Static Synchronous Compensator (STATCOM) based Power Injection and Current Injection Models in Power Flow Application: A Comprehensive Analytical Study

[1]Mohammad Isharat Khan,[2] Dheeraj Kumar Palwalia

[1]Research Scholar, EED, CP University, Kota, Rajasthan, [2]Assistant Professor, RT University, Kota, Rajasthan

Abstract — Static Compensator is most widely use electronic device which is frequently used in flexible alternating current transmission application. Static Compensator commonly also known as STATCOM. Increasing usage of power in different sector has encourage research scholar's across the world to find optimal solution for transmission of power over long distances as the installation and utilization of power is situated at long distances. Transmission of AC power over long distance inherits vulnerabilities like poor efficiency, poor power factor and system stability. Different technique are develop to enhance the stability of power system by injecting current, VAR or injecting voltage at different location to counter vulnerabilities. In this research article STATCOM Power Injection Model has been presented and simulation of the model had been carried I MATLAB Simulator and a compression had been done with previously or in practice methodology.

***Indexed Terms* — Static Compensator, FACTS, Voltage Sourced Converter, Current Injection**

I. INTRODUCTION

Flexible Alternating Current Transmission System commonly denoted as FACTS devices are static power electronics based instruments. With the applications of FACTS technology, bus voltage magnitude and power flow along the transmission lines can be more flexibly controlled. Among the FACTS controllers, the most advanced type is the controller that employs Voltage Sourced Converter that is VSC as synchronous sources. Representative of the VSC type FACTS controllers are the Static Synchronous Compensator, which is a shunt type controller, the Static Series Compensator that is SSSC, which is a series type controller and the Unified Power Flow Controller (UPFC), a combined series-shunt type controller. Of all the VSC the most widely used is the STATCOM. It can provide bus voltage magnitude control. Computation and control of power flow for power systems embedded with STATCOM appear to be fundamental for power system analysis and planning purposes. Power flow studies incorporating STATCOM requires accurate model in solution algorithms.

There are mainly two models of STATCOM which have well tested in power systems. There are the Current Injection Model (CIM) and the Power Injection Model (PIM). The CIM STATCOM has a current source connected in shunt the bus for voltage magnitude control. The PIM models the STATCOM as shunt voltage source behind an equivalent reactance or impedance, which is also referred to as voltage source model (VSM). This steady state power injection model of STATCOM has proved reliable when incorporated in power systems and is well documented.

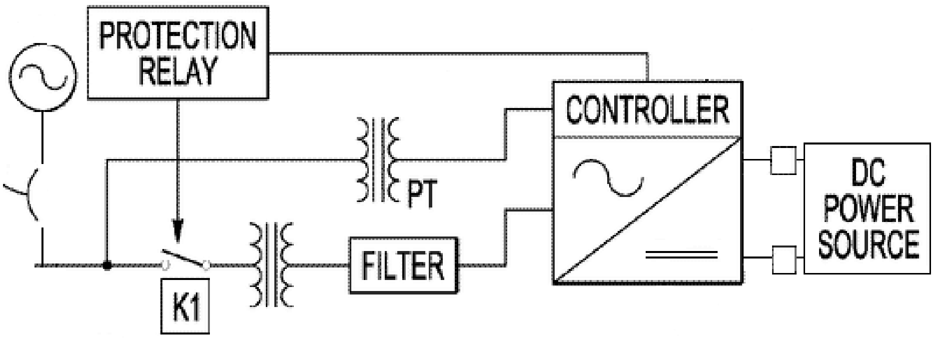

Figure 1- STATCOM Based Reactive Power Injection Technique

The use of this STATCOM in power system simulators has therefore increased over the last one decade and is therefore adopted implementation in this work with the voltage expressed in rectangular coordinate.

II. LITERATURE SURVEY

The literature survey shows that there has been a lot of work done in the field of FACTS controllers and even then there is a great need to improve the real and reactive power control strategy, voltage control and transient stability enhancement. The application of SSSC in long distance power system has received much attention by researchers in recent years. By virtue of its ability to provide continuous and rapid control of reactive power and voltage, SSSC can enhance several aspects of transmission system performances such as transient stability enhancement, sub synchronous resonance damping and power oscillation damping. The improvement in the performances of the transmission system is effective when FACTS devices are integrated with energy storage systems.

