INTELLIGENT SYSTEM BASED CONTROL IMPLEMENTATION OF THE FACT DEVICE IN A DISTRIBUTED POWER GENERATION SYSTEM

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Abstract: *This paper proposes a flexible ac transmission system device such as STATCOM with intelligent controller scheme for enhancement operation of Distributed power generation system. It is refers to power generation at the point of consumption and also are being interested in order to diminish the burden on the national grid. Distributed generation systems comprise of local fossil fuel based generators with facilities for extending renewable real power sources through the STATCOM. In addition to the objective of real power injection the STATCOM can give the additional support of reactive power as well. In this research the control methodology for the management of the STATCOM, which provides reactive and renewable energy based real power support, using the Adaptive Neuro Fuzzy Inference System based Control system (ANFIS) is investigated. It has been established using MATLAB / SIMULINK based simulation environment. The result-s reveal that the ANFIS based control scheme outperforms the traditional methods.*
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Key words: *Distributed generation, FACTS,STATCOM, ANFIS*

1. Introduction

The growing interest in environmental issues, combined with the progress of technologies to couple renewable sources to the grid and liberalization of energy market have led to a growing share of grid connected distributed generation (DG) [1-2] Distributed generation applications are located near load.it reduces transmission and distribution cost [3-4] The distributed generation system plays a key role in power supply to all over the world by utilizing various energy sources With the rapid development of new energy technologies, more renewable sources are being integrated into power systems in the form distributed generations (DG).These DGs,such as wind and solar, are highly intermittent and hence they along with the variations in loads can affect the voltage regulation in a point of common coupling adversely [5-8].To meet the challenges of these voltage instability and reactive power compensation used FACTS devices. It has revolutionised the power transmission systems leading to more flexible power transaction. voltage sag and swell, mitigation, prevention of system black out during faults, reactive power support are some of the advantages we have got using the FACTS devices[9-12]. The STATCOM, one of the members of the family of FACTS devices is an indispensable work horse that is mainly used for reactive power support while it can offer other features such as source current balancing and harmonic mitigation etc. [13-16]. Renewable energy sources such as the Photo Voltaic Power generation system be connected to the DC link of the STATCOM and the converter of the STATCOM can be used to link this DC power into the AC bus bar of the system after duly converting the DC sources into AC of the required amplitude, frequency and phase [17-23]. The direction of research has been in the areas of control system pertaining to the control strategies of the power transaction requirements and it is essentially the generation of the reference signal. Traditional control systems such as the PI and the PID control schemes have been very popular [24-25]. Where it was difficult to mathematically model the plant and the associated compensators, the mathematical controllers like PI and PID could not help much and intelligent controllers like the fuzzy logic controller and the Artificial Neural Network based (ANN) control systems were designed and implemented [26-34]. This paper focuses the possibilities of the development of fuzzy logic control system and the ANN in the management of the control schemes of the STATCOM.It has been verified as depicted in the following chapters that both the fuzzy logic control scheme and the ANN scheme are good, the fusion of these two, deriving and tapping the advantages of both these schemes, combining them into a hybrid scheme leading to the ANFIS methodology outperforms the control techniques. The proposed methodology has been verified using the MATLAB SIMULINK based simulation.

2. Distributed Generation

Distributed generations have become more popular alternative to bulk amount of electric power generation. Distributed generation refers to generating power on-site, rather than centrally, eliminates the cost, complexity, indecencies. And improved environmental performance. Distributed generation encompasses a wide range of prime mover technologies, such as micro turbine, photovoltaic cells, fuel cells and wind powered units will be optimally located near the load side due to presence of dynamic load such as inductive loads which make voltage profiles worsen. Else, it is possible and can be convenient to integrate power quality functions by compensating the reactive power and the current harmonics by adopting FACTS controller device. In this proposed method STATCOM is used for managing active and reactive power of DG units in distribution system. The figure1shows the position of a STATCOM in a typical distributed power generation scheme.

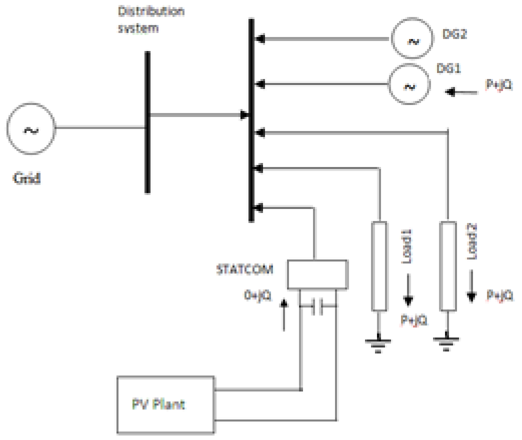


Fig 1. Position of STATCOM in Distributed system

3. Static Synchronous Compensator

The STATCOM is the work horse in the FACTS family. The STATCOM is a bi directional two port power converter in which one of the two ports is meant to handle three phase AC while the other side is meant to handle DC. On the DC link is a capacitor called the DC link capacitor. Real and reactive power can be transacted across the AC and DC side of the STATCOM in both directions. The main objective of the STACOM is to source the reactive power demand of the load thus relieving the main source from being burdened with reactive demand that could otherwise cause low power factor on the AC side. The three terminals of the three phase AC side of the STATCOM are connected to the AC bus bar in the shunt configuration and the system obeys the Kirchoff's Current law as indicated by figure 2.

