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Placement of Multiple Svc on Nigerian Grid System for Steady State Operational Enhancement

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ABSTRACT: *Electric power consumption is on the increase due to ever growing power requirements of domestic and industrial loads. This has caused transmission lines to be driven close to or even beyond their transfer capacities resulting in equipment overload, network congestions and unprecedented power outages. The emerging Flexible AC Transmission Systems (FACTS) devices provide technical possibilities to address these problems by controlling power flows and voltages. In order to minimize the capital investment cost of these devices whilst maximizing their enhancement capabilities with respect to the existing facilities, optimal placement of these devices is imperative. This has continued to attract research interests in most developed power systems globally. This work presents comprehensive investigations carried out on the optimal location of static var compensators (SVCs) in a transmission network in order to improve its loading margin from different perspectives. More specifically, various scenarios are formulated as a mixed integer programming problem aimed at placing multiple SVCs optimally in a given network topology to maximize their steady performances in a network. Given the non-linear nature of the problem, an interior point method has been implemented in tandem with mixed integer linear programming software (CPLEX) to efficiently solve the associated optimal power flow problem. Detailed numerical simulations on Nigeria national grid system are used as test systems to demonstrate the effectiveness of the proposed solution methodology.*

I. INTRODUCTION

The evolution of power system began at the end of 19 century when the first generations of transmission lines were constructed [1]. Over the years, the system has grown with numerous generators and loads connected to them due to ever growing increase in consumption. The need to transmit large amount of power over long distances is a necessity due the disperse nature of load centres which must be melt by increasing the voltage levels of the power lines. In addition, in other to enable exchanges between difference utilities and to improve security, neighboring systems were connected. However, power systems are the product of a long lasting building process resulting in very large, complex system and very expensive process [2].

Power outages usually affect the everyday activities and can also paralyze the entire nation moreover extensive failures cause serious economic losses. Therefore operation of power system cannot be over emphasized as this is the key to any national growth [3].

Over the years the electric energy demands increases continuously leading to additional stress on the transmission system and higher risk of power outages also, electric power trades across borders have increased due to the power system liberalization of electricity market [4]. These results in exchanging of load flow patterns require a transmission grid system which is capable of handling this daily modification in power generation and load distribution. In several areas the grid is not able to meet this demand any longer and as a result some lines are even driven close to or even beyond their limit. But the extension of the system require to further guarantee secure transmission is difficult for environmental and political reason, a promising, excellent and competitive alternative option is the use of FACTs devices [1] these devices are capable of influencing power flows and voltages thereby providing the possibility of enhancing the security of the system.

In other to have the maximum benefit from these devices there control setting and proper location in the system have to be chosen appropriately, in most cases the determination of these values are cumbersome.

The aim of this work is focused on the optimization and enhancements of steady state power system operational performances secured via distributed application of optimally sited and rated FACTS devices.

II. REVIEW OF FACTs DEVICES

2.1 Series FACTS devices

Series FACTS devices could be variable impedance, such as capacitor, reactor, etc., or power electronics based variable source of main frequency, sub-synchronous and harmonic frequencies (or a combination) to serve the desired [5]. In principle, all series FACTS devices inject voltage in series with the transmission line. An example of this type of FACTS device is Thyristor Controlled Series Capacitor (TCSC) amongst others.

2.2 Shunt FACTS devices

Shunt FACTS devices may be variable impedance, variable source, or a combination of these. They inject current into the system at the point of connection [5]. Herein, Static VAR Compensator (SVC) and static synchronous compensator (STATCOM) are classified as shunt FACTS devices.

2.3 Combined series and shunt FACTS devices

Combined series-shunt FACTS device is a combination of separate shunt and series devices, which are controlled in a coordinated manner or one device with series and shunt elements. Example of this FACTS device is Unified Power Flow Controller (UPFC).

Padhy and [6] proposed a new generalized current injection model of the modified power system using Newton-Raphson power flow algorithm with the presence of Thyristor Controlled Series Compensator (TCSC), Unified Power Flow Controller (UPFC) and Generalized Unified Power Flow Controller (GUPFC) [7] proposed an effective method of locating series compensator for voltage stability enhancement using sensitivity analysis. [8] Studied the performance of UPCF in a power transmission system. They incorporated their model into the Newton-Raphson algorithm for power flow analysis.