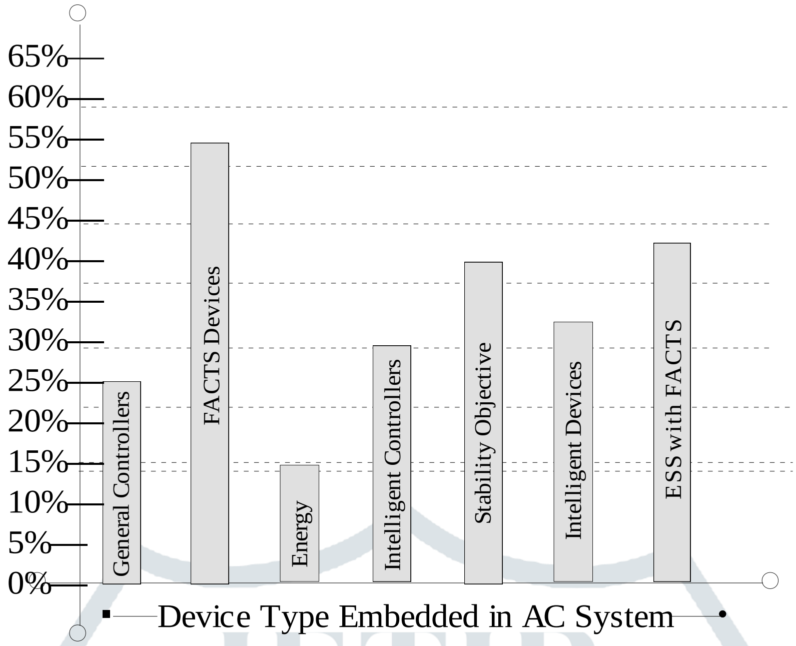

Figure. 2 - Distribution of Literature Survey

The works reported in the literature are the application of many FACTS devices such as SVC, TCSC, SSSC, UPFC, SMES etc. in power system network. Conventional PI, PID controllers, Energy function approach, multi control and MIMO systems are used as control schemes for FACTS devices. Decoupled techniques for the control of SSSC, internal and external control schemes, chopper control for energy storage systems are also reported in the survey.

Due to recent advances in power electronics, FACTS devices have gained good popularity during the last few years. FACTS devices have been mainly used for solving various power system control problems such as voltage regulation, power flow control, and transfer capability enhancement, damping the inter-area modes and enhancing power system stability

The vision of the FACTS has been formulated by the Electric Power Research Institute (EPRI) in the late 1980s. The various power electronics based controllers regulate power flow and transmission voltage and mitigate dynamic disturbances. The main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes. Hingorani (1988, 1991) and Hingorani and Gyugyi (2000) have proposed the concept of FACTS.

There are two generations for the realization of power electronics based FACTS controllers: the first generation uses conventional thyristor switched capacitors and reactors, and quadrature tap-changing transformers and the second generation uses Gate Turn-Off (GTO) thyristor-switched converters as Voltage Source Converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor- Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS). The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC). The two groups of FACTS controllers have distinctly different operating and performance characteristics.

The thyristor-controlled set-up has capacitor and reactor banks with fast solid-state switches in shunt or series circuit arrangements. By varying the on and off periods of the thyristor switches, variable reactance values of the fixed capacitor and reactor banks are obtained.

The voltage source converter (VSC) type FACTS controller set-up has self-commutated DC to AC converters, using GTO thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. The converter with energy storage device can also exchange real power with the system, in addition to the independently controllable reactive power. Yong Hua Song and Allan T. Johns (1999) have proposed that the VSC can be used uniformly to control transmission line voltage, impedance, and angle by providing reactive shunt compensation, series compensation, and phase shifting, or to control directly the real and reactive power flow in the line.

Hanson et al (2002) have described the emergence of second generation FACTS devices as serious alternatives to the conventional devices. The effectiveness of STATCOM to control power system voltage has been presented by Wang et al (2002). Uros Gabrijel and Rafael Mihalic (2003) have proposed three methods of transient stability analysis in power systems with FACTS controllers. First is the time domain digital simulations that numerically integrate differential equations and a solution in the form of system trajectory is obtained. The second approach is the direct methods that employ Lyapunov energy functions. The third approach is the hybrid method by combining digital simulation and direct methods.

Haque (2004) has demonstrated the capability of the STATCOM to provide additional damping to the low frequency oscillations by the use of energy function. The STATCOM damping characteristics have also been analyzed and addressed. Different approaches to STATCOM-based damping controller design such as loop-shaping (Rahim et al, 2002), pole-placement (Lee and Sun 2002), multivariable feedback linearization (Sahoo et al 2004), +’ control (Al-Baiyat, 2005) and intelligent control (Morris et al 2003) have been adopted.

The SSSC has been applied to different power system studies to improve the system performance. A comparative study of the STATCOM and SSSC has been investigated for stability study by Haque (2005).

The voltage source inverter for SSSC is initially devised with 3 level inverters. Then 6 pulse, 12 pulse and 24 pulse inverters are designed for the purpose to use in SSSC. Control schemes to enhance the dynamic performance of STATCOM and SSSC have been proposed by Amir H. Norouzi and Sharaf (2005). 24 pulse VSI is designed for STATCOM and SSSC. A new automatic gain controller is proposed to ensure the stable operation of STATCOM under various load conditions.

