ISSN No: 2348-4845
International Journal & Magazine of Engineering,
Technology, Management and Research
A Peer Reviewed Open Access International Journal

Design and Analysis of Delta Connected STATCOM in Transmission with Fuzzy Controller

I Siva Prasad
Academic Consultant
Department of EEE
School of Engineering and Technology - Sri Padmavathi MahilaVisvavidyalayam,
Padmavathi Nagar, Tirupati Chittoor(D.T),
Andhra Pradesh 517502.
Sivaprasad309@yahoo.co.in

Sk Shaphia
M.Tech Power Electronics and Drives
Department of EEE
School of Engineering and Technology - Sri Padmavathi MahilaVisvavidyalayam,
Padmavathi Nagar, Tirupati Chittoor(D.T),
Andhra Pradesh 517502.
Shaphia.248@gmail.com

ABSTRACT

This paper presents a transformerless static synchronous compensator (STATCOM) system based on multilevel H-bridge converter with delta configuration. In this paper, a fuzzy logic controller is designed for static synchronous compensator (STATCOM) to enhance interconnected power system stability. The power frequency model for STATCOM with conventional PI (Proportional Integral) controller is presented first. Fuzzy logic controller in then designed for main controller of the STATCOM. This paper investigates the application of a rule based fuzzy logic control technique for controlling a STATCOM at steady and transient condition. The control strategy is evaluated by simulation(MATLAB/SIMULINK) programs and the comparison indicates the fuzzy logic based STATCOM gives improved performance compared with PI STATCOM controller based technique. This previous control methods devote themselves not only to the current loop control but also to the dc capacitor voltage control. With regards to the current loop control, a nonlinear controller based on the passivity-based control (PBC) theory is used in this cascaded structure STATCOM for the first time. As to the dc capacitor voltage control, overall voltage control is realized by adopting a Proportional Resonant controller(PR). Clustered balancing control is obtained by using an Active disturbances rejection controller(ADRC). Individual balancing control is achieved by shifting the modulation wave vertically which can be easily implemented in a Field-programmable gate array(FPGA). H-bridge cascaded STATCOMs rated at 10 kV 2 MVA are constructed and a series of verification tests are executed. The experimental results prove that H-bridge cascaded STATCOM with the proposed control methods has excellent dynamic performance and strong robustness. The dc capacitor voltage can be maintained at the given value effectively.

KEYWORDS: ***Active disturbances rejection controller (ADRC), H-bridge cascaded, passivity-based control (PBC), Proportional resonant (PR) controller, Fuzzy controller shifting modulation wave,static synchronous compensator (STATCOM).***

I. INTRODUCTION

Static Synchronous Compensator (STATCOM) is an important flexible ac transmission systems (FACTS) controller in power system. Because of natural modularand high-quality output spectrum a cascaded H-bridge converter with equal dc voltage is widely used for STATCOM application [1]–[7]. The cascaded single phase H-bridge converter saves a large amount of clamped diodes and flying capacitors compared with diode clamped converter and flying capacitor converter, [8]. In high-power application further improvement of power efficiency and waveform quality is expected of cascade H-bridge topology [9]. Either by increasing switching frequency or number of cascaded modules, a low distorted ac voltage waveform can be achieve but which may results in high power loss or high cost to the STATCOM system.

A good tradeoff between waveform quality and switching loss can be obtained by hybrid multilevel technology [9]. Increased voltage levels of output waveform, improved ac current quality, reduced switching frequency resulting in low switching loss and also enhanced converter efficiency are the main advantages of hybrid multilevel converters. Hybrid multilevel‖ concept is proposed in literature [10], which paid great attentions to this field. Many hybrid multilevel approaches has been discussed in literature [11]. Compared with traditional ones this topology effectively produces higher voltage levels with same number of switches but faces aproblem of dc voltage control. All dc-link voltages are controlled by controlled purely by control algorithm in Flexible ac transmission systems (FACTS) are being increasingly used in power system to enhance the system utilization, power transfer capacity as well as the power quality of ac system interconnections [1], [2]. As a typical shunt FACTS device, static synchronous compensator (STATCOM) is utilized at the point of common connection (PCC) to absorb or inject the required reactive power, through which the voltage quality of PCC is improved [3]. In recent years, many topologies have been applied to the STATCOM. Among these different types of topology, H-bridge cascaded STATCOM has been widely accepted in high-power applications for the following advantages: quick response speed, small volume, high efficiency, minimal interaction with the supply grid and its individual phase control ability [4]–[7]. Compared with a diode-clamped converter or flying capacitor converter, H-bridge cascaded STATCOM can obtain a high number of levels more easily and can be connected to the grid directly without the bulky transformer. This enables us to reduce cost and improve performance of H-bridge cascaded STATCOM [8].There are two technical challenges which exist in H-bridge cascaded STATCOM to date. First, the control method for the current loop is an important factor influencing the compensation performance. However, many non ideal factors, such as the limited bandwidth of the output current loop, the time delay induced by the signal detecting circuit, and the reference command current generation process, will deteriorate the compensation effect. Second, H-bridge cascaded STATCOM is a complicated system with many H-bridge cells in each phase, so the dc capacitor voltage imbalance issue which caused by different active power losses among the cells, different switching patterns for different cells, parameter variations of active and passive components inside cells will influence the reliability of the system and even lead to the collapse of the system. Hence, lots of researches have focused on seeking the solutions to these problems.