From the foregoing overview of FACTS devices, it is clear that modeling of FACTS devices is very critical in assessing their enhancement capabilities in specific power system network infrastructure of interest. In the next sub section, we will review briefly the steady state models of FACTS devices considered in this research.

2.4 Steady state modeling of FACTS devices

The functional block diagrams of FACTS devices considered in this thesis are shown in Fig. 8. There are several ways of modeling the selected class of FACTS devices bearing in mind that the suitability of a model depends on the specific problem at hand. Some of the three basic modeling techniques according to [9] are: injection model, total susceptance model and firing angle model. Each FACTS device is assumed to take a fixed number of discrete values within its permissible range. The power injection model is a good model for FACTS devices because its capability for handling the FACTS devices adequately and conveniently in the power flow computation problem [10]

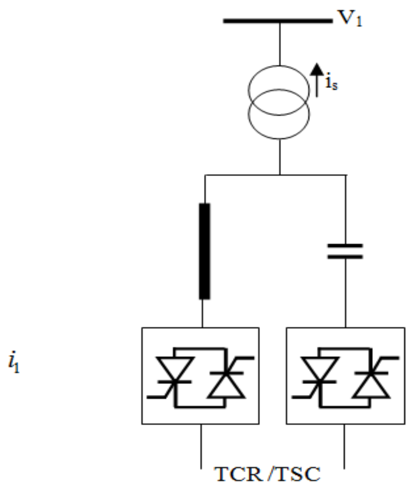
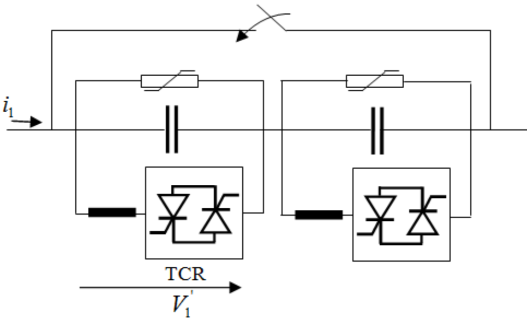
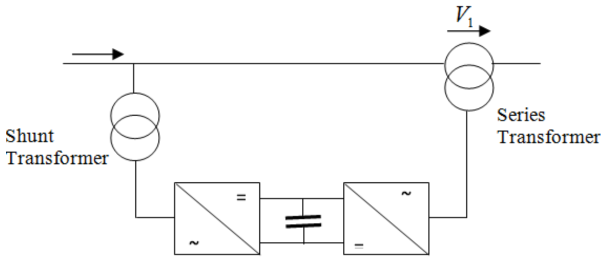


Fig 1 (a) SVC Schematic Representation with Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC)



(b) Schematic Representation of TCSC



(c) Configuration Principles of UPFC

In an interconnected power system, power flows obey all the relevant circuit theory laws. Based on practical engineering assumptions, the resistance of the transmission line is small compared to its reactance. Also the transverse conductance is close to zero. The active power transmitted by a line between the buses **i** and **j** may therefore be approximated as;

$$P_{ij} = \frac{V_i V_j}{X_{ij}} sin\delta_{ij} \qquad \ldots(1)$$

$$Q_{ij} = \frac{1}{X_{ij}}(V_i^2 - V_i V_j)cos\delta_{ij} \qquad \ldots(2)$$

$$\mathrm{P_{ij}} = \frac{\mathrm{V_i V_j}}{\mathrm{X_{ij}}} \sin \emptyset_{\mathrm{ij}} \qquad (1)$$

Where, V_i and V_j are the voltage at buses *i* and *j*;
X_{ij} is the reactance of the line; and
θ_{ij} is the angle between the V_i and V_j.

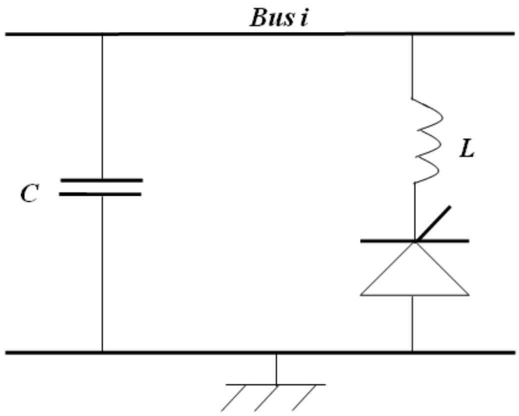
Under the normal operating condition for high voltage line, the voltage V_i = V_j and δ_{ij} is small. The active power flow P_L coupled with δ_{ij} and the reactive power flow is linked with difference between the V_i and V_j. Note that, the control of X_{ij} directly impacts both active and reactive power flows according to eqns. (1) and (2) respectively.