III. MATHEMATICAL MODEL

The STATCOM is a FACTS controller based on voltage sourced converter. A VSC generate a synchronous voltage of fundamental frequency, controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer as shown in Fig. 1, the resulting STATCOM can

inject or absorb reactive power to or from the bus to which it is connected and thus regulate the bus voltage magnitude [4]. This STATCOM model is known as Power Injection Model (PIM) or Voltage Source Model (VSM). Steady state modelling of STATCOM within the Newton-Raphson method in rectangular co-ordinates is carried out as follows:

The Thevenin equivalent circuit representing the fundamental frequency operation of the switched-mode voltage sourced converter and its transformer is shown in Figure 1.

$$V_{STC} = V_k + Z_{SC} I_{STC} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots Eqs.1$$

is expressed in Norton equivalent form

$$I_{STC} = I_N - Y_{SC} V_k \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots Eqs.2$$

Where

$$I_N = Y_{SC} V_{STC}$$

In these expressions, V k represents bus k voltage and V STC represents the voltage source inverter. I N is the Norton's current while I STC is the inverter's current. Also, Z SC and Y SC are the transformer's impedance and short-circuit admittance respectively. The STATCOM voltage injection V STC bound constraints is as follows:

$$V_{STC\,min} \le V_{STC} \le V_{STC\,max} \cdots\cdots\cdots\cdots\cdots\cdots\cdots Eqs.3$$

Where
V_{STC} min and V_{STC} max are the STATCOM's minimum and maximum voltages.
The current expression in (2) is transformed into a power expression by the VSC and power injected into bus k as shown in equations (4) and (5) respectively.

$$S_{STC} = V_{STC} I_{STC}^* = V_{STC}^2 Y_{SC}^* - V_{STC} Y_{SC}^* V_K^* \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots Eqs.4$$

$$S_k = V_k I_{STC}^* = V_{STC} Y_{SC}^* V_k^* - V_k^2 Y_{SC}^* \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots Eqs.5$$

Using the rectangular coordinate representation,

$$V_K = e_k + jf_k$$
$$V_{STC} = e_{STC} + jf_{STC}$$
$$|V_{STC}| = (e_{STC}^2 + f_{STC}^2)^{\frac{1}{2}}$$
$$\delta_{STC} = \tan^{-1}\left(\frac{f_{STC}}{e_{STC}}\right)$$

Where V_{STC} and δSTC are the STATCOM voltage magnitude and angle respectively e_k and f_k are the real and imaginary parts of the bus voltage respectively. e_{STC} and f_{STC} are the real and imaginary parts of the STATCOM voltage respectively The active and reactive powers for the STATCOM and node k respectively are:

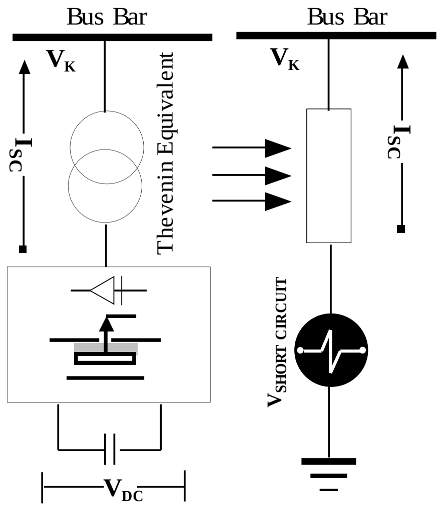

Figure 3- Thevenin Equivalent Circuit Diagram of STATCOM

$$P_{STC} = G_{SC}\{(e_{STC}^2 + f_{STC}^2) - (e_{STC}e_k + f_{STC}f_k)\} + B_{SC}(e_{STC}f_k - f_{STC}e_k) \cdots\cdots\cdots Eqs. 6$$

$$Q_{STC} = G_{SC}(e_{STC}e_k - f_{STC}e_k) + B_{SC}(-e_{STC}^2 - f_{STC}^2 + e_{STC}e_k + f_{STC}f_k) \cdots\cdots\cdots Eqs. 7$$

$$P_k = G_{SC}\{e_k^2 + f_k^2 - (e_k e_{STC} + f_k f_{STC})\} + B_{SC}(e_k f_{STC} - f_k e_{STC}) \cdots\cdots\cdots Eqs. 8$$

$$Q_k = G_{SC}(e_k f_{STC} - f_k e_{STC}) + B_{SC}\{(e_k f_{STC} + f_k e_{STC}) - (e_k^2 + f_k^2)\} \cdots\cdots\cdots Eqs. 9$$

Linearised Power Equations

A single-phase power network with n-buses is described by 2*(n-1) non-linear equations. The inclusion of one STATCOM model augments the number of equations by two. The solution of the combined system of non-linear equations is carried out by iteration using the full Newton-Raphson method. The Jacobian used in conventional power flow is suitably extended to take account of the new elements contributed by the STATCOM. The set of linearised power flow equations for the complete system is the Jacobian elements in equation (10) are given in Appendix "A" attached.

IV. IMPLEMENTATION

A MATLAB based program was developed for the power flow analysis of electrical power systems without and with steady-state model of the FACTS controller, STATCOM. The program is referred to as "Flexible Alternating Current Transmission System Power Flow" (FACTSPF). The procedure for power flow solution by the Newton-Raphson method without and with FACTS controllers is shown in flowchart of Figure 2. The input data includes the basic system data needed for conventional power flow calculation, i.e., the number and types of buses, transmission line data, generation and load data and the values of STATCOM control parameters. System admittance matrix and conventional Jacobian matrix is formed due to incoming of STATCOM. At the next step, Jacobian matrix and the mismatched power flow equations are modified. The bus voltages are updated at each iteration. Convergence is checked and if no, Jacobian matrix is modified and power equations are mismatched until convergence is achieved. If yes, power flow results are displayed. Power Analysis Toolbox (PSAT) is a MATLAB toolbox for static, dynamic analysis and control of electric power systems. PSAT includes power flow; continuation power flow; optimal power flow, small signal stability analysis and time domain simulation [12],[13]. It has steady-state and dynamic models of three voltage sourced converter FACTS controllers, namely STATCOM, SSSC, HVDC and UPFC. The STATCOM model implemented in PSAT is a Current Injection Model (CIM) which is fully developed. In order to validate the results of FACTSPF, simulation of power system incorporating STATCOM were carried out using the two packages, PSAT and FACTSPF. The results when the two packages were applied to 5-bus system are subsequently presented.

