POWER SYSTEM QUALITY IMPROVEMENT USING FLEXIBLE AC TRANSMISSION SYSTEMS BASED ON ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

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ABSTRACT:

This paper introduces comprehensive fast control characteristics and continuous compensation means using Adaptive Neuro-Fuzzy Inference System. Flexible AC Transmission System (FACTS) devices have been investigated and adopted in power engineering area. There are so many advantages in using FACTS devices. It can increase dynamic stability, loading capability of transmission lines, improve power quality as well as system security. It can also increase utilization of lowest cost generation. This paper presents a detailed Adaptive Neuro-Fuzzy Inference System based algorithm for improving power system quality using Advanced Flexible AC Transmission Systems (FACTS) controllers. Namely, Advanced Thyristor Controlled Series Capacitors (ATCSCs), and Advanced Static Var Compensator (ASVC) were utilized in this research. This paper focuses on the operation of the FACTS device under generator fault that may cause any other transmission lines to be overflowed. Adaptive Neuro-Fuzzy Inference System (ANFIS) is used to determine the value of capacitor connected to the FACTS. The proposed algorithm in this paper is tested on the IEEE 30 bus system as well as IEEE 14 bus system.

Key Words: Adaptive Neuro-Fuzzy Inference System, *Flexible AC Transmission System, Power Quality, Voltage Sag, Total Harmonic Distortion.*

1. INTRODUCTION

Studies of power quality phenomena have emerged as an important subject in recent years due to renewed interest in improving the excellence of the electricity supply. As sensitive electronic equipment continues to proliferate, the studies of power quality have been further emphasized [1]. There are two main ways for improving power quality:

- The cost-free improving power quality.
- Not cost-free improving power quality.

The cost-free means for improving power quality include actions like:

- Operation of tap changing transformers.
- Operation of conventional compensating devices.
- Control by FACTS devices.

Flexible AC Transmission Systems (FACTS) forms a new domain in power system control engineering, using power electronic devices and circuits and the more recent existing technologies in automatic control.

The two main objectives of FACTS are:

a) To increase transmission capacity of lines.
b) Control power flow over designated transmission, electronically and statically, without need of operator's actions and without need of mechanical manipulations or conventional breakers switching.

The collapse points are known as maximum loadability points, the voltage collapse problem can be restated as an optimization problem where the objective is to maximize certain system parameters typically associated to load levels [2, 3, 4, and 5]. It is well known that shunt and series compensation can be used to increase the maximum transfer capabilities of power networks [6]. Hence, voltage collapse techniques may also be used to compute the maximum power that can be transmitted through the transmission system, also known in the new competitive energy market as Total Transfer Capability (TTC) [7]. With the improvements in current voltage handling capabilities of power electric devices that have allowed for the development of FACTS, the possibility has arisen of using different types of controllers for efficient shunt and series compensation. Thus, FACTS controllers based on thyristor controlled reactors (TCRs), such as Thyristor Controlled Series Reactors (TCSRs) and Thyristor Controlled Series Capacitors (TCSCs), are being used by several utilities to compensate their systems [8]. More recently, various types of controllers for shunt and series compensation, based on voltage source inverters (VSIs), Shunt and Series Static Synchronous Compensators (STATCOMs and SSSCs) and Unified Power Flow Controllers (UPFCs), have been proposed and developed [9]. In [10], the authors used approximate SVC and TCSC models together with typical collapse computational tools and optimization techniques to determine the appropriate location and size of these controllers; dynamic simulations using more detailed models are then performed to study the effect of these controllers in the overall stability of the network. In [11], the authors used standard voltage collapse analysis tools to study the effect of the maximum load margin on the location of a given SVC; an approximate SVC model is used for the computations. In [12] power quality is related to balancing of the unbalanced three-phase load voltages and line currents, while improving load power-factors to unity and performing load voltages regulation, this can be achieved by using (FACTS). In [13] an approach to locate, and size the Static Var Compensator (SVC) using modal analysis in a power system in order to increase the Steady State Voltage Stability (SSVS) margin. In [14] the optimizations are made on three parameters: the location of the devices, their types and their sizes, the FACTS devices are located in order to enhance the system security, five types of FACTS controllers are modeled for steady-state studies: TCSC, TCVR, TCPST, SVC and UPFC. In [15] a mixed integer based non-linear programming approach for optimal location of UPFC for system loadability enhancement in competitive electricity markets. In [16] a method to determine the optimal location of thyristor controlled series compensators has been suggested in this paper based on real power performance index and reduction of total system reactive power loss. Published research work [17] presents one of the heuristic methods i.e. a Genetic Algorithm to seek the optimal location of FACTS devices in a power system. In [18] the optimal location and parameters of Unified Power Flow Controllers (UPFCs) in electrical power systems is studied. In [19] the optimal location of Flexible AC Transmission Systems (FACTS) in multimachine power system using Genetic Algorithm, the objective is to obtain the bus voltages of the system within healthy limits, TCSC is the FACT device chosen for the proposed algorithm, the location of FACT devices and their rated values are optimized simultaneously. In [20] location of FACTS devices in the power system are obtained on the basis of static and/or dynamic performances, the best locations are in the line congested or near that line. Moreover, the proposed algorithm in this paper is tested and verified on the IEEE 30 bus system and IEEE 14 bus system by using ATP simulation program.