2.5 Static var compensator (SVC)

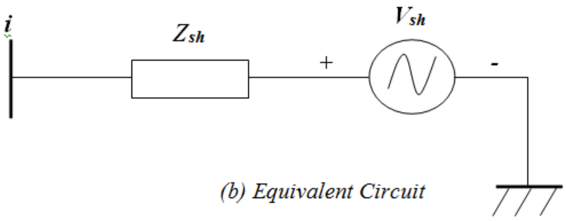
As earlier investigated, SVC is a shunt-type FACTS device, which can control bus voltage at weak points in a network by injecting reactive power as in eqn. (2). The working range of SVC is typically between -10MVar and +100MVar [11]. The SVC can inject or absorb its reactive power (Q_{SVC}) at an installed bus.

$$Q_{SVC}^{min} \leq Q_{SVC} \leq Q_{SVC}^{max} \qquad \ldots(3)$$

According to Jumaat *et al.*, (2011), SVC injects reactive power in to the system if $Q_{SVC} < 0$ and absorbs reactive power from the system if $Q_{SVC} > 0$. The schematic representation and equivalent circuit of SVC is shown in Fig. 1(a). For the sake of this research work, SVC model is represented as a controlled voltage source V_{sh}, connected to bus *i* through impedance Z_{sh} as shown in Fig. 1(b).

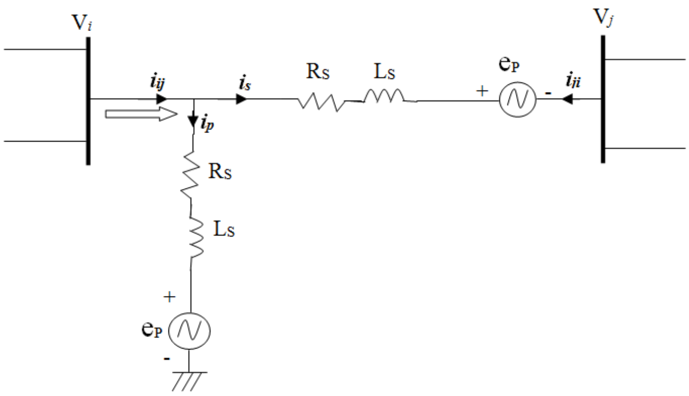


(a) Schematic Diagram



(b) Equivalent Circuit

Figure 2: SVC Schematic Representation and Modeling



(b) UPFC

Figure 2: TCSC and UPFC Circuit Model

2.6 *Unified power flow controller (UPFC)*

When UPFC is placed in a transmission line connected between buses *i* and *j* it can be modeled as shown in Fig. 10(b), [12]. The describing equation for the resulting complex voltage ($\vec{V}_i'$) can be expressed as follows:

$$\vec{V}_i' = \vec{V}_i + \vec{V}_{UPFC} \qquad \ldots(4)$$

Where, $\vec{V}_i$ is the initial bus voltage without UPFC and $\vec{V}_{UPFC}$ is the complex voltage of the UPFC given by eqn. (5).

$$\vec{V}_{UPFC} = V_m \angle \alpha_i \qquad \ldots(5)$$

Where, α_i is the angle of the UPFC to be determined and V_m is the magnitude of the UPFC voltage.

