

# 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 (AFACTS) 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 AFACTS. 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 a main subject in recent years due to renewed interest in improving the excellence of the generation of power. 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:

- Using of tap changing transformers.
- Operation of conventional compensating devices for example capacitor bank.
- 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 the capability of 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 by thyristor controlled reactors (TCRs), such as Thyristor Controlled Series Reactors (TCSR) and Thyristor Controlled Series Capacitors (TCSCs), are being used by several utilities to compensate their systems [8]. 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. The optimal location of FACTS devices in the power system are obtained on [15-20]. 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. This paper presents as follow: Section two introduces the power quality, steady state compensator, and the theory. Section three presents the systems under study. Section four presents decision making logic via Adaptive Neuro-Fuzzy Inference System. Section five calculates

total harmonic distortion. While Section six introduces conclusion and high light of this paper. The article has an updated list of references were given.

## 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 as given as [24- 26].

### 2.1 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.

### 2.2 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  $\delta$  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:

$$P_s = P_r = P \tag{2}$$

$$= (V \cos(\delta/2))((2V \sin(\delta/2))/X) \tag{3}$$

$$= (V^2 \sin\delta)/X \tag{3}$$

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

$$Q_s = -Q_r = Q$$

$$= (V \sin(\delta/2))((2V \sin(\delta/2))/X)$$

$$= (V^2(1-\cos\delta))/X \tag{4}$$

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

### 2.3 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.

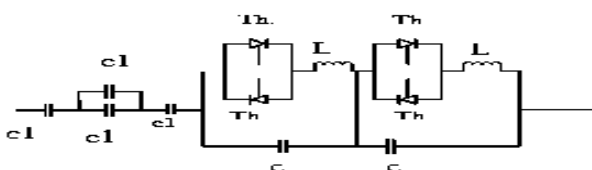
$$P = (V^2 \sin\delta)/(X-X_c) \tag{5}$$

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

This can be done by one of the following method.

#### 2.3.1 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:

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

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

### 2.4 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 ( $\alpha$ ) yields shunt virtual variable susceptances  $B(\alpha)$  at each firing angle given by:

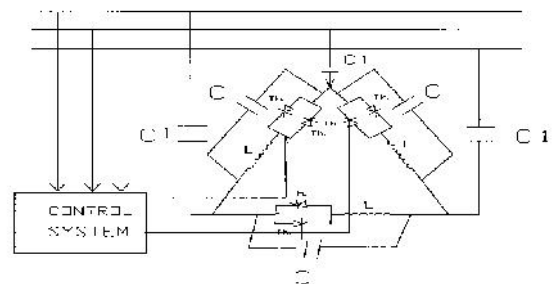
$$B(\alpha) = I^2(\alpha) X_c / V \tag{9}$$

Where:

- $X_c$  fixed FACTS reactance
- $I(\alpha)$  the actual FACTS drawn fundamental current
- $V$  terminal voltage magnitude