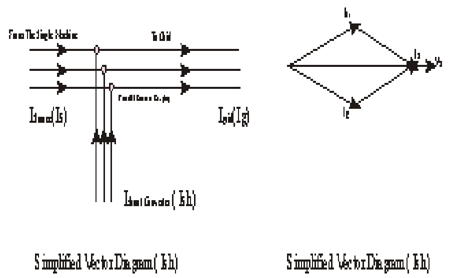


Fig 2. Vector diagram of the STATCOM

In between the STATCOM and the three phase AC bus bar a three phase reactor is inserted. The real and reactive power transactions happening over the reactor are given by the following equations. The real power transferred between the point of common coupling (PCC) and the terminals of the STATCOM is governed by Equation (1).

$$P = \frac{(V_1 V_2 \sin \delta)}{X} \quad (1)$$

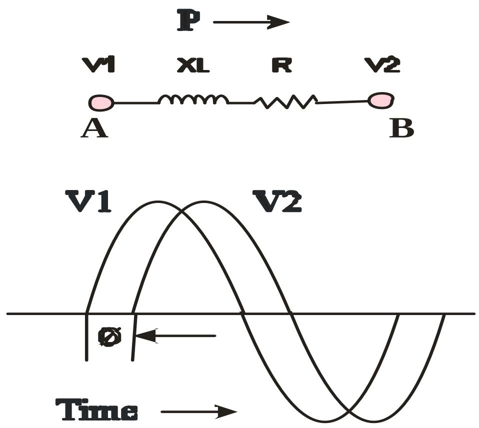


Fig 3. Real power flow

With reference to figure 3 and in accordance with Equation (1) the direction of flow of real power can be controlled using the angular phase shift between the voltages at the ends of the reactor connecting the point of common coupling and the terminals of the STATCOM converter unit.
This phenomenon of reactive power transaction is governed according to the equation. (2).

$$Q = \left(\frac{V_1 (V_1 - V_2)}{X} \right) Cos\delta \quad (2)$$

With reference to figure 4 and in accordance with Equation (2) the direction of flow of reactive power can be controlled using the amplitude control on the voltages existing at the ends of the reactor which are the terminals of the STATCOM and the PCC.Thus it can be viewed that the real power transaction happened between two nodes is function of the phase angle difference between the nodal voltage waves and the reactive power transaction happening over the nodes is function of the difference between the amplitudes of the nodal voltages. In the case of the STATCOM governed power transaction schemes the amplitude of the reference signal, which is the modulation index of the converter, can be used to control reactive power transaction and the phase angle of this reference signal can be used to control real power transaction.

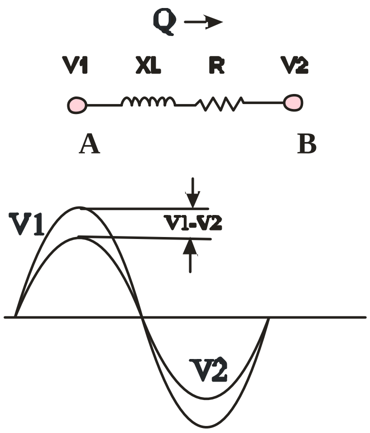


Fig 4. Reactive power flow

3.1Generation of the reference signal

In a typical PWM based power electronic converter, the challenge is to find the reference signal that will be embedded with the requirements of power transactions. The appropriately developed reference signal that has been developed based on the power system requirements can ensure the expected power transaction parameters. Once the reference signal is generated it is used in any modulation scheme like the SPWM or the SVPWM or even the SHE PWM to produce the switching pulses. Reference signals are generated according the power transaction requirements and also the control system requirements. PI, PID, FLC, ANN based control schemes, meant for reference signal generation, have been used in the industry since a long time.

3.2The mathematical relations of the STATCOM.

The variables and the mathematical relations associated with the Single Machine Infinite Bus Bar system are given below:

V_s is the Single Machine side terminal voltage
I_s is the current drawn from the single machine.
I_{sh} is the shunt converter injected current.
V_R the grid side voltage or the receiving end voltage.
$I_s + I_{sh}$ is the current drawn by the grid.

The quantities V_s, V_r, V_{sh},, I_s and I_{sh} are all vector quantities. The STATCOM has a DC link voltage and the three phase voltage output of the STATCOM is decided and governed by the modulation index, MI and phase angle of the reference signal.The enhancement in power transferability of the single machine, with the aid of the STATCOM is analysed in the ANFIS environment of control strategy. The shunt converter injects the current I_{sh} such that the reactive current requirement of the load is not drawn from the single machine thus improving the source side power factor and the voltage at the PCC.The shunt converter acts as a controlled current source and its output current should be sufficient to support the reactive power demand of the grid or the load. The reactive power demand of the grid would otherwise burden on the single machine.

3.3The DQ Transformation

The quantities of interest like the source side three phase voltages and the load side voltages are sinusoidal in nature. And these quantities are to be converted into respective DC quantities and then used in the controllers. The conversion of the three phase voltages denoted as V_{abc} into V_d and V_q in the rotating frame is known as DQ transformation. The vector $[v_a\, v_b\, v_c]$ can be transformed into another vector $[v_d\, v_q\, v_o]$ with the help of a transformation matrix.

It can be viewed that

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & 1 \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} \tag{4}$$

The vector $[v_a\ v_b\ v_c]$ and the elements of the transformation matrix are time varying but the output vector $[v_d\ v_q\ v_0]$ is not time varying. However any change in the amplitude of either of v_a or v_b or v_c is reflected in the vector elements $[v_d\ v_q\ v_0]$.One of the two controllers used in the STATCOM use the source side voltage in the format $[v_d\, v_q\, v_0]$.

4. Control scheme for the STATCOM

There are two parameters associated with the STATCOM that are to be taken care of by the control system. They are the DC link voltage Vdc and the voltage at the point of common coupling Vpcc. These two are the controlled parameters and the associated manipulated parameters are Theta and Modulation Index (MI) According to figure 5 the first controller is used to make the error between the actual Vdc and the set point Vdc as zero. The second controller is used to make the error between the actual Vpcc and the set point Vpcc as zero. In any control system the objective of the controller is to make the error zero and it is nothing but to make the input of the controller unit zero. The controller unit can be any one of the PI, PID, and FLC or of the ANN type. If the mathematical model of the plant under control is known then the mathematically verifiable controllers like PI or the PID can be used. However if the mathematical model of the plant under control is not available or too complex then intelligent controllers like the FLC or ANN can be used.