Equation (4) can now be expressed in polar form as follows:

$$\vec{V}_i' = V_i \angle \delta_i + V_m \angle \alpha_i \qquad \ldots(6)$$

Eqn. (8) can also be expressed in rectangular form as follows:

$$\vec{V}_i' = V_i cos\delta_i + V_m cosa_i + j(V_i sin\delta_i + V_m sina_i) \qquad \ldots(7)$$

where, θ_i is the angle of bus i

The typical range of values for V_{UPFC} and α respectively are given as[9]:

$$\alpha = [-180^o, +180^o] \qquad \dots(8)$$

and, $$\vec{V}_{UPFC} = [0\ to\ V_m \angle \alpha_i]\ \ V_m \angle \alpha\ \ ]. \qquad \dots(9)$$

It is evident that UPFC can be modeled using two voltage sources $\vec{V}_{UPFC}$ and $\vec{V}_{Shunt}$. For system that pertains to steady state or dynamic analysis, the control variables $\vec{V}_{UPFC}$ and $\vec{V}_{Shunt}$ can be transformed into injected nodal currents as follows:

$$\Delta \bar{I}_i = \bar{V}_{UPFC} \big/ Z_{Line} + \bar{V}_{Shunt} \big/ Z_{Line} \qquad \dots(10)$$

$$\Delta \bar{I}_j = \bar{V}_{UPFC} \big/ Z_{Line} \qquad \dots(11)\ \vec{\mathrm{V}}_{\mathrm{UPFC}}$$

III. RESULTS AND DISCUSSIONS

This section is devoted to the presentation of results that emerged from this work based on two case study systems. In order to ascertain the usefulness of the proposed mixed integer linear programming approach, cases of single and multi period scenarios were tested extensively on two test systems. For the multi period scenario, 30 periods were considered for both the Nigerian 41-bus network and IEEE 30-bus network. The results are then discussed extensively. Several other results obtained from the continuation power flow and OPF are also presented and discussed.

3.1 Single Period Scenario Results

The single period scenario studies involved the consideration of constant load profile which can be varied by application of loading factors, λ. Under this single period scenario, the case study systems were simulated on MILP Solver (IBM CPLEX Studio Suite) platform with results obtained set forth in the next two subsections.

3.2 Optimal locations and var sizing of SVCs for 30-Bus IEEE network

The proposed mixed integer linear programming approach has applied to solve optimal locations and var sizing of SVCs formulation with respect to 30-Bus IEEE Network considering single period scenario (i.e. constant demand). In this regard, MILP solver software platform has been utilized to generate meaningful results. The resulting voltage profile obtained from the simulation of 30-bus IEEE network on the MILP solver platform for different number of SVCs installed at a base case loading scenario (λ=1.0) is shown in Fig 3.1. Similar results for this case study system for higher loading factors of 1.2 and 1.4 and having varying numbers of SVCs installed are shown in Figs. 4.2 and 4.3, respectively. The optimal locations and var sizing for up to three SVCs for different loading factors are presented in Table 4.1. The comparison of the percentage error of the losses obtained from proposed linearization approach and the Newton-Raphson algorithm implemented in the power system Analysis Toolbox has been found to be very close with negligible errors implied. The results obtained are found to be superior to published results on the same scenario study from the standpoint of lower SVC ratings utilized in this investigation to achieve improved bus voltage profiles and lower system losses. Figure 3.5 depicts losses for different numbers of SVCs installed in the 30-bus IEEE network. A cursory look at this figure reveals 1 or 2 SVC installations are adequate for loss minimization objective.

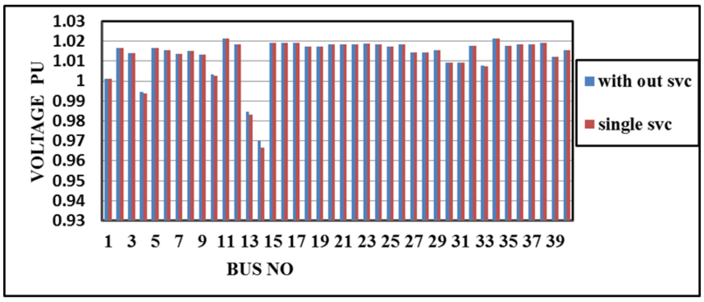


Figure.3.1: 30-IEEE Network voltage profile for λ=1.0

Figure.3.2: 30-IEEE Network voltage profile for λ=1.20

3.3 Optimal locations and var sizing of SVCs for 41 Nigerian Grid System

Against the backdrop of the satisfactory results achieved in respect of widely used 30-Bus IEEE system, similar simulation studies were carried out on the 41-Bus Nigerian Grid System using the same software platform. Figures 3.5 and 3.6 show the voltage profiles obtained for two loading factors for single period scenario considered for this dissertation. Note that for a loading factor of λ = 1.4 (i.e. 140%) of its base case loading, the Nigerian power system would require at least one installation of SVC to maintain its operational integrity at steady state at such load level. The transmission infrastructural inadequacy is clearly evident.