Power Flow Analysis Embedding FACTS Controllers

In order to investigate the performance of the PIM of STATCOM, the CIM and PIM STATCOM were embedded in a standard 5-bus system. The test system is shown in Figure 3. The 5-bus power system data as well as the STATCOM data are given in the appendix.

The STATCOM model (PIM) was installed in the 5-bus system for voltage magnitude control. The 5-bus was also simulated using PSAT and its STATCOM current injection model used for bus voltage control. The power flow analysis of FACTSPF and that of PSAT were then compared. From the power flow results for the 5-bus system (Table 1), it can be observed that the voltage magnitudes at bus Lake, bus Main and bus Elm are lower than 1.0p.u. And are therefore potential buses for the application of STATCOM. The five-bus network was modified to include one STATCOM connected at Lake, to maintain the bus voltage magnitude at 1 p.u. (Figure 5).

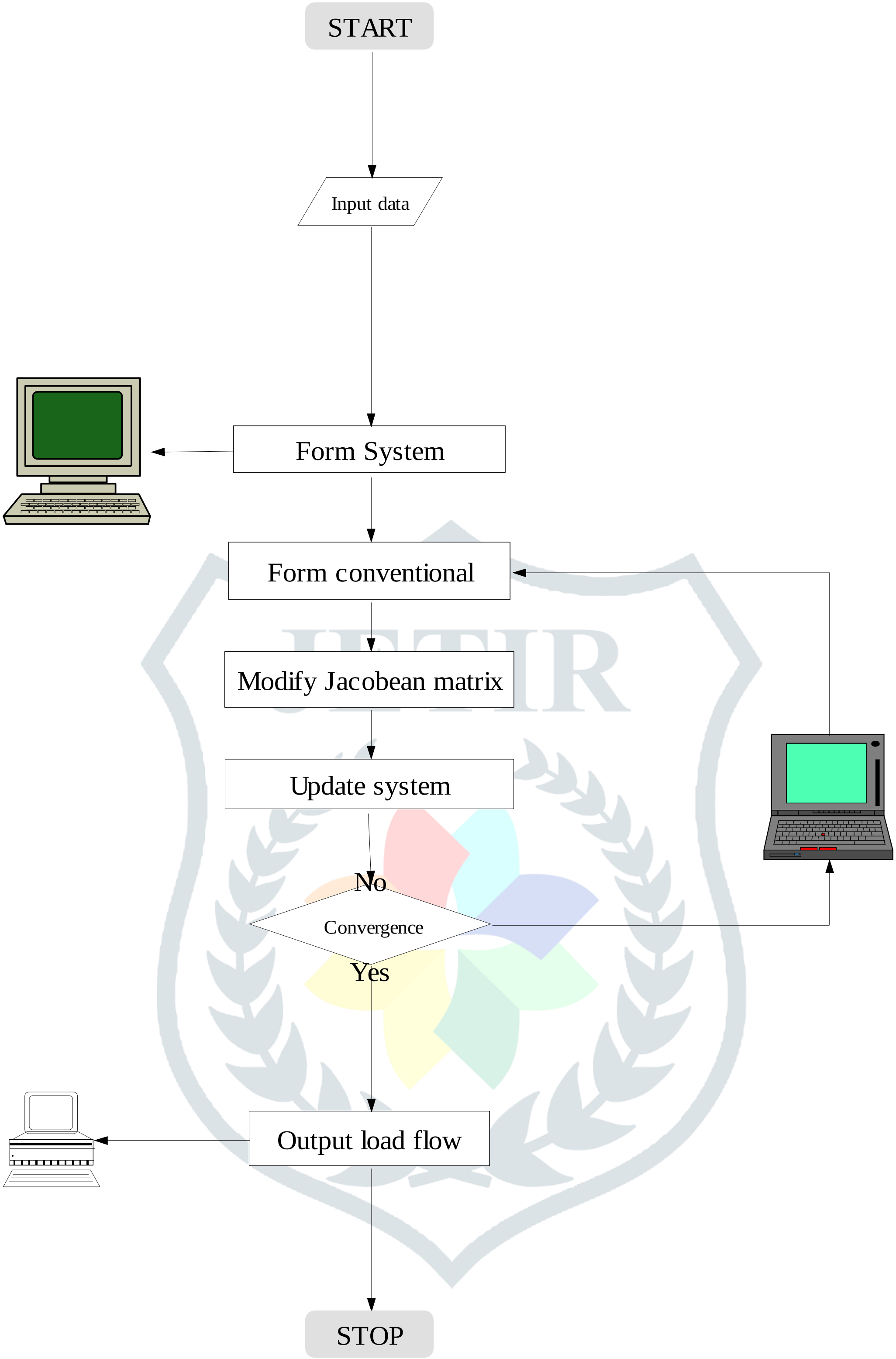

Figure 4: Flowchart for Power Flow Solution by STATCOM Controller

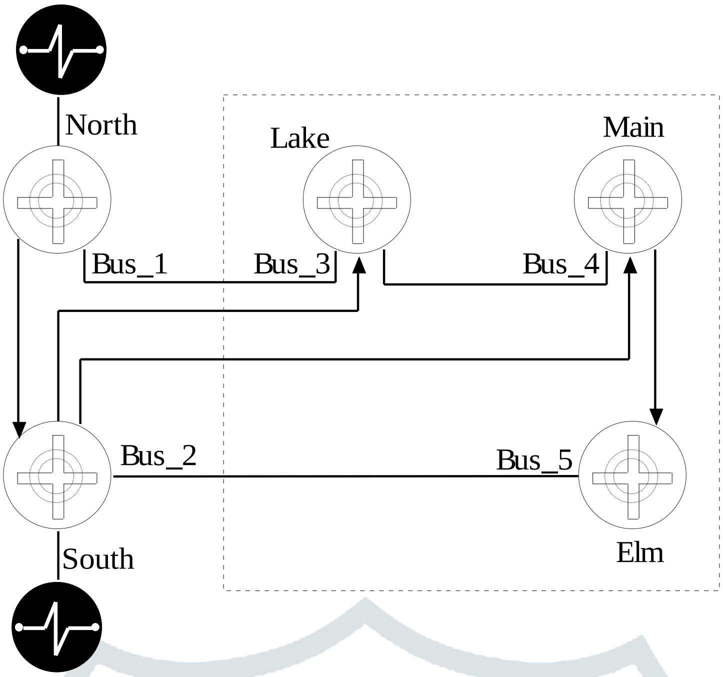

Figure 5: 5-bus Test System Source

The 5-bus system implementation in PSAT is shown in Figure 4b.The resulting power flow solution is shown in Table 2, and it indicates an improvement in the voltage profile of the system with Lake Voltage regulated at 1.0p.u. Note that the STATCOM injected reactive power of 20.48Mvar at bus Lake while the STATCOM voltage magnitude and phase angle were maintained at 1.0205 p.u. and 0 □ 4.83 respectively.

The installation of the STATCOM resulted in improved network voltage profile. The slack generator reduces its reactive power generation by 5.9% compared with the base case, and the reactive power flow from North to lake reduces by more than 32%. The reactive power absorbed by the south generator increased by 25% of the base case. In general, more reactive power is available in the network when compared with the base case due to the installation of STATCOM. As expected the active power flows were slightly affected. The system active power loss reduces to 6.06MW. PSAT was also used to simulate the 5-bus system with STATCOM installed to control Lake Bus voltage magnitude at 1.00p.u.