2. CONSIDERATION ON POWER QUALITY

The nonlinear characteristics of various office and industrial equipment connected to the power grid could cause electrical disturbances leading to poor power quality. These electrical disturbances could destroy certain sensitive equipment connected to the grid or in some cases could cause them to malfunction. There is virtually no piece of office or industrial equipment that does not depend on electricity in some form or other. Among the office equipment are computers, fax machines, copiers, and telephones etc. Computers have dominated the work place while the others in modern days have microprocessors. All this electronic equipment when connected to the power system can actually generate electrical disturbances, which can adversely affect other equipment within the power network. Heavy industrial equipment such as nonlinear variable speed drives powered through power electronic converters cause the power disturbances. The transient problems such as sags and swells when repeatedly experienced can damage electronic equipment connected to the network [24- 26].

3. STEADY STATE COMPENSATOR

There are several FACTS devices used in power system. Some of them are already installed in the power system and in operation. Those devices can be categorized into 3 groups. One group in category is series compensators - TCSR, TCSC. Another group is shunt compensators such as SVC, STACOM. The last one is combined compensators like UPFC. Among those compensators, series compensators are adapted in [21] because it shows highly cost efficient characteristics in controlling the active power flow. The use of FACTS devices to improve the power transfer capability in a high voltage transmission line is of greater interest these days [22]. In [23] a residue factor method used to obtain the optimal location of TCSC device to damp out the inter-area mode of oscillations.

3.1 THEORY

In the case of a no-loss line, voltage magnitude at receiving end is the same as voltage magnitude at sending end:

$$V_s = V_r = V. \tag{1}$$

Transmission results in a phase lag δ that depends on line reactance X.
As it is a no-loss line, active power P is the same at any point of the line:

$$\begin{aligned} P_s = P_r &= P \quad (2) \\ &= (V\cos(\delta/2))((2V\sin(\delta/2))/X) \\ &= (V^2 \sin\delta)/X \quad (3) \end{aligned}$$

Reactive power at sending end is the opposite of reactive power at receiving end:

$$\begin{aligned} Q_s &= -Q_r \quad = Q \\ &= (V\sin(\delta/2))((2V\sin(\delta/2))/X) \\ &= (V^2(1-\cos\delta))/X \quad (4) \end{aligned}$$

As δ is very small angle, active power mainly depends on δ whereas reactive power mainly depends on voltage magnitude.

3.2 SERIES FACTS

FACTS for series compensation modify line impedance: the total transmission system reactance X is decreased so as to increase the transmittable active power. However, more reactive power must be provided.

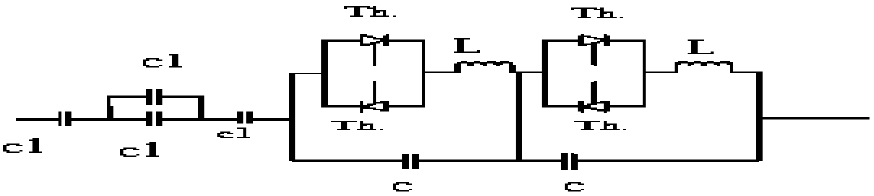
$$P = (V^2 \sin\delta)/(X-X_c) \qquad (5)$$

$$Q = (V^2(1-\cos\delta))/(X-X_c) \qquad (6)$$

This can be done by one of the following method.

3.2.1 ADVANCED THYRISTOR CONTROLLED SERIES CAPACITOR (ATCSC):

It is a capacitive reactance compensator which consists of a series capacitor bank shunted by thyristor controlled reactor TCR, in order to provide a smoothly variable series capacitive reactance X_C and connected to series capacitor bank reactance X_{C1eq}. ATCSC components are given in Figure 1.



c=1F, L=1H, Th.: Vig=3V, Ihold=0.1A, Tdeion=0.0001sec.

Figure (1): Layout of Advanced Thyristor Controlled Series Capacitor (ATCSC)

In the case of ATCSC the following equation is used:

$$P = (V^2 \sin\delta)/(X-X_c) + X_{C1eq}\, V^2 \sin\delta \cos\delta \qquad (7)$$

$$Q = (V^2(1-\cos\delta))/(X-X_c) + X_{C1eq}\, V^2 \sin^2\delta \qquad (8)$$

3.3 SHUNT FACTS

Reactive current is injected into the line to maintain voltage magnitude. Transmittable active power is increased but more reactive power is to be provided.

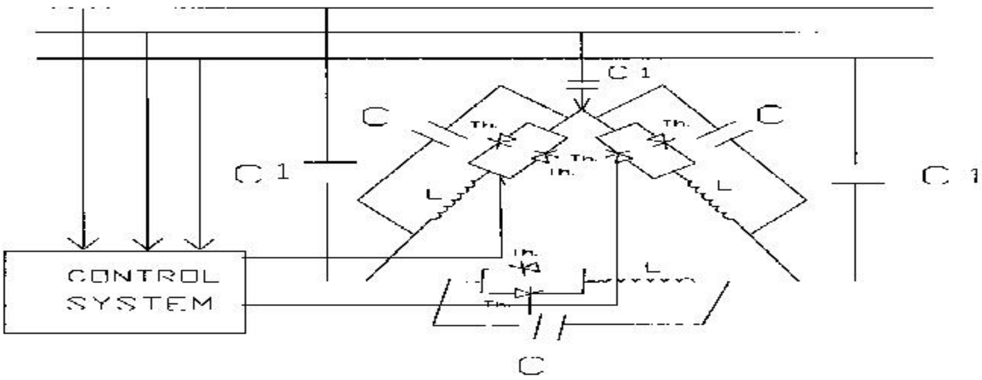
A shunt FACTS controlled by thyristors firing angles (α) yields shunt virtual variable susceptances B(α) at each firing angle given by:

$$B(\alpha) = I^2(\alpha)\, X_c / V \qquad (11)$$

Where: X_c	fixed FACTS reactance
I (α)	the actual FACTS drawn fundamental current
V	terminal voltage magnitude

3.3.1 ADVANCED STATIC VAR COMPENSATOR (ASVC):

The thyristor-controlled shunt compensator is called Advanced Static VAR Compensator (ASVC). The ASVC has the big advantages of fast response and energy conversion with low losses. ASVC components are given in Figure (2).



c=0.8F, L=1H, Th.: Vig=3V, Ihold=0.1A, Tdeion=0.0001sec.