#### 2.4.1 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).



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

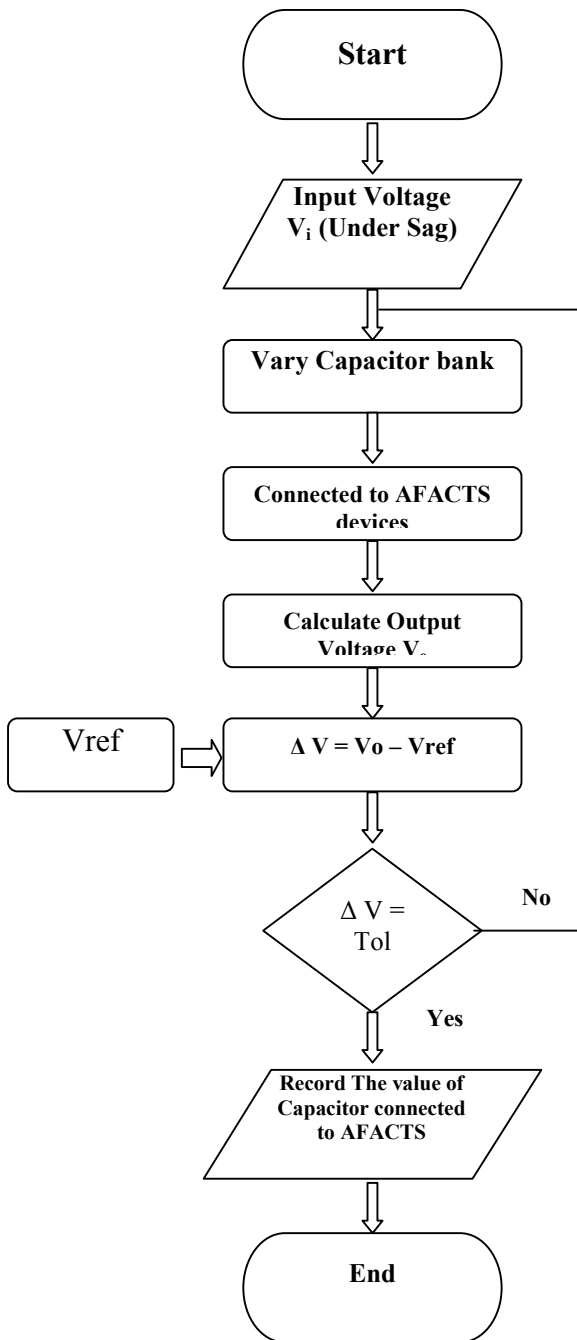
Figure (2): Advanced Static VAR Compensators (ASVC)

### 3. SYSTEMS UNDER SIMULATIONS STUDY:

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

#### 3.1 IEEE 30 BUS SYSTEM

IEEE 30 bus system under study was shown in [25].

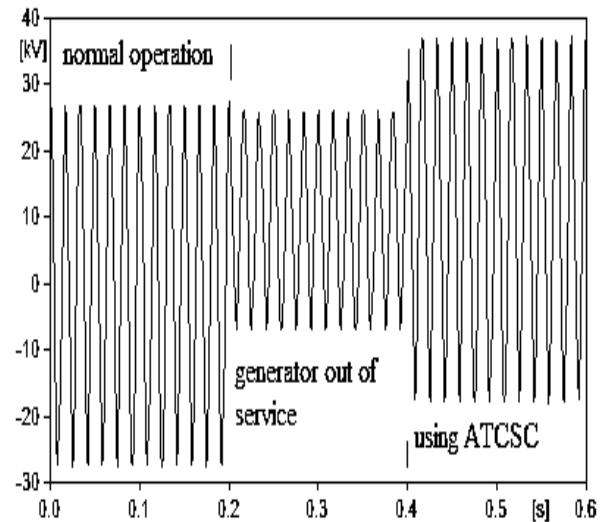


*Tol = 0.001*

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

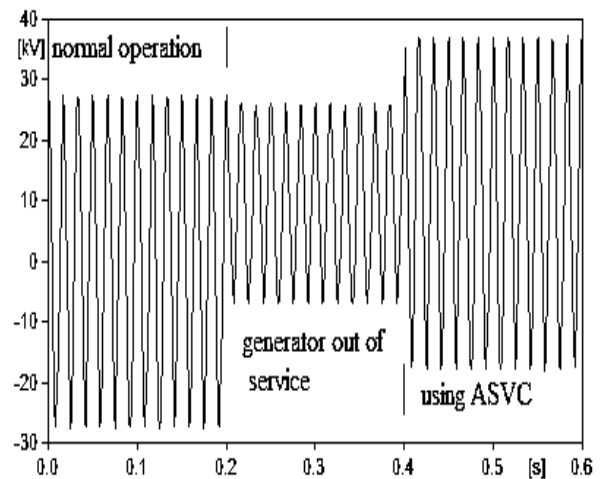
Figure 3 explain the block diagram of closed loop control system used to control of power quality problem (sag problem) by using advanced FACTS devices.

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 (4): The Voltage At Bus 3 When ATCSC is Used**

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 (5): The Voltage At Bus 3 When ASVC is Used**

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).