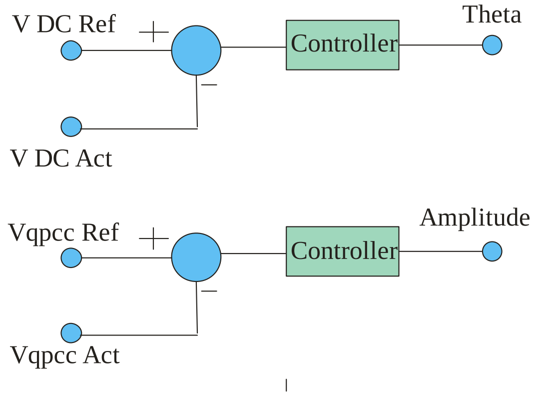


Fig 5 General control structure.

4.1Fuzzy Logic Control System

Fuzzy logic is a technique to deal with approximate data to arrive at an agreeable result. Fuzzy logic uses the knowledge a priori of the plant or the experience of the plant operator. This knowledge base is formatted as a rule base comprising of a set of IF THEN statements. The figure 6 gives the fuzzy logic based control scheme as applied to the STATCOM in the management of real and reactive power.

Fuzzy logic uses linguistic variables in place of numeric variables. The entire range of the error and error rate called the universe of discourse of error and error rate are segmented into a number of segments. These segments are assigned with linguistic variables. These linguistic variables are named Very Low, Low, Medium, High and Very High. The actual numeric values of the error and the error rate are fitted into the linguistic variable segments with the respective degrees of membership called the Degrees Of Belief and this procedure is called fuzzification.

The rule base relates the segments of the inputs with the segments of the output. All the segments of the universe of discourse may or may not be of equal range and decided according to the problem at hand. The variation of the degree of membership of each of the input or output parameters in a segment is called the membership function which is typically Triangular, Gaussian Trapezoidal etc. There are two phases in which an FLC works. In the first phase, called the inference phase, the segment or label in which the output should fall is found with the help of the rule base and once this is found the degree of membership of the output parameter in the selected output segment is found based on the degrees of membership of the input parameters in their respective segments. Thus the output segment and the degree of membership of the output in that segment are found. This quantity being fuzzy in nature will be converted into the required crisp form of implementation and this operation is called defuzzification. The numerical value thus got after defuzzification is used as the controller output.

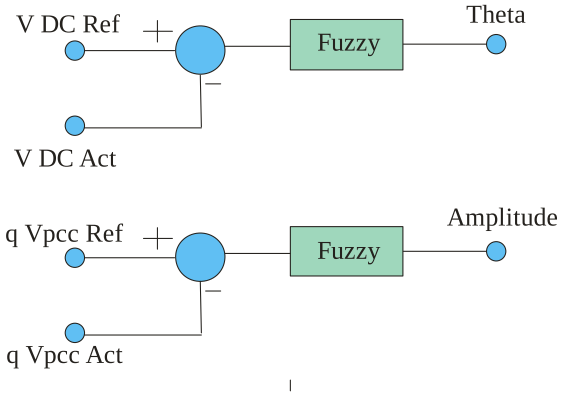


Fig 6. FLC controller

4.2The ANFIS based Control System

The Adaptive Neuro Fuzzy Inference System is a hybrid system that exploits the advantages of Neural Networks and the Fuzzy Logic systems. Basically the Fuzzy Logic system is good for control applications and the Artificial Neural Networks are good at cognition.

In a typical fuzzy logic controller there are various steps and these steps are carried out using the human experience. The segmentation of the universe of discourse into a number of segments and the assigning the membership functions for each such segment and the formation of the rule base are operations associated with the FLC that involves human experience.

In this case the ANN is set to get trained by the experimental data a good deal of training is imparted to the ANN that will now decide the membership functions and the rule base. Such a hybrid system that uses the features of the ANN and the FLC is called the ANFIS.

This control model as shown in figures [7-9].In this application it is assumed that the mathematical model of the complete system is not available or is very complex because of the inclusion of so many sub systems like the main source, the load, the distributed generator system, the renewable energy based generation system etc. Therefore it is neither easy to formulate a mathematical model of the system nor it is easy to design a comprehensive control system. As such we have opted for the more intelligent ANFIS model of controller for the management of the STATCOM.

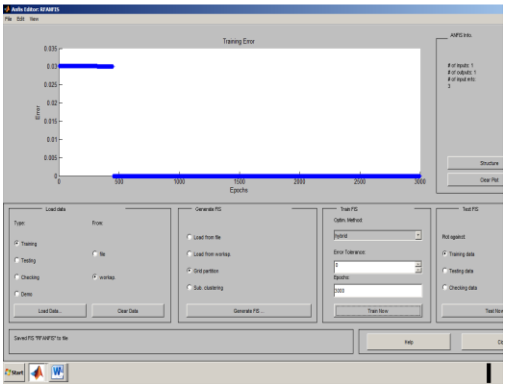


Fig 7. The ANFIS training

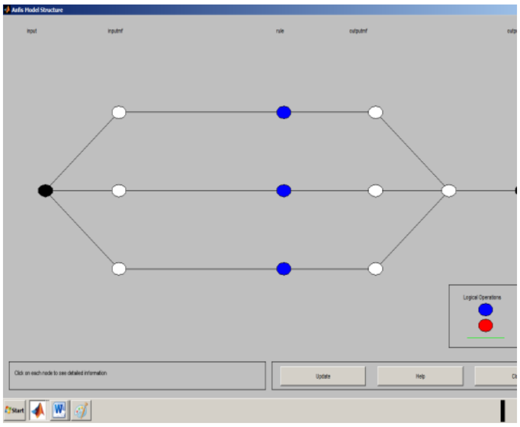


Fig 8. ANFIS Structure

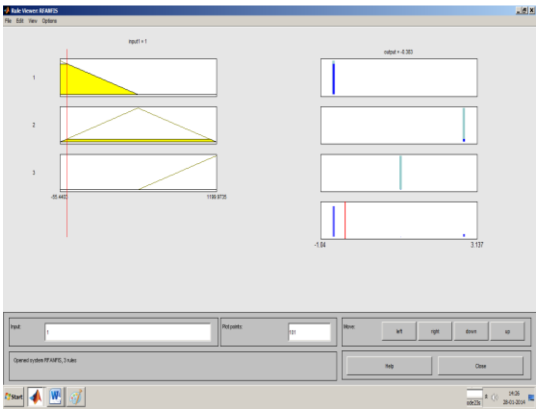


Fig 9. ANFIS in action

5. Simulation using the MATLAB / SIMULINK environment

MATLAB / SIMULINK offer a convenient platform for the development of an ANIFS based control system. Figure 10 shows the complete SIMULINK model that shows the position of the different sources and the loads and also the STATCOM.

