopted to determine the optimal location of STATCOM on the basis of the line with maximum reactive power losses. The 3-machine 9-bus Power Test System is modeled in PSAT environment and simulation is carried out under two scenarios: at the base case and inclusion of STATCOM in the case study. The One-Line Diagram of the Test System is shown in the figure 3.

IV. SIMULATION, RESULTS AND DISCUSSION OF RESULTS

The 3-machine 9-bus power system network was simulated in PSAT environment with fault initiated at bus 4 at 3seconds which was subsequently cleared at 3.25seconds. The simulation was carried out in two scenarios, viz, when the system was at its base and when STATCOM was connected to the system. The Power Flow study converged in 0.31sec with FACTS as compared to 0.39sec without FACTS. The results obtained at the system load flow indicated drastic reduction of transmission losses when properly tuned STATCOM was connected to the system as compared to its base case. The 3-machine 9–bus System total loss before placement was 4.71MW, 92.16MVar, and with FACTS Device in place, it was 4.21MW, 93.85MVar. Therefore, the total reduction in losses was 0.49MW and 1.69MVar. Furthermore, the voltage profiles of buses were greatly enhanced (see Table 1 and Figure 4).

TABLE I
VOLTAGES ON BUSES

No. of Buses	VOLTAGES WITHOUT STATCOM	Voltages with STATCOM
1	1.04	1.154
2	1.025	1.121
3	1.025	1.125
4	1.0258	1.127
5	0.99363	0.99998
6	1.0127	1.1147
7	1.0258	1.0297
8	1.019	1.085
9	1.0324	1.0455

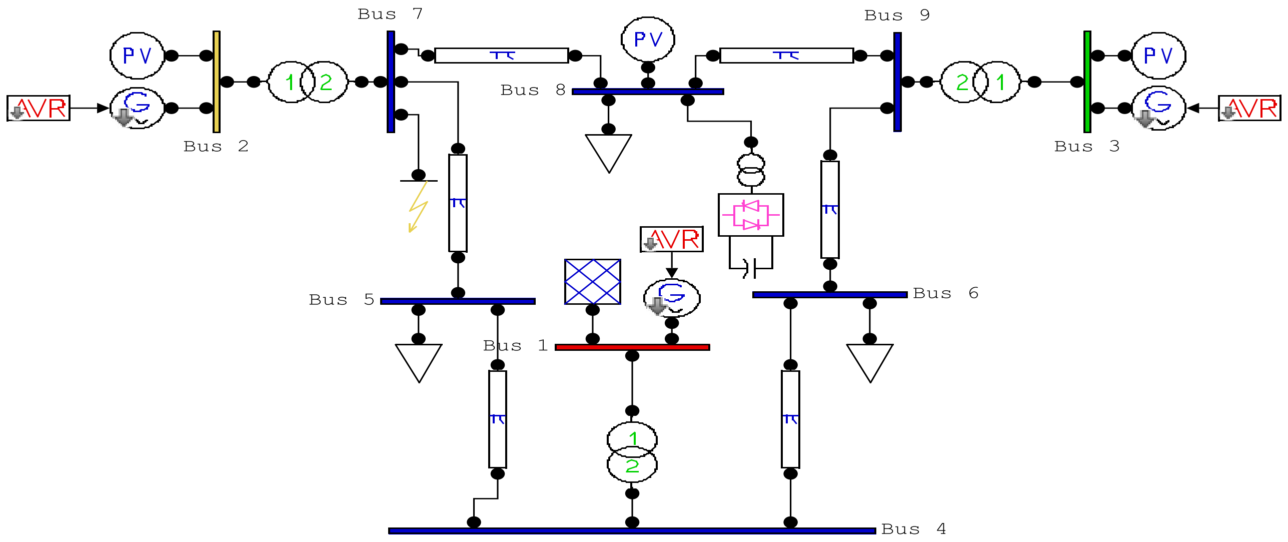

Fig 3. PSAT representation of 3-machine 9-bus power system network

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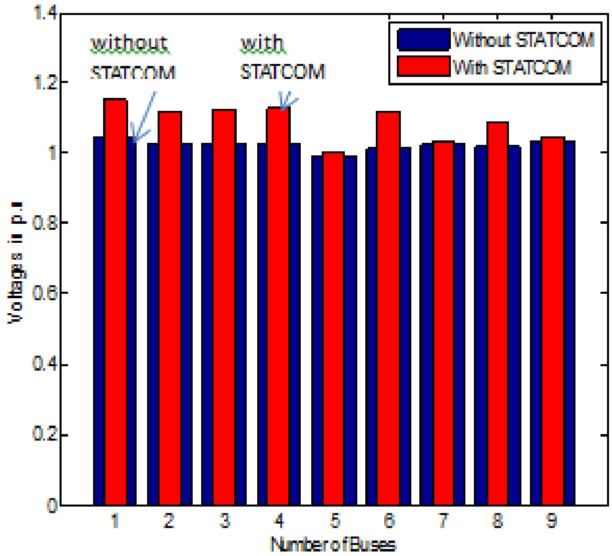