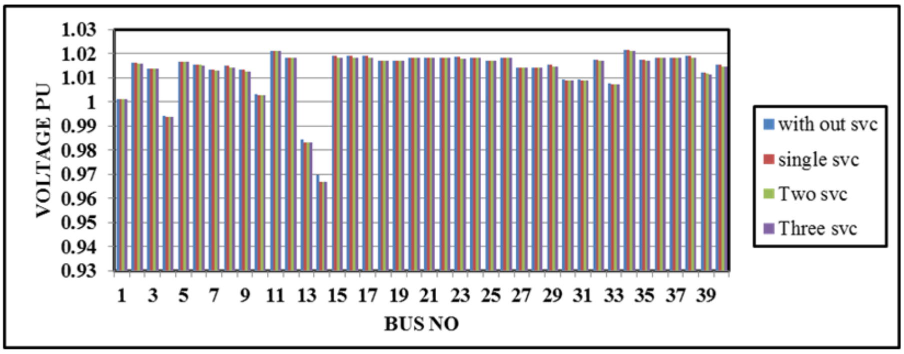


Figure.3.5: 41-Bus Nigerian Grid system voltage profile for λ=1.0

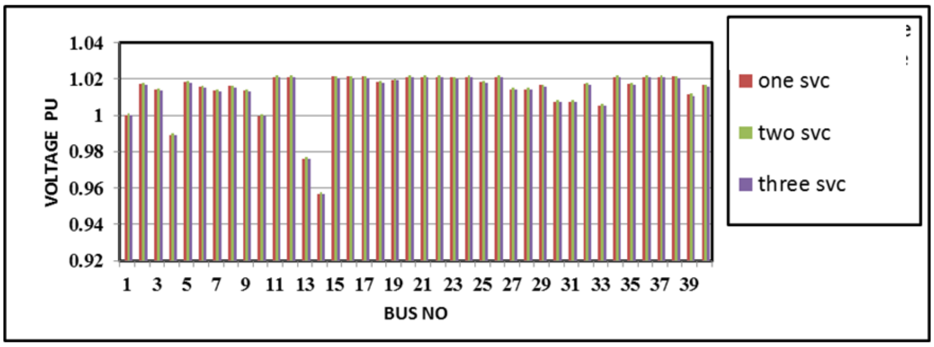


Figure.3.6: 41-Bus Nigerian Grid system voltage profile for λ=1.4

Likewise, the optimal locations and var sizing considering up to a maximum of five SVCs installations in the Nigerian grid system are summarized in Table 3.2 for different loading factors. The system losses for the Nigerian grid system for optimal allocations of different numbers of SVCs are depicted in Fig. 3.7. In all the cases of optimal installations of SVC, note that Bus 14 corresponding to Gombe Bus is always selected as a candidate.

Table 3.2: Loss minimization for a single period of the 41-bus Nigerian Grid System

(a) Loading Factor, λ = 1.0

Number of SVCs	Losses (pu)	Location of SVC (bus number)	Mvar of SVC (pu)
0	0.2500	-	-
1	0.2257	14	1.0691
2	0.2119	14 29	1.0691 2.7742
3	0.2111	14 29 39	1.0691 2.6695 0.3516
4	0.2105	14 29 39 23	1.0691 2.0313 0.3516 0.6382
5	0.2102	14 29 39 23 13	0.9700 2.0313 0.3516 0.6382 0.2064

b) Loading Factor, λ=1.2

Number of SVCs	Losses (MW)	Location of SVC (bus number)	Mvar of SVC (pu)
0*	-	-	-

1	0.3533	14	1.329
2	0.3299	14 29	1.2829 3.5231
3	0.3285	14 29 39	1.2829 3.3375 0.4794
4	0.3274	14 29 39 23	1.2829 2.5351 0.4794 0.80
5	0.3271	14 29 39 23 28	1.2829 2.4639 0.4777 0.8024 1.8599
	c) Loading Factor, λ=1.2		
Number of SVCs	Losses (MW)	Location of SVC (bus number)	Mvar of SVC (pu)
0	-	-	-
1	0.3533	14	1.329
2	0.3299	14 29	1.2829 3.5231
3	0.3285	14 29 39	1.2829 3.3375 0.4794
4	0.3274	14 29 39 23	1.2829 2.5351 0.4794 0.80
5	0.3271	14 29 39 23 28	1.2829 2.4639 0.4777 0.8024 1.8599