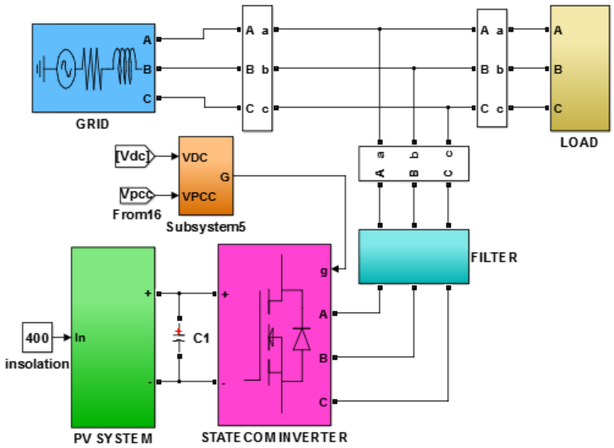


Fig 10. Simulink model of STATCOM

System Specifications:

AC voltage-380 V

DC Link Voltage- 1200

DCV link Capacitor-6600μF

Configuration of Switches- MOSFETS

Three cases of operations have been studied and the performance of the system with and without the STATCOM has been recorded. Also the cases of the STATCOM included with PI, Fuzzy and ANFIS models of control schemes have also been compared and contrasted. The two cases of consideration are:

a. Reactive power support.
b. Voltages sag and swell management.

Reactive power support is required so that the system operates at a higher power factor such that it is capable of supporting more loads. That is, the overall system capacity is improved. Due to sudden inclusion or removal of reactive loads the terminal voltage on the load side may be disturbed causing unwanted voltage sag or swell respectively.

Since the system involves a number of renewable energy sources these may enter into the system or leave the system now and then unpredictably because of the nature of the naturally available driving forces like wind or solar insolation. This will result in the fluctuation of total power generation. While fluctuations in power generations cannot be avoided, the system can be designed with controllers such that, atleast, and of course mandatorily voltage regulation is ensured.

6. Results and discussion:

The results of simulations under various operating conditions have been shown in figures (11 to 27).

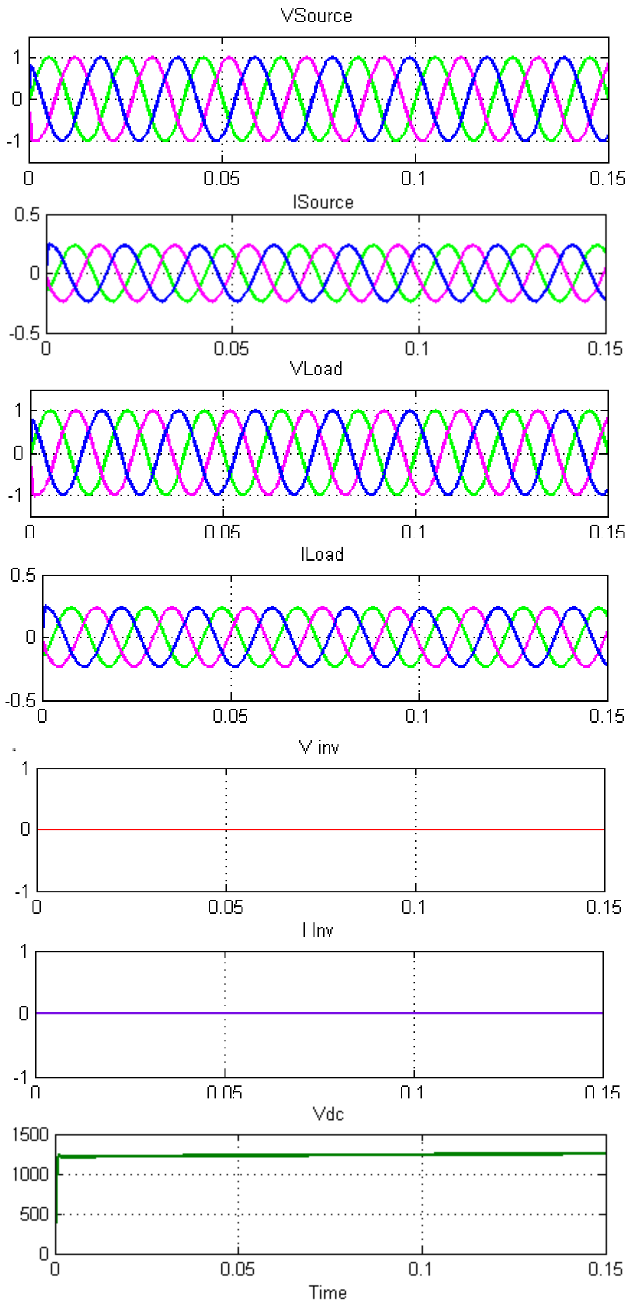
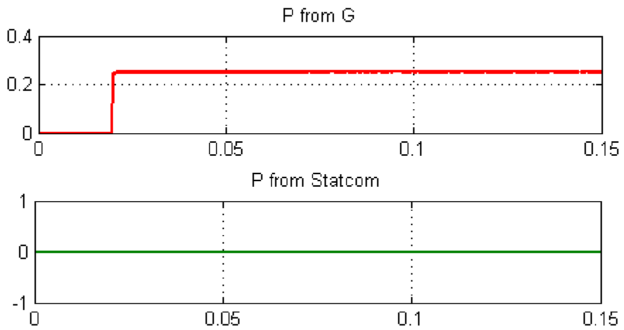