Figure (2): Advanced Static VAR Compensators (ASVC)

4. SYSTEMS UNDER SIMULATIONS STUDY:

IEEE 30 bus system and IEEE 14 bus system are studied in this section. ATP simulation program is used.

4.1 IEEE 30 BUS SYSTEM

IEEE 30 bus system under study was shown in [25]. Figure 3 explain the block diagram of closed loop control system used to control of power quality problem (sag problem) by using advanced FACTS devices. Figure 4 shows the voltage at bus 3 at normal state from 0 to 0.2 sec. (voltage=27.3Kvolt) and when generator connected to bus 1 is out of service from 0.2 to 0.4 sec. (voltage=16.25Kvolt) and when uses Advanced Thyristor Controlled Series Capacitor (ATCSC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=27.3Kvolt). Figure 5 shows the voltage at bus 3 at normal state (voltage=27.3Kvolt) from 0 to 0.2 sec. and when generator connected to bus 1 is out of service (voltage=16.25Kvolt) from 0.2 to 0.4 sec. and when uses Advanced Static VAR Compensator (ASVC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=27.3Kvolt). Figure 6 shows the voltage at bus 2 at normal state from 0 to 0.2 sec. (voltage=27.3Kvolt) and when generator connected to bus 2 is out of service from 0.2 to 0.4 sec. and the voltage is decreased (voltage=11.2Kvolt) and when uses Advanced Thyristor Controlled Series Capacitor (ATCSC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=27.3Kvolt). Figure 7 shows the voltage at bus 2 at normal state (voltage=27.3Kvolt) from 0 to 0.2 sec. and when generator connected to bus 2 is out of service (voltage=11.2Kvolt) from 0.2 to 0.4 sec. and when uses Advanced Static VAR Compensator (ASVC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=27.3Kvolt). A simple and efficient model for optimizing the location of FACTS devices used for improving power quality by controlling the device parameters. Improving power quality using FACTS devices requires a two steps approach:

- The optimal location of the devices in the network must be ascertained

- The settings of the control parameters optimized.

The best locations are in the line need to improve power quality or near that line. ATP simulation program is used. Table 1 illustrates a comparison between different FACTS devices used in IEEE 30 bus system.

4.2 IEEE 14 BUS SYSTEM

IEEE 14 bus system under study was shown in [25]. Figure 8 shows the voltage at bus 1 at normal state from 0 to 0.2 sec. (voltage=3.6kVolt) and when generator connected to bus 1 (G1) is out of service from 0.2 to 0.4 sec. (voltage=1.875kVolt) and when uses Advanced Thyristor Controlled Series Capacitor (ATCSC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=3.6kVolt). Figure 9 shows the voltage at bus 1 at normal state from 0 to 0.2 sec. (voltage=3.6kVolt) and when generator connected to bus 1 (G1) is out of service from 0.2 to 0.4 sec. (voltage=1.875kVolt) and when uses Advanced Static Var Compensator (ASVC) from 0.4 to 0.6 sec. and the voltage increased (voltage=3.41kVolt). Figure 10 shows the voltage at bus 2 at normal state from 0 to 0.2 sec. (voltage=3.72kVolt) and when generator connected to bus 2 (G2) is out of service from 0.2 to 0.4 sec. (voltage=2.29kVolt) and when uses Advanced Thyristor Controlled Series Capacitor (ATCSC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=3.72kVolt). Figure 11 shows the voltage at bus 2 at normal state from 0 to 0.2 sec. (voltage=3.72kVolt) and when generator connected to bus 2 (G2) is out of service from 0.2 to 0.4 sec. (voltage=2.29kVolt) and when uses Advanced Static Var Compensator (ASVC) from 0.4 to 0.6 sec. and the voltage increased (voltage=3.43kVolt). Table 2 demonstrates comparison between FACTS used in IEEE 14 bus system [25].

Table 1 Comparison Between AFACTS Used in IEEE 30 Bus System Using RANN

Generator outage	Voltage at Bus	At normal state	When generator is out of service	Series AFACTS	Shunt AFACTS	AFACTS connected at bus
				by using ATCSC	by using ASVC	
Connected to bus 1	3	27.3kV	16.25kV	27.3kV	27.3kV	3
Connected to bus 2	2	27.3kV	11.2kV	27.3kV	27.3kV	2

Table 2 Comparison Between AFACTS Used in IEEE 14 Bus System Using RANN

Generator outage	Voltage at Bus	At Normal State	When generator is out of service	Series AFACTS	Shunt AFACTS	AFACTS connected at bus
				by using ATCSC	by using ASVC	
Connected to bus 1	1	3.6kV	1.875kV	3.6kV	3.41kV	1
Connected to bus 2	2	3.72kV	2.29kV	3.72kV	3.43kV	2

5. DECISION MAKING LOGIC VIA ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

The acronym ANFIS derives its name from Adaptive Neuro-Fuzzy Inference System. Using a given input/output data set, the toolbox function ANFIS constructs a Fuzzy Inference System (FIS) whose membership function parameters are tuned (adjusted) using either a backpropagation algorithm alone, or in combination with a least squares type of method. This allows fuzzy systems to learn from the data modeling. Adaptive Neuro-Fuzzy Inference System is used to determine the value of capacitor connected to ATCSC, and ASVC. Two input data (voltage under sag and power factor) and one output data (value of capacitor). Table 3 shows these values for IEEE 30 bus system. While Table 4 shows these values for IEEE 14 bus system. Table 5 shows comparison between FACTS used in IEEE 30 bus system by using ANFIS. While Table 6 shows comparison between FACTS used in IEEE 14 bus system by using ANFIS.