The power flow results for the PIM model and CIM STATCOM are similar; the only difference can be seen in Lake Voltage angle with the VSM model being 4.830 while that of CIM is 4.840. The difference can be attributed to the computation errors which are different for each program. The parameters of the STATCOM models are shown in Table 2. In order to control the Lake bus voltage magnitude at1.00 p.u., the VSM model injected a reactive power 20.47Mvar with voltage magnitude of 1.0205 p.u. and phase angle 4.830. For the CIM STATCOM, it injected a current of 0.2047p.u.

The power flow and the system loss for the PIM and CIM STATCOM are essentially the same to four significant figures. Two other scenarios were simulated using the two models to control voltage magnitude at bus 4 (Main) and bus 5 (Elm). The power flow analyses carried out produced similar output results.

The two programs converged quadratic ally in five iterations to maximum absolute power mismatch of 1E-012 per unit as shown in Figure 5. Shown in Table 3 are the Power flow computation times for the two programs. It can be observed from Table 3 that FACTSPF completes the power flow computation in lesser time when compared to that of PSAT. It has been shown that the developed STATCOM model (PIM) is very effective in the control of bus voltage magnitude of a vulnerable bus.

Table I
Power flow results of 5-bus system

Bus No	Bus Type	FACTSPF		PSAT	
		Bus Voltage		Bus Voltage	
		Magnitude (p.u.)	Phase angle (deg)	Magnitude (p.u.)	Phase angle (deg)
1	Swing	1.060	0.00	1.060	0.00
2	PV	1.000	-2.06	1.000	-2.06
3	PQ	0.987	-4.64	0.987	-4.64
4	PQ	0.984	-4.96	0.984	-4.96
5	PQ	0.972	-5.77	0.972	-5.77