Fig 11. Simulation result of voltages and current without STATCOM



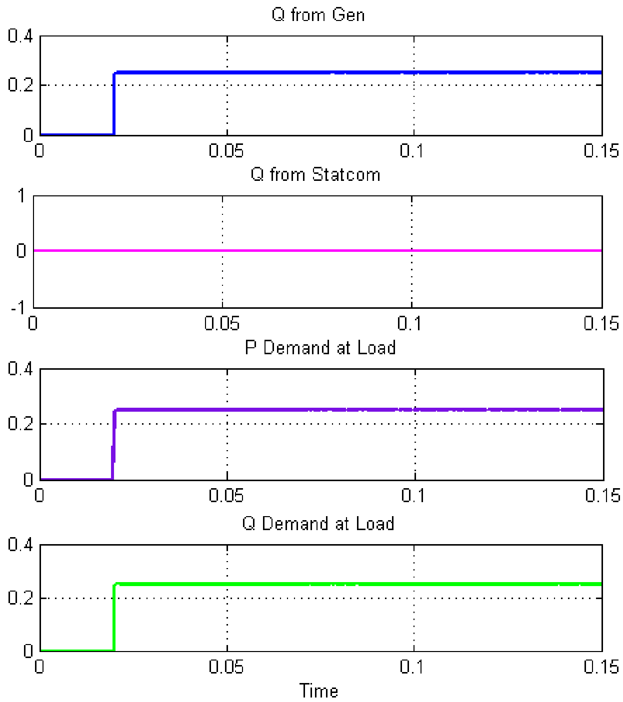
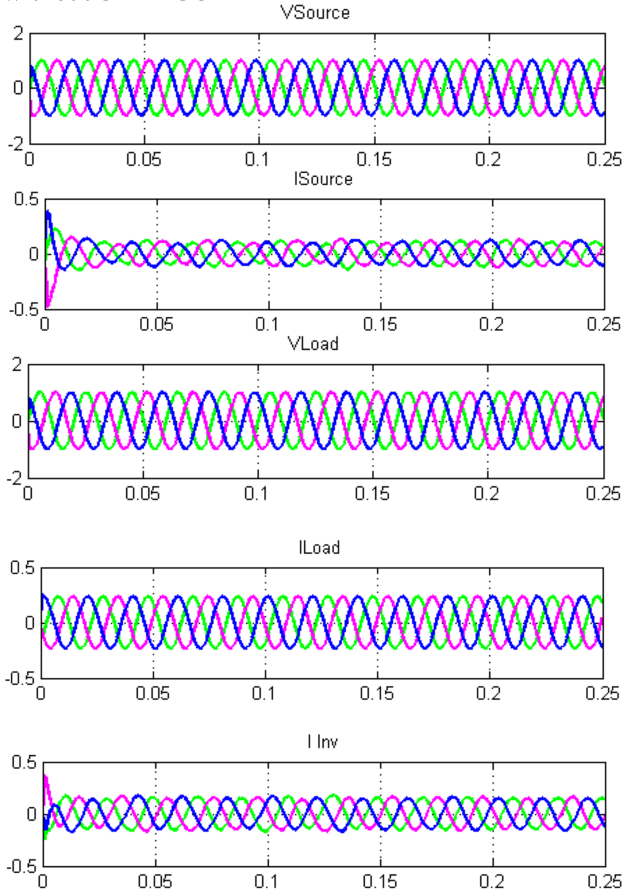