6. TOTAL HARMONIC DISTORTION:

One of the most common indices expressing harmonic effects is the Total Harmonic Distortion factor (THD), which can be calculated for either voltage or current :

$$\text{THD}= \left[\sqrt{\sum_{h=2}^{h_{max}} M_h^{\,2}} \right] / M_1 \qquad (12)$$

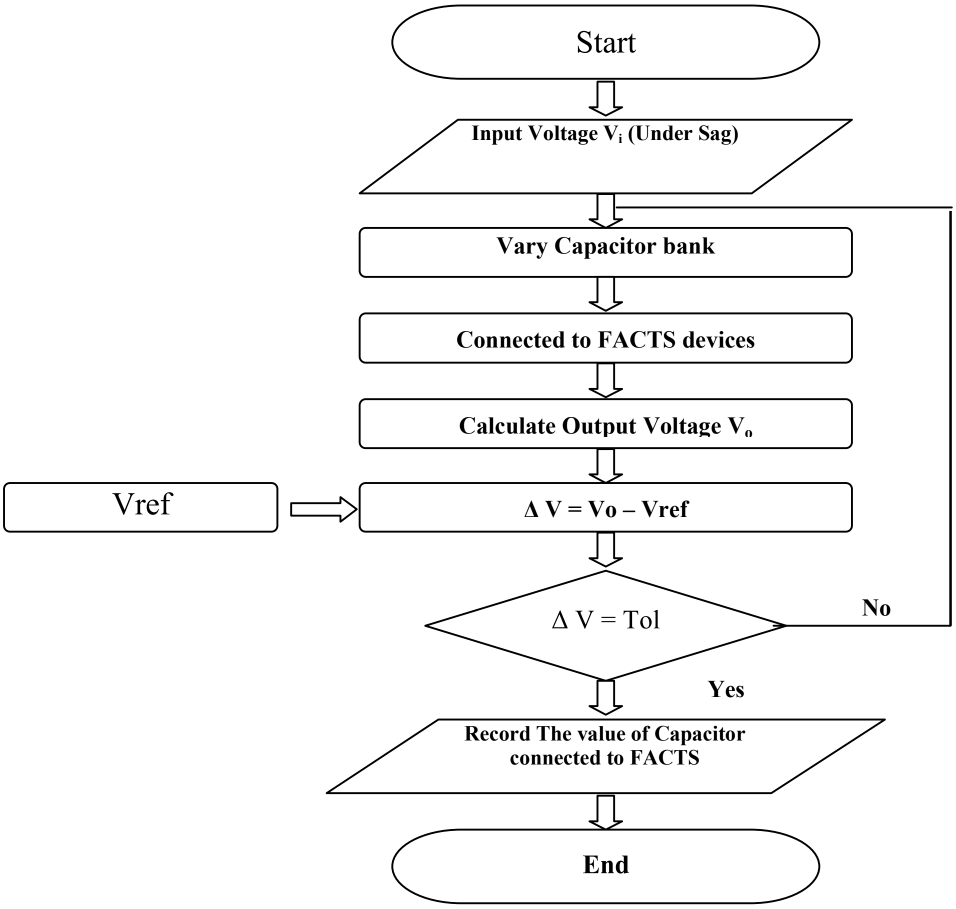
Where M_h is the r.m.s value of harmonic component h of the quantity M.

Table (7) shows the comparison THD between used FACTS in IEEE 30 Bus System. THD at Bus 3 when ATCSC used is less than the other FACTS used. THD at Bus 2 when ASVC used is less than the other FACTS used.

Table (8) shows the comparison THD between used FACTS in IEEE14 Bus System. THD at Bus 1 when combination between ASVC and ATCSC used is less than the other FACTS used. THD at Bus 2 when ATCSR used is less than the other FACTS used.

7. CONCLUSION

In this paper, ATCSC, and ASVC are used to improve power quality. The proposed algorithm was tested on the IEEE 30 bus as well IEEE 14 bus power system. The optimal location to connect FACTS is the bus recommended for improving power quality; based on the Alternative Transient Program (ATP) simulation program. The Alternative Transient Program (ATP) facilities were used for power flow calculations. The best type of FACTS used to improve power quality is ATCSC because of fixed series capacitors shunted by thyristor controlled reactor are provided so as to guarantee service continuity during control actions. Adaptive Neuro-Fuzzy Inference System (ANFIS) is used to determine the value of capacitor connected in FACTS devices. The results are promising for power quality improvement.