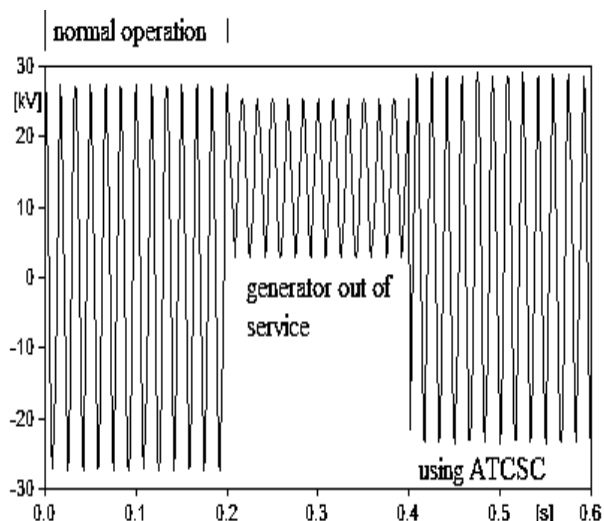


Figure (6): The Voltage At Bus 2 When ATCSC is Used

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).

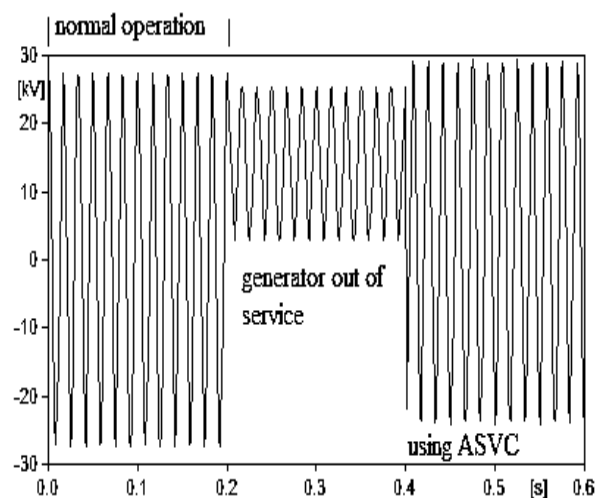


Figure (7): The Voltage At Bus 2 When ASVC is Used

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.

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

Voltage at Bus	At normal state	When generator is out of service	Series AFACTS	Shunt AFACTS
			by using ATCSC	by using ASVC
3	27.3kV	16.25kV	27.3kV	27.3kV
2	27.3kV	11.2kV	27.3kV	27.3kV

### 3.2 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).

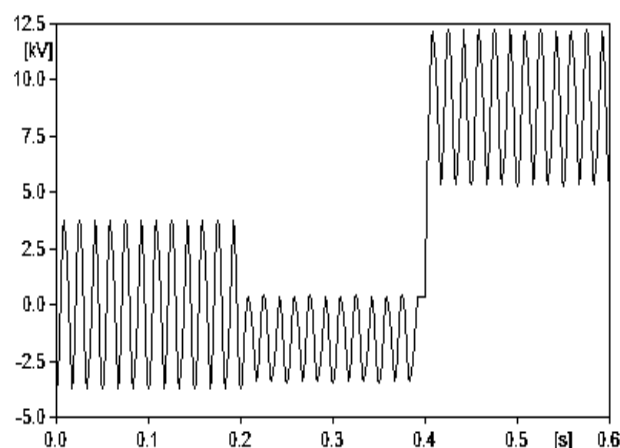
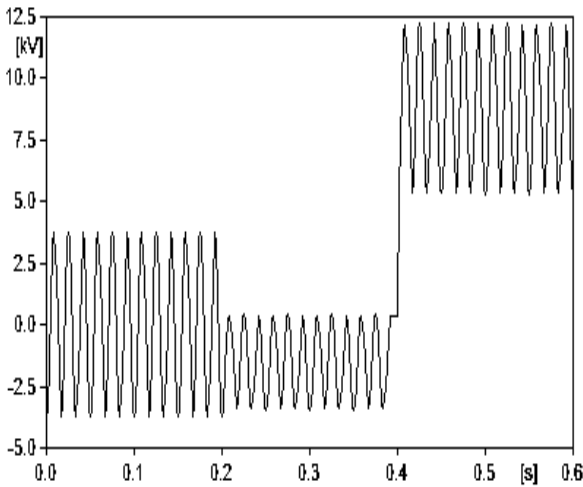