Fig 12. Simulation result of real and reactive power without STATCOM



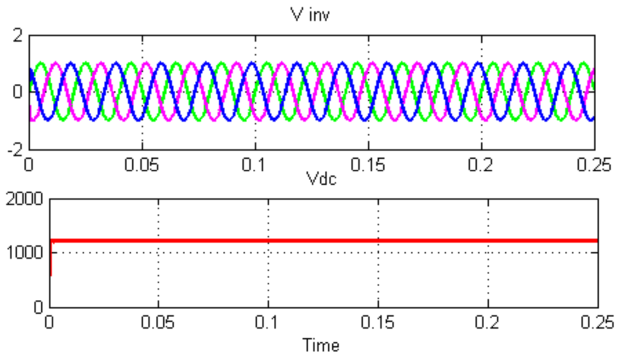


Fig 13. Simulation result of voltage and currents using PIcontroller

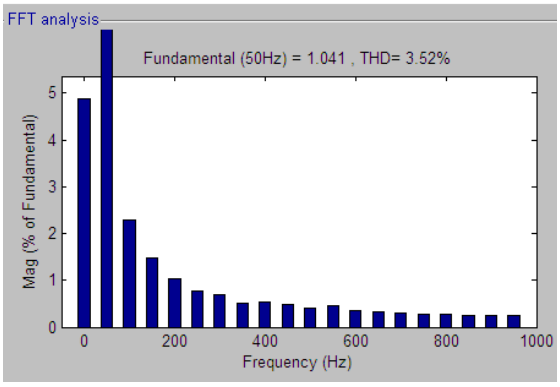


Fig 15. THD of source current using PI controller

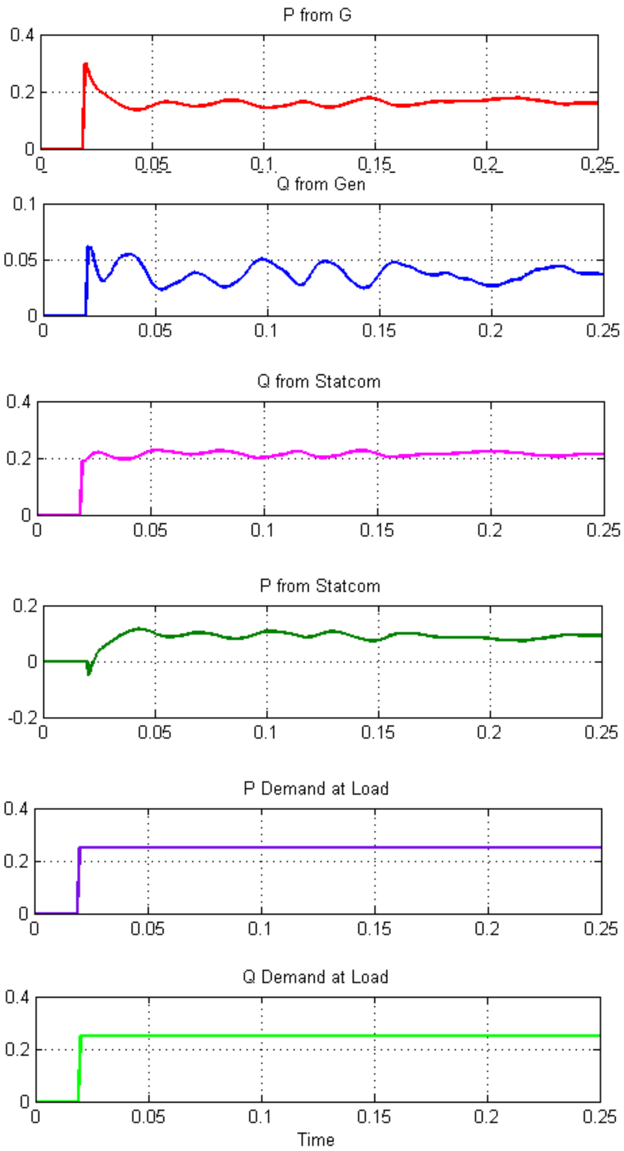
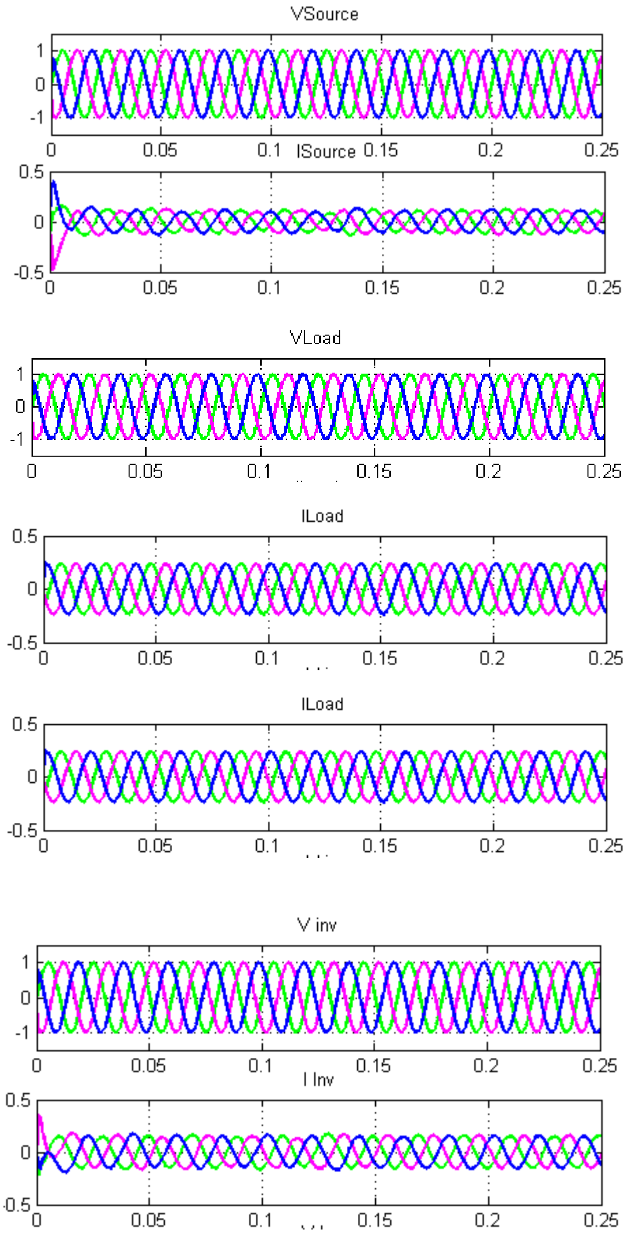