Tol=0.001

Figure (3): Flow chart of Closed Loop Control System

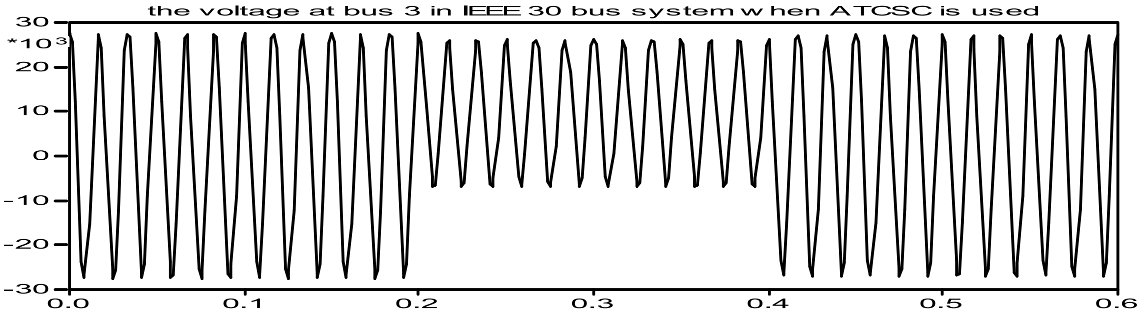


Figure (4): The Voltage At Bus 3 When Uses (ATCSC)

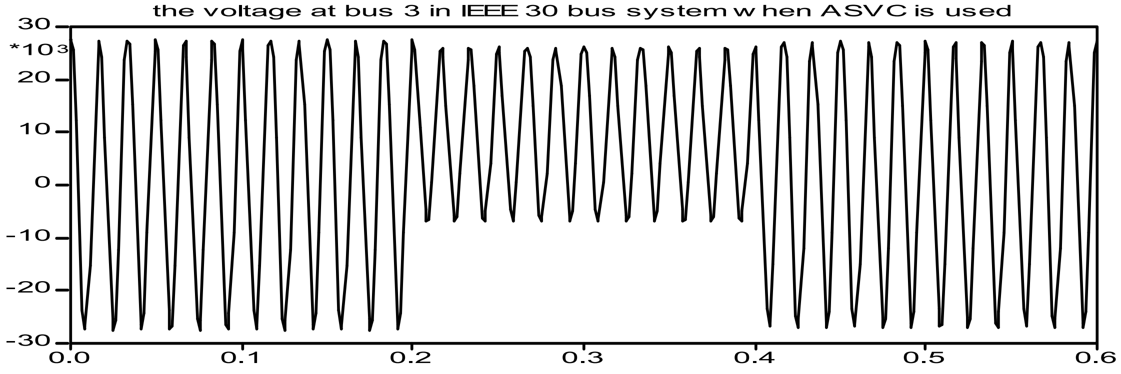


Figure (5): The Voltage At Bus 3 When Uses (ASVC)

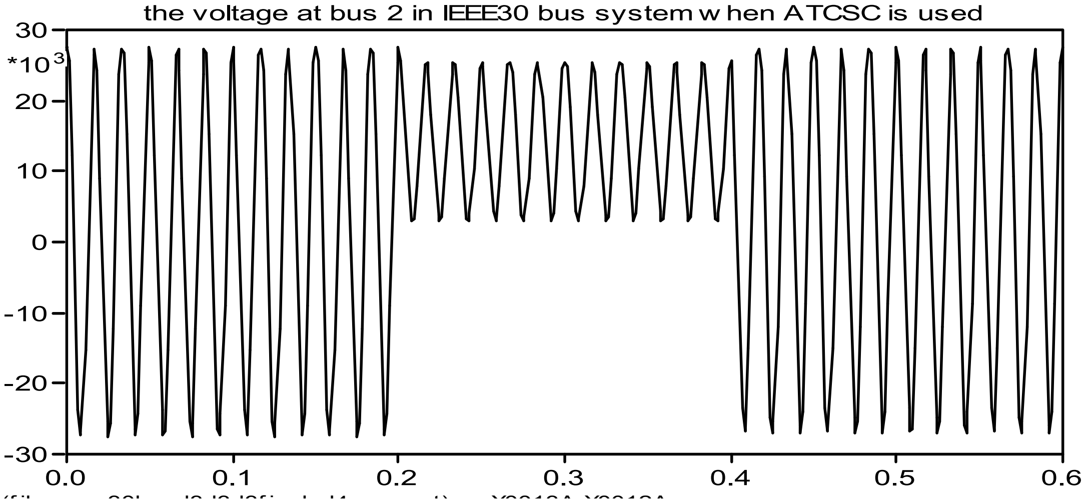


Figure (6): The Voltage At Bus 2 When Uses (ATCSC)

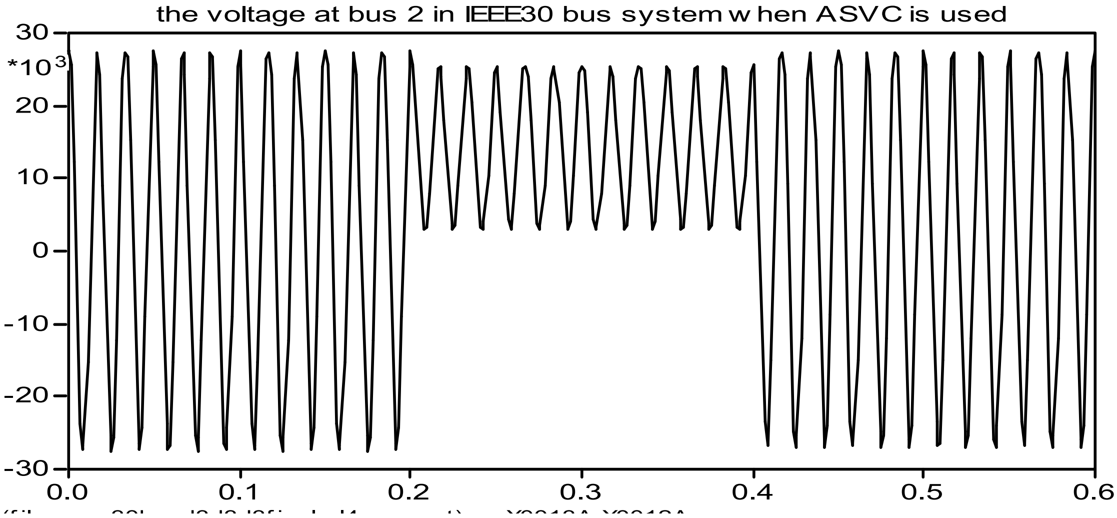


Figure (7): The Voltage At Bus 2 When Uses (ASVC)