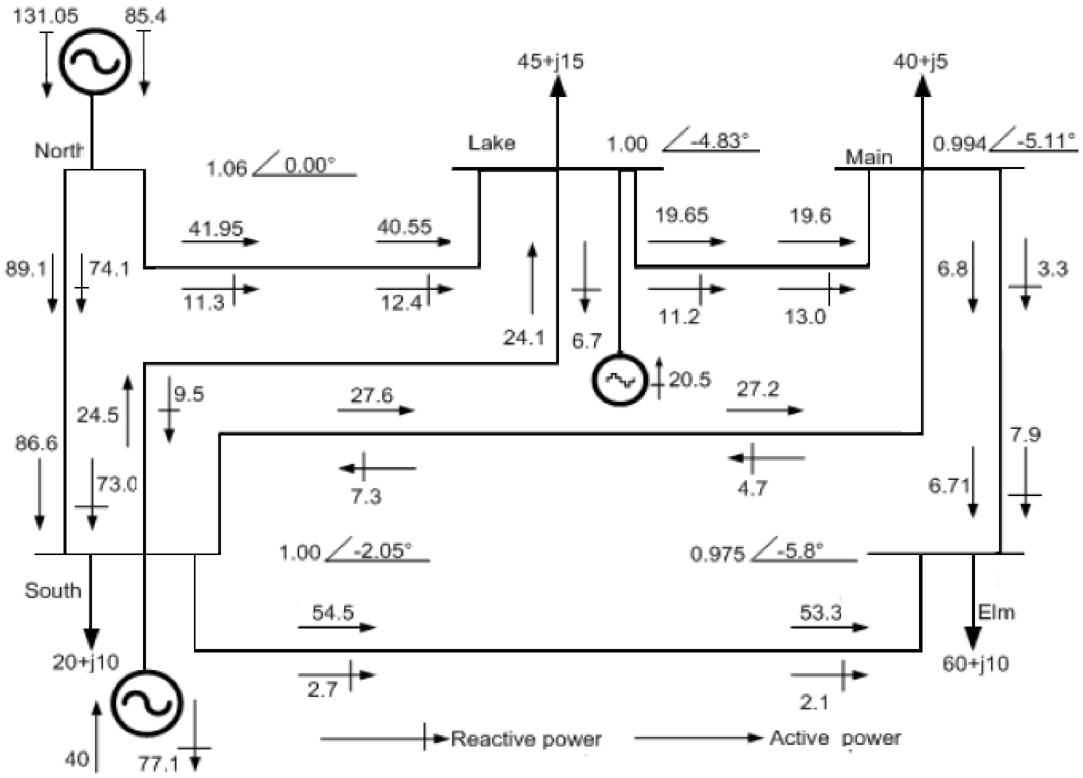

Figure 6- Power Flow Results of 5-bus with STATCOM at Bus 3

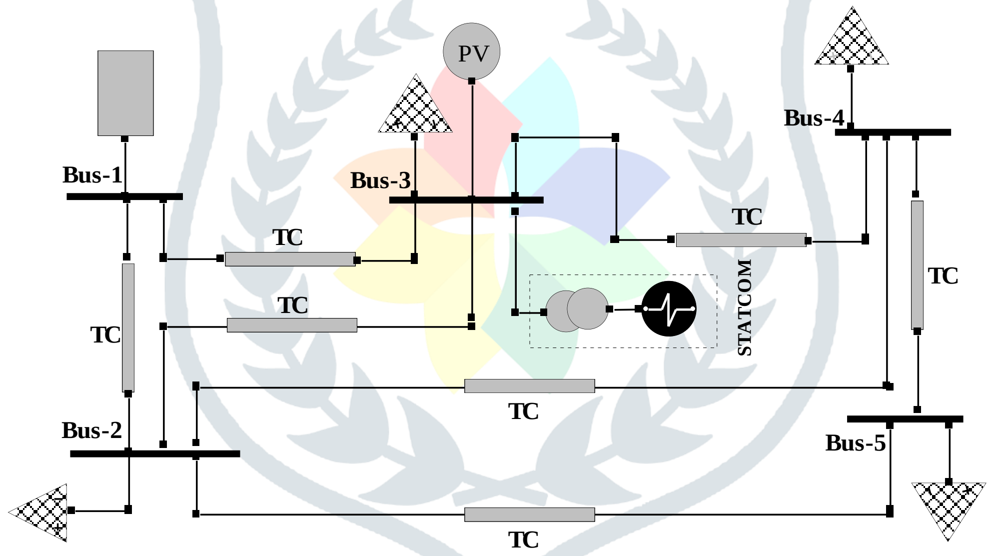

Figure 7- STATCOM-upgraded 5-bus system in PSAT

Table II

Power Flow Results of 5-bus System without and with STATCOM

Bus No	Bus Type	FACTSPF		PSAT	
		Nodal Voltage		Nodal Voltage	
		Magnitude (p.u.)	Phase angle (deg)	Magnitude (p.u.)	Phase angle (deg)
1	Swing	1.060	0.00	1.060	0.00
2	PV	1.000	-2.06	1.000	-2.05
3	PQ	0.987	-4.64	0.987	-4.84
4	PQ	0.984	-4.96	0.984	-5.11
5	PQ	0.972	-5.77	0.972	-5.80