Fig 14. Simulation result of real and reactive power using PI controller



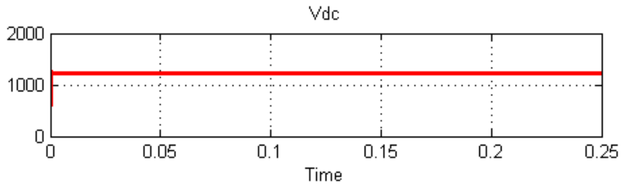


Fig 16. Simulation result of voltage and currents using FLC controller

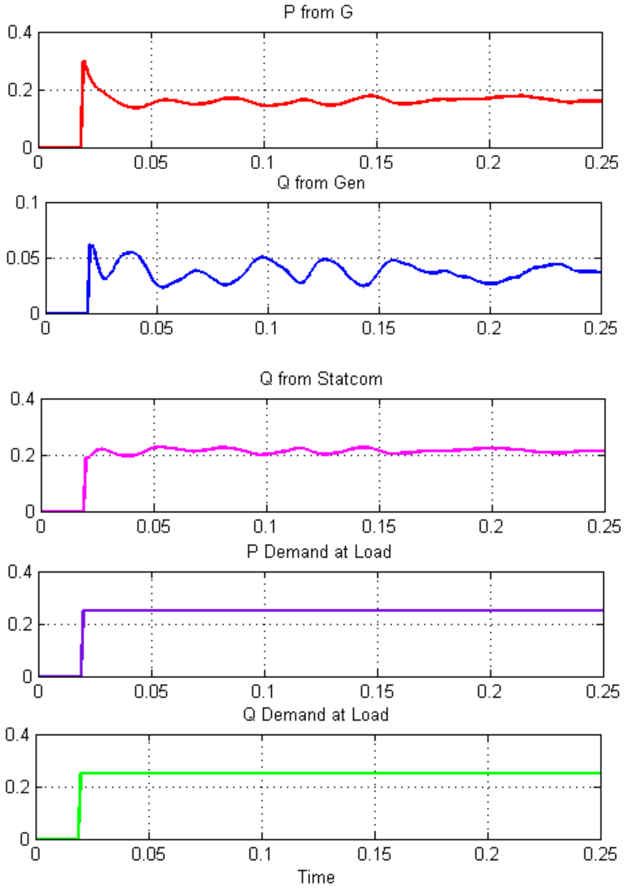


Fig 17. Simulation result of real and reactive power using FLC controller

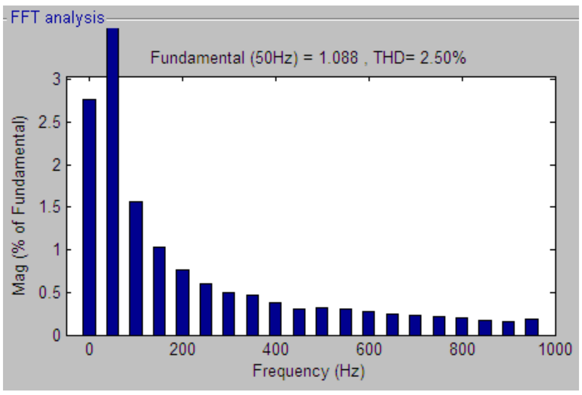


Fig 18. THD of source current using FLC controller

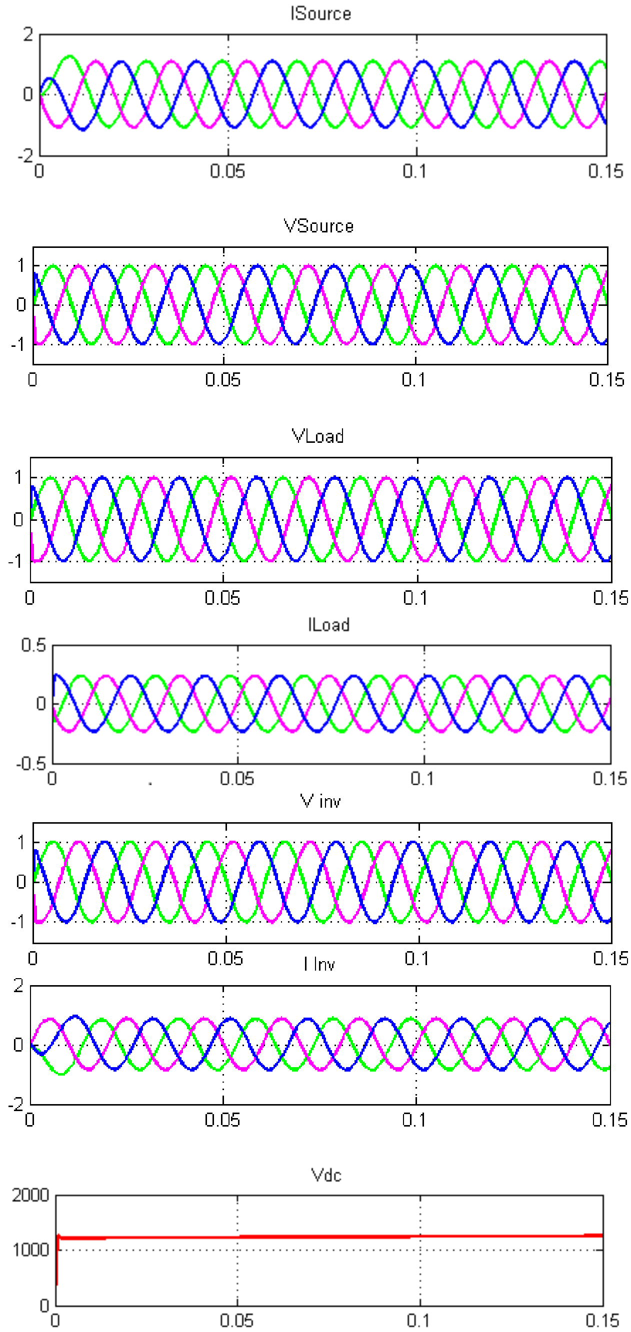
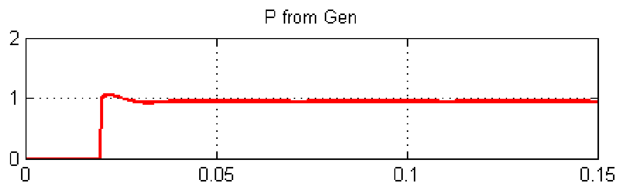