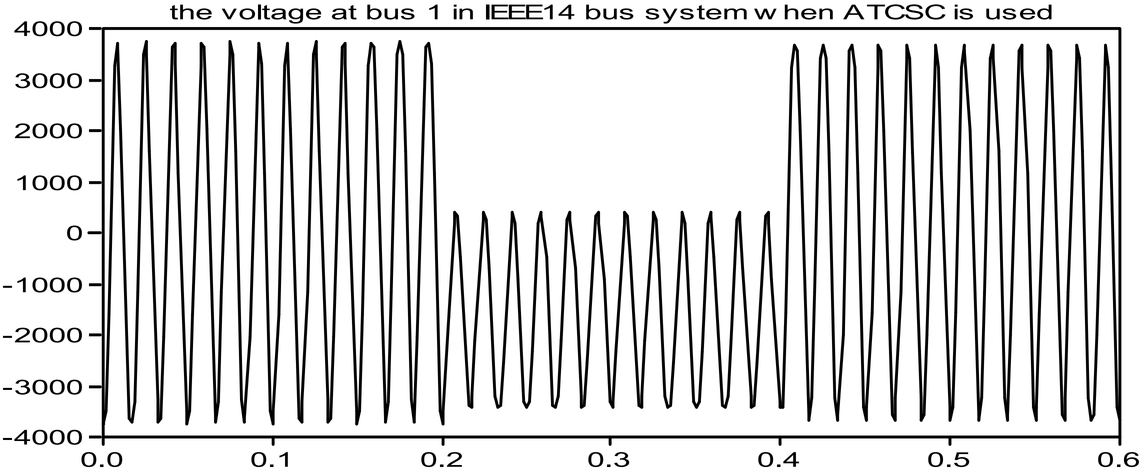


Figure (8): The Voltage At Bus 1 When Uses (ATCSC)

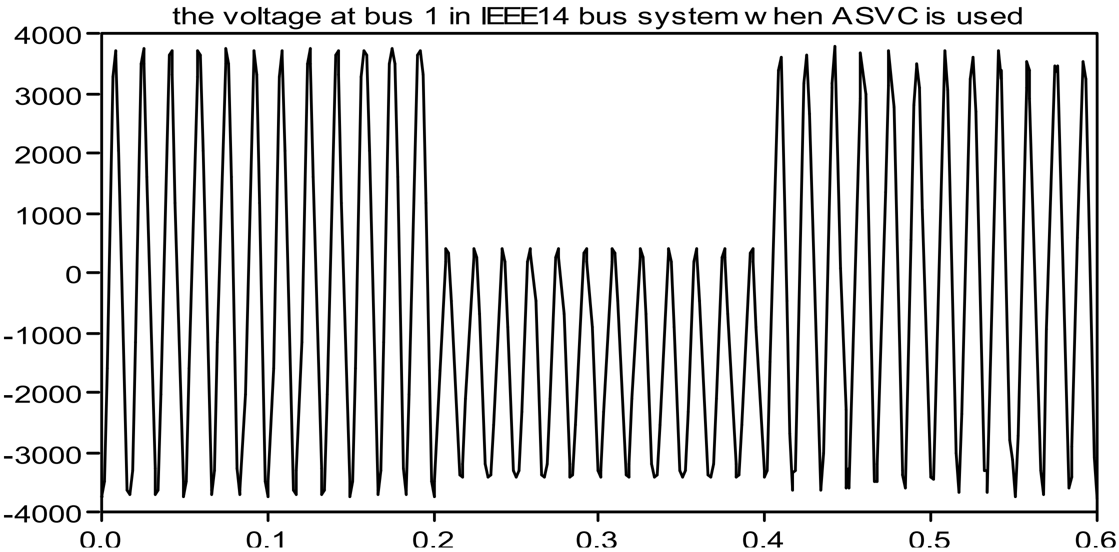


Figure (9): The Voltage At Bus 1 When Uses (ASVC)