Fig 4. The system voltages with and without STATCOM

The graphs of the Losses versus Line Numbers of 3-machine 9–bus power system are depicted in Figures 5 and 6 as well as Tables 2 and 3.

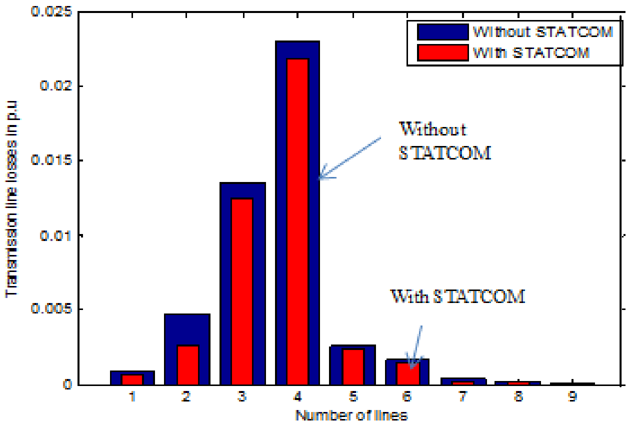

Fig 5. Real power losses on transmission lines with and without STATCOM

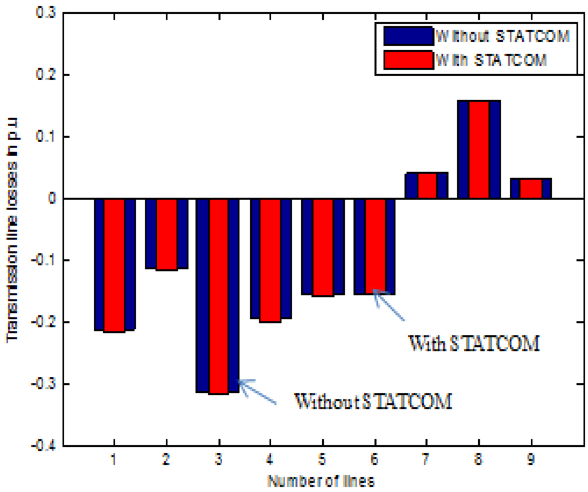

Fig 6. Reactive power losses on transmission lines with and without STATCOM

TABLE II
REAL POWER LOSSES ON TRANSMISSION LINES

Transmission line/No of Buses	Real Power losses WITHOUT STATCOM	Real Power losses with STATCOM
3-9/1	0.00088	0.00072
2-7/2	0.00475	0.00268
9-6/3	0.01354	0.01248
7-5/4	0.02300	0.02187
5-4/5	0.00258	0.00239
1-4/6	0.00166	0.00153
7-8/7	0.00040	0.00020
9-8/8	0.00020	0.00016
6-4/9	0.00010	0.00009

TABLE III
REACTIVE LOSSES ON TRANSMISSION LINES

Transmission line/No of Buses	Reactive losses WITHOUT STATCOM	Reactive losses with STATCOM
3-9/1	-0.21176	-0.21673
2-7/2	-0.11502	-0.11764
9-6/3	-0.31531	-0.31847
7-5/4	-0.19694	-0.19954
5-4/5	-0.15794	-0.15969
1-4/6	-0.15513	-0.15683
7-8/7	0.04096	0.04179
9-8/8	0.15832	0.15805
6-4/9	0.03123	0.03057

V. Conclusion

This paper established the uncommon effect of STATCOM on the transmission line of the power network that consequently reduced the transmission line losses and computational time at which the power flow converged. Moreover, almost all the bus voltages are enhanced as empirically determined. Thus, with the optimally located STATCOM device on the 3-machine 9-bus Power System, good results by way of reducing computation time, improving voltage profiles of the buses and losses reduction on the transmission lines were achieved.

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