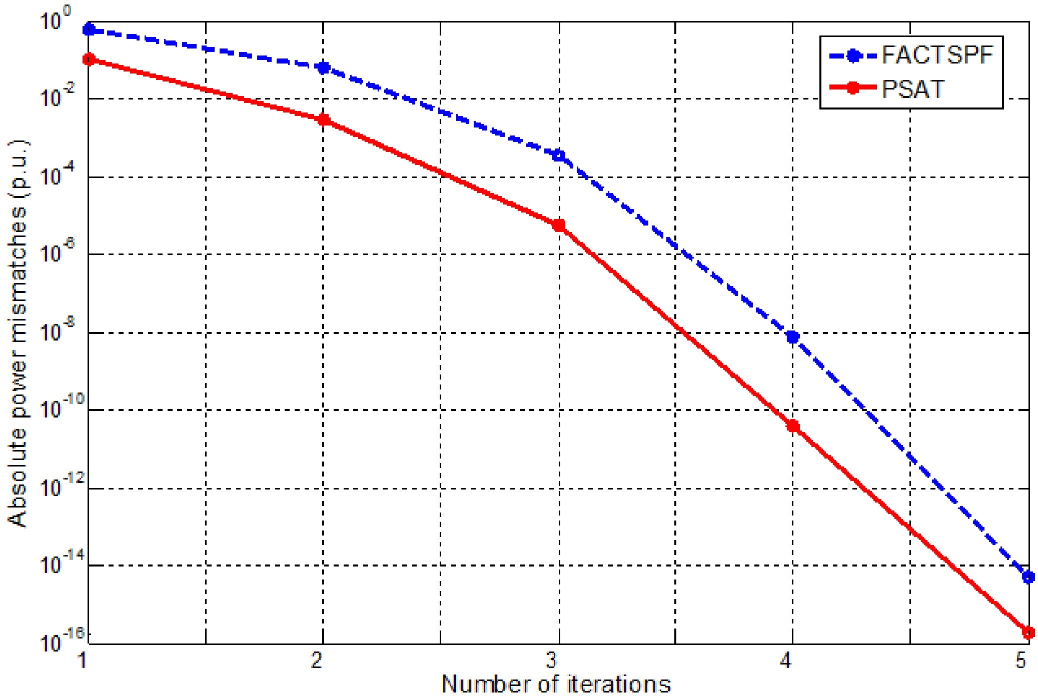

Figure 8- Absolute Power Mismatches as Function of Number of Iterations for PSAT and FACTSPF

Table III
Power Flow computation time for FACTSPF and PSAT

Program	Computation time
FACTSPF	0.359
PSAT	0.406

4. CONCLUSION

In this paper the PIM of STATCOM has been presented with the voltage expressed in rectangular form. A MATLAB based power flow program developed was extended to incorporate the STATCOM and named Flexible Alternating Current Transmission System Power Flow (FACTSPF). 5-bus power system with the incorporation of the PIM and CIM were simulated using the FACTSPF and PSAT respectively. The STATCOM was able to effectively regulate the bus voltage magnitude at which was connected. The results obtained by FACTSPF are matched with those of PSAT in acceptable tolerance and thus confirms the robustness of the PIM. The PIM of STATCOM is effective and reliable in terms of computation speed and accuracy. It is a reliable substitute for CIM.

REFERENCES

[1] N. Ammasagounden, and M. Subbiah, Microprocessor based voltage controller for wind-driven self-excited induction generators, IEEE Transaction Industrial Electronics, Vol. 37, No. 6, December 1990, pp. 531-537.
[2] G. Boyle, Renewable Energy: Power for Sustainable Future,(Oxford University Press, 2000).
[3] N. Jenkins, R. Allan, P. Crossley, D. Kirschen, and G. Strbac, Embedded generation (The Institute of Electrical Engineers, 2000).
[4] G. Raina, and O.P. Malik, Wind energy conversion using a self-excited induction generator, IEEE Transaction on Power Apparatus and Systems, Vol. 102, No. 12, 1983, pp. 3933-3936.
[5] Elder J.M., Boys J.T., and Woodward J.L., Self-excited induction machines as a small low cost generator, Proceeding IEE, Vol. 131, Part C, No. 2, pp. 33-41, 1984.
[6] Power Electronics for Distributed Energy Systems and Transmission and Distribution Applications, Technical Report Oak Ridge National Laboratory ORNL/TM-2005/230 Dec. 2005.
[7] W. Kramer, S. Chakraborty, B. Kroposki, H.Thomas, "Advanced Power Electronics Interfaces for Distributed Energy Systems," Technical Report National Renewable Energy Laboratory NREL/TP-581-42672 March 2008.
[8] R. H. Staunton, B. Ozpineci, "Micro turbine power conversion technology review," Report Oak Ridge National Laboratory ORNL/TM-2003/74, April 2003
[9] Frede Blaabjerg, Zhe Chen,and Soren Baekhoej Kjaer, "Power Electronics as Efficient Interface in Dispersed Power Generation Systems," IEEE Trans. Power Electron.,vol. 19, no. 5, pp. 1184-1194, Sep. 2004.
[10] F. Delfino, R. Procoppio, "Photovoltaic generating units as reactive supply ancillary service providers," in International Journal of Emerging Electric Power Systems, vol. 9, no. 4, Oct. 2008.

[11] A.K. At Jabri and A.I. Alodah, "Capacitance requirements for isolated self-excited induction generator," Proc. IEE, Vol. 137,Part B, No. 3, pp.154-159, May 1990.