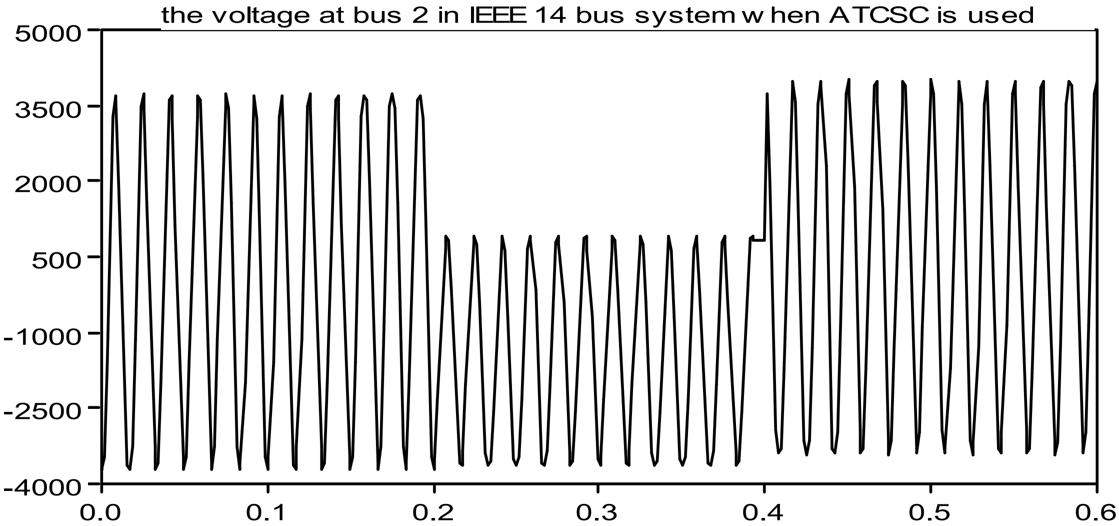


Figure (10): The Voltage At Bus 2 When Uses (ATCSC)

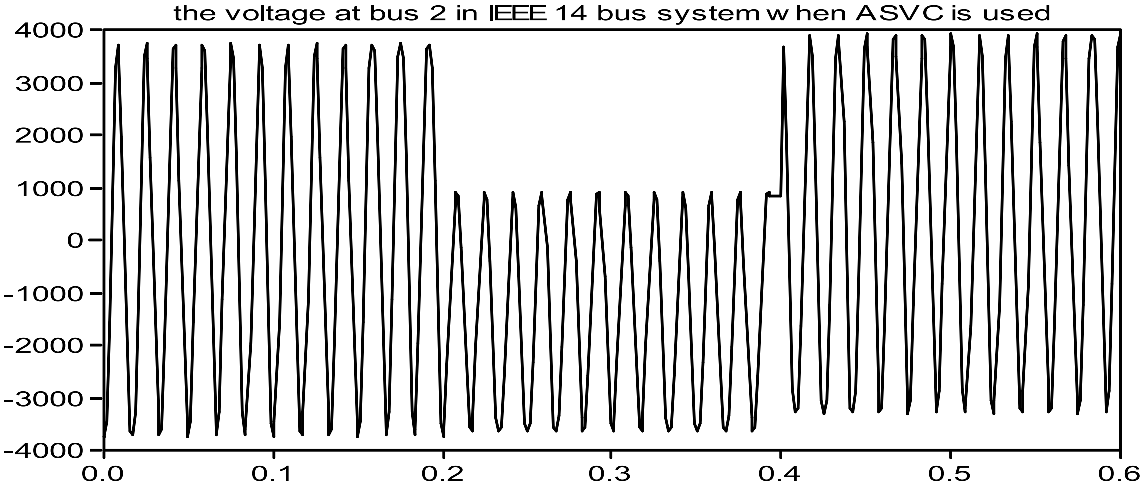


Figure (11): The Voltage At Bus 2 When Uses (ASVC)

Table 3 Value of Capacitor Connected in AFACTS in IEEE 30 bus system by Using ANFIS

FACTS connected at Bus	Values of each capacitor connected in Series AFACTS	Values of each capacitor connected in Shunt AFACTS
	by using ATCSC	by using ASVC
3	0.9948F	0.04289F
2	0.0819F	0.0819F

Table 4 Value of Capacitor Connected in AFACTS in IEEE 14 bus system by Using ANFIS

FACTS connected at Bus	Values of each capacitor connected in Series AFACTS	Values of each capacitor connected in Shunt AFACTS
	by using ATCSC	by using ASVC
1	0.02896F	0.009999F
2	0.02496F	0.502F

Table 5 Comparison Between AFACTS Used in IEEE 30 Bus System by Using ANFIS

Generator outage	Voltage at Bus	At normal state	When generator is out of service	Series AFACTS	Shunt AFACTS	AFACTS connected at bus
				by using ATCSC	by using ASVC	
Connected to bus 1	3	27.3kV	16.25kV	27.23kV	26.73kV	3
Connected to bus 2	2	27.3kV	11.2kV	24.65kV	24.65kV	2

Table 6 Comparison Between AFACTS Used in IEEE 14 Bus System by Using ANFIS

Generator outage	Voltage at Bus	At Normal State	When generator is out of service	Series AFACTS	Shunt AFACTS	AFACTS connected at bus
				by using ATCSC	by using ASVC	
Connected to bus 1	1	3.6kV	1.875kV	3.53kV	3.35kV	1
Connected to bus 2	2	3.72kV	2.29kV	3.62kV	3.24kV	2

Table (7) The Comparison THD Between Used AFACTS in IEEE 30 Bus System

THD at Bus	THD At normal state	THD When generator is out of service	Series AFACTS	Shunt AFACTS
			THD by using ATCSC	THD by using ASVC
3	2.6665%	2.6665%	2.8177%	2.8181%
2	2.6665%	2.6659%	2.6936%	2.6934%

Table (8) The Comparison THD Between AFACTS Used in IEEE 14 Bus System

THD at Bus	THD At normal state	THD When generator is out of service	Series AFACTS	Shunt AFACTS
			THD by using ATCSC	THD by using ASVC
1	2.678%	2.6781%	2.7038%	2.7038%
2	2.6849%	2.7004%	2.7015%	2.7282%

6. REFERENCES

[1] Mohamed Ramadan, "Power quality detection and classification by using modern computer techniques" Master thesis, Ain shams university, Faculty of engineering, Egypt, 2004.