Figure (8): The Voltage At Bus 1 When ATCSC is Used

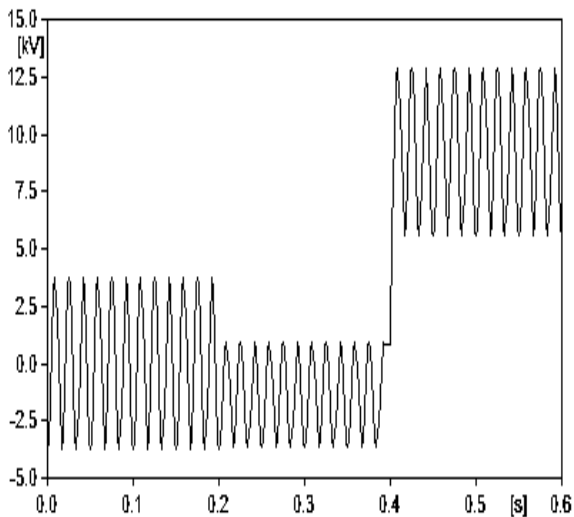
Figure 9 shows the voltage at bus 1 at normal state from 0 to 0.2 sec. (voltage=3.6kVolt) and when generator connected to bus 1 (G1) is out of service from 0.2 to 0.4 sec. (voltage=1.875kVolt) and when uses Advanced Static Var Compensator (ASVC)

from 0.4 to 0.6 sec. and the voltage increased (voltage=3.41kVolt).



**Figure (9): The Voltage At Bus 1 When ASVC is Used**

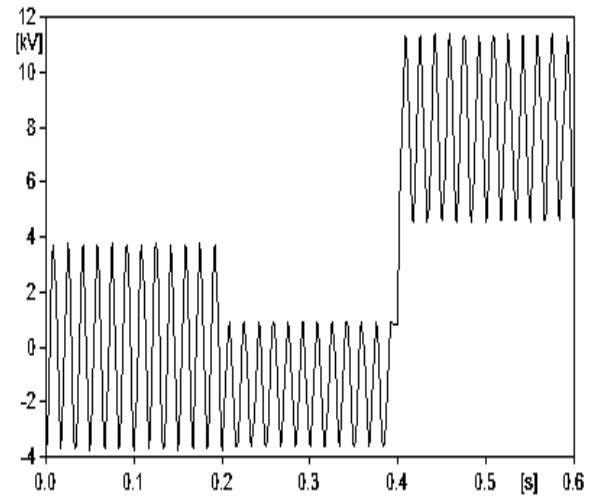
Figure 10 shows the voltage at bus 2 at normal state from 0 to 0.2 sec. (voltage=3.72kVolt) and when generator connected to bus 2 (G2) is out of service from 0.2 to 0.4 sec. (voltage=2.29kVolt) and when uses Advanced Thyristor Controlled Series Capacitor (ATCSC) from 0.4 to 0.6 sec. and the voltage increased to the normal state (voltage=3.72kVolt).



**Figure (10): The Voltage At Bus 2 When ATCSC is Used**

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).



**Figure (11): The Voltage At Bus 2 When ASVC is Used**

Table 2 demonstrates comparison between AFACTS used in IEEE 14 bus system [25].

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

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

**4. 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.

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

AFACTS 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

While Table 4 shows these values for IEEE 14 bus system.

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

AFACTS 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 shows comparison between AFACTS used in IEEE 30 bus system by using ANFIS.

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

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

While Table 6 shows comparison between AFACTS used in IEEE 14 bus system by using ANFIS.

**5. 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 [25]:

$$THD = [\sqrt{\sum_{h=2}^{h_{max}} M_h^2}] / M_1 \tag{10}$$

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 AFACTS used. THD at Bus 2 when ASVC used is less than the other AFACTS used.

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

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

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

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) 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 AFACTS used. THD at Bus 2 when ATCSR used is less than the other AFACTS used.

**6. 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 AFACTS 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 AFACTS devices. The results are promising for power quality improvement. If this new research will apply the cost of generation of power is less than the cost of generation of power now and the power quality will improve. Moreover, voltage sag problem will be eliminated, therefore continuity of power supply will be granted.

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

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%

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