IV. CONCLUSION AND RECOMMENDATION

In this work, a mixed integer linear programming based methods have been developed and applied to determining the optimal location of some selected FACTS devices in IEEE 30- Bus network and 41-Bus Nigerian grid systems. In the two systems, the optimal locations of SVC were achieved by relying on the sensitivity factors. Test results obtained with respect to the two power systems showed the effectiveness of the proposed techniques. It was conclusively established that that shunt reactive power control using SVC is very effective while series reactive power compensation control using TCSC and series-shunt reactive power compensation control using UPFC have not been so effective with respect to the Nigerian grid system because of its radial topology.

In addition, this dissertation presented the detailed formulations of the single and multi period scenarios for allocating reactive power compensators in order to minimize losses. Results indicate that the multi period formulation is better suited for capturing the varying nature of the load profile in any network. Allocating reactive power compensators for improving the loadability margin was also formulated in this dissertation. It was observed that the network loadability margin may not increase as more compensators are added to a network. Another observation of the results in this dissertation reveals that the optimal locations selected from a load flow perspective are in most cases within the neighborhood of those obtained from the circuit theory approach. Congestion management is an important issue in deregulated power systems. FACTS devices such as SVC by controlling the power flows in the network can help to reduce the flows in heavily loaded lines. Because of the considerable costs of FACTS devices, it is important to obtain optimal location for placement of these devices.

Reference

[1]. J. G. Singh, S. N. Singh, and S. C. Srivastava, "Placement of FACTS controllers for enhancing power system loadability," in *Power India Conference, 2006 IEEE*, 2006, p. 7-23.

[2]. J. G. Singh, S. N. Singh, and S. C. Srivastava, "An approach for optimal placement of static VAr compensators based on reactive power spot price," *Power Systems, IEEE Transactions on*, vol. 22, pp. 2021-2029, 2007.

[3]. N. Aminudin, T. K. A. Rahman, and I. Musirin, "Optimal power flow for load margin improvement using evolutionary programming," in *Research and Development, 2007. SCOReD 2007. 5th Student Conference on*, 2007, pp. 1-6.

[4]. G. Baskar and M. R. Mohan, "Contingency constrained economic load dispatch using improved particle swarm optimization for security enhancement," *Electric Power Systems Research*, vol. 79, pp. 615-621, 2009.

[5]. X.-P. Zhang, C. Rehtanz, and B. Pal, *Flexible AC transmission systems: modelling and control*: Springer, 2006.

[6]. R. Bacher and H. Glavitsch, "Loss reduction by network switching," *Power Systems, IEEE Transactions on,* vol. 3, pp. 447-454, 1988.

[7]. V. Ajjarapu and B. Lee, "Bibliography on voltage stability," *Power Systems, IEEE Transactions on,* vol. 13, pp. 115-125, 1998.

[8]. T. Orfanogianni and R. Bacher, "Steady-state optimization in power systems with series FACTS devices," *Power Systems, IEEE Transactions on,* vol. 18, pp. 19-26, 2003.

[9]. R. Natesan and G. Radman, "Effects of STATCOM, SSSC and UPFC on Voltage Stability," in *System Theory, 2004. Proceedings of the Thirty-Sixth Southeastern Symposium on*, 2004, pp. 546-550.

[10]. N. Mithulananthan, C. A. Canizares, J. Reeve, and G. J. Rogers, "Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations," *Power Systems, IEEE Transactions on,* vol. 18, pp. 786-792, 2003.

[11]. H. Seifi and M. S. Sepasian, *Electric Power System Planning*: Springer.

[12]. N. G. Hingorani, "Power electronics in electric utilities: role of power electronics in future power systems," *Proceedings of the IEEE,* vol. 76, pp. 481-482, 1988.

[13]. S.-H. Song, J.-U. Lim, and S.-I. Moon, "Installation and operation of FACTS devices for enhancing steady-state security," *Electric Power Systems Research,* vol. 70, pp. 7-15, 2004.