Fig 19. Simulation result of voltage and currents using ANFIS controller



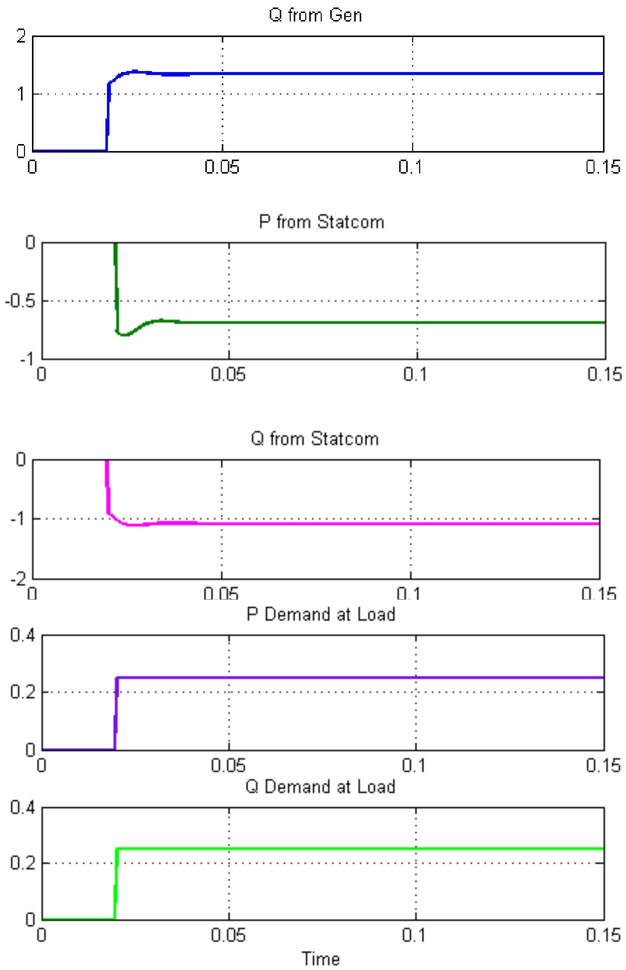


Fig 20. Simulation result of real and reactive power using ANFIS controller

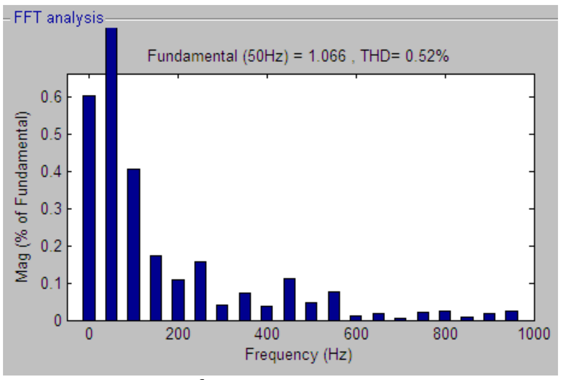


Fig 21. THD of source current using ANFIS controller

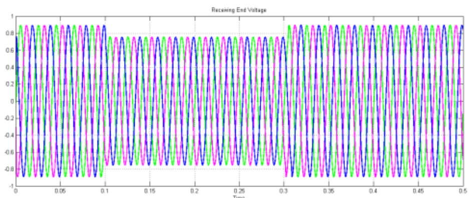


Fig 22. Voltages sag by inclusion of inductive load at 0.1 sec and removal of inductive load at 0.3 sec without STATCOM

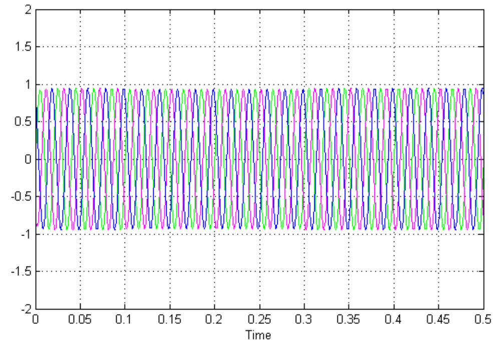


Fig 23. Voltage sag compensated by STATCOM using PI controller

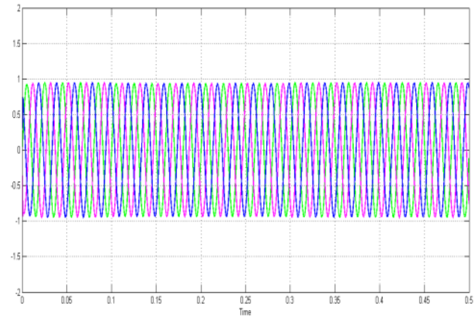


Fig 24. Voltage sag compensated by STATCOM using ANFIS controller

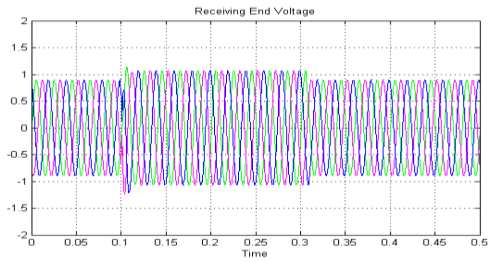


Fig 25. Voltage swells by inclusion of capacitive load at 0.1 sec and removal of capacitive load at 0.3 sec without STATCOM.

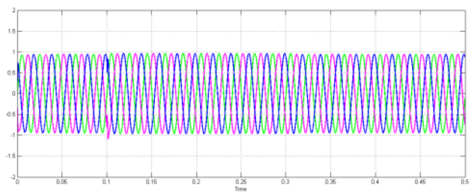


Fig 26. Voltage swell compensated by STATCOM using PI controller.

Table 1 show a comparison of operational improvements with STATCOM has been compared with the case that does not use a STATCOM; a comparison is also carried out among the PI, FLC and ANFIS in the case of using the STATCOM

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Table 1Parameters	Without STATCOM	PI	Fuzzy	ANFIS
P Demand	0.25	0.25	0.25	0.25
Q Demand	0.25	0.25	0.25	0.25
Q Demand	0.25	0.25	0.25	0.25
Q from Sources	0.25	0.05	0.037	1.25
P to STATCOM	0	0.15	0.089	-0.75
Q from STATCOM	0	0.2	0.212	-1
PF at Source	0.7071	0.912	0.925	0.9825
THD of source current	-	3.52%	2.50%	0.52%

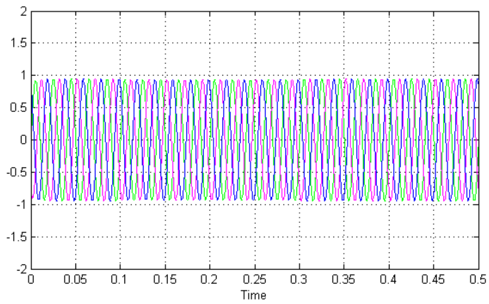

Fig 27. Voltage swell compensated by STATCOM using ANFIS controller**.**

7. Conclusion

A novel intelligent based implementation of an ANFIS controller for the management of a STATCOM in the renewable energy based power system environment has been proposed, designed developed and tested. Simulation has been carried out and the results validate the proposed idea. The ANFIS based control scheme outperforms the PI control system in terms of efficient power transaction, reduced THD of the source side current and much improved reactor power compensation. The sag and swell caused by inclusion of inductive and capacitive loads have also been compensated. The application of the STATCOM for the purpose of real power augmentation during day time using the photo voltaic panel has also been verified. It is concluded that the control scheme based on the ANFIS is more suitable for a complex system of sources and loads where it is difficult to arrive at a precise mathematical model.

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