[12] AI-Bahrani, A.H., and Malik, N.H, "Selection of the Excitation Capacitor for Dynamic Braking ofInduction Machines", Proc. IEE, Vol. 140, Part. B,No. 1, pp. 1-6, 1993

[13] AI-Bahrani, A.H., and Malik, N.H, "Steady state analysis and Performance Characteristics of a three phase Induction Generator Self-Excited with a single capacitor", IEEE Trans. on Energy Conversion, Vol4, No. 4, pp. 725-732, 1990

[14] T.F. Chan, "Capacitance requirements of Self-Excited Induction Generators", IEEE Trans. on Energy Conversion, Vol. 8, No. 2, pp. 304-310, June 1992.

[15] S.M. Alghuwainmen, Steady-state analysis of self-excited induction generator including transformer saturation, IEEE Transactions on Energy Conversion, Vol. 14, No. 3, September 1999. McPherson G., and Laramore R.D., An Introduction to Electrical Machines and Transformers. (New York, Wiley, 1981).

[16] L. Quazene and G. G. McPherson Jr., Analysis of an isolated induction generator, IEEE Transactions on Power Application System, Vol. 102, No. PAS-8, August 1983, pp. 2793-2798.

[17] T.S.Jayadev, Windmills stage a comeback, IEEE Spectrum, Vol. 13, No. 11, November 1976, pp. 45-49.

[18] R.C. Bansal, Three-phase self-excited induction generators: an overview, IEEE Transactions on Energy Conversion, Vol. 20, No. 2, June 2005, pp. 292-299.

[19] F.C. Dezza, A.D. Geriando, and R. Perini, Performance comparison among different converters fed by selfexcited wind driven induction generators, Proceeding 7th International Conference on Electric Machine Drives, pp. 438-443, 1995.

[20] M.S. Vicatos, and J.A. Teqopoulos, Steady state analysis of a doubly-fed induction generator under synchronous operation, IEEE Transaction Energy Conversions, Vol. 4, No. 3, September 1989, pp. 495-501.

[21] M.G. Loannides, Determination of frequencies in autonomous double output asynchronous generator, IEEE Transactions Energy Conversions, Vol. 7, No. 4, December 1992, pp. 287-297.

[22] Z. Slameh, and S.Wang, Microprocessor control of double output induction generator, Part-I: inverter firing circuit, IEEE Transaction Energy Conversions, Vol. 4, No. 2, June 1989, pp. 172-176.

[23] R.C. bansal, T.S. Bhatti, and D.P. Kothari, A bibliographical survey on induction generator for application of non conventional energy systems, IEEE Transactions on Energy Conversions, Vol. 18, No. 3, September 2003, pp. 433-439.

[24] R.C. bansal, T.S. Bhatti, and D.P. Kothari, Induction generator for isolated hybrid power system applications: A review, Proceeding 24th National Conference on Renewable Energy Conversion, Bombay, pp. 462-467, 2000.

[25] A.K. Tandon, S.S. Murthy, and G.J. Berg, "Steady State Analysis of Capacitor Self Excited InductionGenerators," IEEE Trans. on Power App. and Sys.Vol. PAS-103, No. 3, pp. 612- 618, 1984.

[26] Rahim, Y.H.A., "Excitation of Isolated Three-phase Induction Generator by a single capacitor", IEE Proc.,Pt. B., Vol.140, No. 1, pp. 44-50, 1993.

[27] Malik, N.H; and Mazi, A.A. "Capacitance requirements for isolated Self excited Induction Generators", IEEE Trans. on Energy Conversion,Vol. EC-2, No. 1, pp. 62-69, 1987.

[28] B. Mogstad, M. Molinas, P. K. Olsen, R. Nilssen, "A power conversion system for offshore wind parks," in Proc. of the 34th Annual Conference of the IEEE Industrial Electronics Society IECON 2008, Florida, USA Nov. 2008.

[29] M. Molinas, O. Skjervheim, P. Andreasen, T. Undeland, J. Hals, T. Moan, B. Sorby,"Power Electronics as grid interface for actively controlled wave energy converters," in Proc. of International Conference of Clean Electrical Power, Capri Italy, May 2007.

[30] .

[31] M. Molinas, D. Moltoni. G. Fascendini, J.A. Suul, R. Faranda, T. Undeland, "Investigation on the role of power electronics controlled constant power

[32] loads for voltage support in distributed AC systems," in Proc. of IEEE Power Electronics Specialists Conference, Rodhes, Greece, June 2008.

[33] IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

[34] E. Santi, D. Franzoni, A. Monti, D. Patterson, F. Ponci, N. Barry, "A fuel Cell Based Domestic Uninterruptible power Supply,", in proc, APEC 2002 Conf, 2002, vol. 1, pp. 605-613.

[35] F. Schimpf, L. Norum,"Grid connected converters for photovoltaic, state of the art, ideas for improvement of transformer less inverters," in Proc of NORPIE 2008, Finland, June 2008.

[36] W. Short, P. Denholm, A preliminary assessment of plug in hybrid electric vehicle in wind energy markets, National Renewable Energy Laboratory NREL/TP-620-39729.

[37] S. Lentendre, P. Denholm, Power Utilities Fortnightly, pp. 28-37, Dec. 2006. Brooks, Vehicle to grid demonstration project: grid regulation ancillary service with a battery electric vehicle, AC propulsion , Dec. 2002