[2] T. Van Cutsem, "A method to compute reactive power margins with respect to voltage collapse" IEEE Trans. Power Systems, February 1991, Vol. 6, No. 1, pp. 145-156.

[3] J. Lu, C. W. Liu, and J. S. Thorp, "New methods for computing a saddle-node bifurcation point for voltage stability analysis". IEEE Trans. Power Systems, May 1995, Vol. 10, No. 2, pp. 978-989.

[4] C. J. Park, I. F. Morrison, and D. Sutanto, "Application of an optimization method for determining the reactive margin from voltage collapse in reactive power planning," IEEE Trans. Power Systems, August 1996, Vol. 11, No. 3, pp. 1473-1483.

[5] C. A. Canizares,"Calculating optimal system parameters to maximize the distance to saddle-node bifurcations," accepted for publication in the IEEE Trans. Circuits and Systems I, May 1997.

[6] A. R. Bergen, "Power Systems Analysis", Prentice-Hall, New Jersey, 1986.

[7] R. P. Klump and T. J. Overbye, "A transmission-based voltage stability measure for available transfer cabability (atc) calculation," Proc. NAPS, MIT, November 1996, pp. 351-357.

[8] D. Maratukulam, editor, Proc. FACTS Conference I the Future in High-voltage Transmission, TR-100504, EPRI, March 1992.

[9] L. Gyugyi, "Dynamic compensation of ac transmission lines by solid-state synchronous voltage sources," IEEE Trans. Power Delivery, April 1994, Vol. 9, No. 2, pp. 904-911.

[10] L. A. S. Pilotto, W. W. Pinr, A. R. Carvalho, A. Wey, W. F. Long, F. L. Alvarado, C. L. DeMarco, and A. Edris, "Determination of needed facts controllers that increase asset utilization of power systems," IEEE Trans. Power Delivery, January 1997, Vol. 12, No. 1, pp. 364-371.

[11] Y. Mansour, W. Xu, F. Alvarado, and C. Rinzin, "SVC placement using critical modes of voltage instability," IEEE Trans. Power Systems, May 1994, Vol. 9, No. 2, pp. 757-763.

[12] M.Z.El Sadek, et al, "Flexible AC Transmission Systems (FACTS) for power quality improvement of unbalanced systems suffering from voltage instability", MEPCON'2001, University of Helwan, Cairo, Egypt.

[13] Mohamed A. H. El-sayed, et al, "Power system voltage stability improvement by SVC", MEPCON'2003, Shebin Elkom, Egypt.

[14] S. Gerbex, R. Cherkaoui, and A. J. Germond, "Optimal Location of FACTS Devices to Enhance Power System Security", IEEE Bologna power tech conference, June 23th-26th, June 2003, Bologna, Italy.

[15] ASHWANI KUMAR,"Optimal Location of UPFC and Comparative Analysis of Maximum Loadability with FACTS in Competitive Electricity Markets", 7th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines, 2007, Venice, Italy.

[16] Seyed Abbas Taher, Hadi Besharat, "Transmission Congestion Management by Determining Optimal Location of FACTS Devices in Deregulated Power Systems", 2008, American Journal of Applied Sciences 5 (3): 242-247, 2008.

[17] K. Lokanadham, "Optimal Location of FACTS Devices in Power System by Genetic Algorithm", global journal of researches in engineering, April 2010, Vol. 10 Issue 1 (Ver 1.0), April 2010.

[18] Ibrahim Oumarou, Daozhuo Jiang, Cao Yijia, "Optimal Placement of Shunt Connected Facts Device in a Series Compensated Long Transmission Line", Proceedings of the World Congress on Engineering 2009, Vol I WCE 2009, July 1 - 3, 2009, London, U.K.

[19] H.O. Bansal et al., "Optimal Location of FACT Devices to Control Reactive Power", International Journal of Engineering Science and Technology, 2010, Vol. 2(6), 2010, 1556-1560.

[20] S.N.Singh, and A. K. David, "Optimal location of facts devices for congestion management", Electrical Power System Research, June 2001, Vol. 58, Issue 2, 21 pages 71-79.

[21] Douglas J. Gotham, "Power Flow Control and Power Flow Studies for Systems with FACTS Devices," IEEE Trans. Power Systems, Feb. 1998, Vol. 13, No.1.

[22] P.K.Dash, S.R. Samantaray, and Ganapati Panda, "Fault Classification and Section Identification of an Advanced Series-Compensated Transmission Line Using Support Vector Machine", IEEE Trans. Power Delivery, Jan. 2007, Vol. 22, No. 1.

[23] N. Magaji and M. W. Mustafa, "Optimal Location of TCSC Device for Damping Oscillations", ARPN Journal of Engineering and Applied Sciences, May 2009, Vol. 4, No. 3.

[24] M. Ramadan Sayed, M. Hanafy Saleh, M.Ahmed Moustafa, A. Abdeltwab Hassan, “Power System Quality Improvement Using Flexible AC Transmission Systems Based on Artificial Neural Network”, International Journal of Innovation in Electrical Power Systems, vol.3,no.2, 2011.

[25] M. Ramadan Sayed, “Improving Power System Quality Using Flexible AC Transmission Systems", Ph.D thesis will be submitted in Minia university, Faculty of engineering, Egypt, 2012.

[26] M.R. Sayed, A.A. Hassan, "Improving Power System Quality Using Flexible AC Transmission System", EIJEST, vol.14, no.2, May 2011.