In terms of current loop control, the majority of approaches involve the traditional linear control method, in which the non- linear equations of the STATCOM model are linearized with a specific equilibrium. The most widely used linear control schemes are PI controllers [9], [10]. In [9], to regulate reactive power, only a simple PI controller is carried out. In [10], through a decoupled control strategy, the PI controller is employed in a synchronous d–q frame. However, it is hard to find the suitable parameters for designing the PIcontroller and the performance of the PI controller might degrade with the external disturbance. Thus, a number of intelligent methods have been proposed to adapt the PI controller gains such as particle swarm optimization [11], neural networks [12], and artificial immunity [13]. In literature [14], [15], adaptive control and linear robust control have been reported for their anti external disturbance ability. In literature [16], [17], a popular dead-beat current controller is used. This control method has the high bandwidth and the fast reference current tracking speed. The steady-state performance of H-bridge cascaded STATCOM is improved, but the dynamic performance is not improved. In [18], a dc injection elimination method called IDCF is proposed to build an extra feedback loop for the dc component of the output current. It can improve the output current quality of STATCOM. How- ever, the circuit configuration of the cascaded STATCOM is the delta configuration, but not the star configuration. Moreover, an adaptive theory-based improved linear sinusoidal tracer control method is proposed in [19] and a leaky least mean square-based control method is proposed in [20]. But these methods are not for STATCOM with the cascaded structure. By using the traditional linear control method, the controller is characterized by its simple control structure and parameter design convenience, but poor dynamic control stability.Other control approaches apply nonlinear control which directly compensate for the system nonlinearities without requiring a linear approximation. In [21], an input–output feedback linearization controller is designed. By adding a damping term, the oscillation amplitude of the internal dynamics can be effectively decreased. However, the stability cannot be guaranteed [22]. Then, many new modified damping controllers are designed to enhance the stability and performance of the internal dynamics [23]–[26]. However, the implementation of these controllers is very complex. To enhance robustness and simplify the controller design, a passivity-based controller (PBC) based on error dynamics is proposed for STATCOM [27]–[30]. Furthermore, the exponential stability of system equilibrium point is guaranteed. Nevertheless, these methods are not designed on the basis of STATCOM with the H-bridge cascaded structure and there are no experimental verifications in these literatures.

In terms of dc capacitor voltage balancing control, there are three pivotal issues: overall voltage control, clustered balancing control, and individual balancing control. In literature [31], under the assumption of all dc capacitors being equally charged and balanced, they can only eliminate the imbalances caused by the inconsistent drive pulses without detecting all dc capacitor voltages. In [32],[34], additional hardware circuits are required inthe methods based on ac bus energy exchange and dc bus energy exchange, which will increase the cost andthe complexity of the system. In [35], a method based on zero-sequence volt- age injection is proposed and it will increase the dc capacitor voltage endurance capacity. On the contrary, the method using negative-sequence current in [36] does not need the wide mar- gin of dc capacitor voltage, but the function of STATCOM is limited. In [8], the active power of the individual phase cluster is controlled independently, while the circuit condition is considered to be limited in practical use. In [37] and [38], a cosine component of the system voltage is superposed to the clustered output voltage, but it is easy to be affected by an inaccurate phase-locked loop (PLL). In [39], the active voltage vector superposition method is proposed. However, the simulated and experimental results do not show the differences in control area and voltage ripple. The selective harmonic elimination modulation method is used in [40] and [41], in which dc voltage balancing control and low-frequency modulation are achieved. Compared with the method in [40] and [41], a method changing the phase-shift angle for dc voltage balancing control is proposed in [42] and [43], through which the desirable effect can be easily achieved, whereas it is limited by the capacity of STATCOM. In [44], the dc voltage and reactive power are con- trolled. However, it cannot be widely used due to fact that many nonideal factors are neglected. In [45] and [46], the proposed method assumes that all cells are distributed with equal reactive power and it uses thecosine value of the current phase angle. It could lead to system instability, when using the zero-crossing point of the cosine value. In [47] and [48], the results of experiments are obtained in the downscaled laboratory system. Thus, they are not very persuasive in this condition.

II. FUZZY CONTROL METHOD

A fuzzy control system is a control system based on fuzzy logic which is a mathematical system for the analysis of analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0'.

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

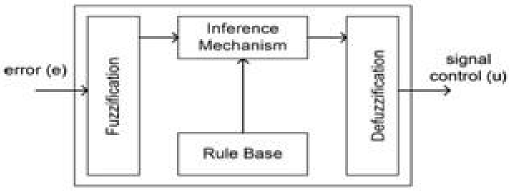


Fig.1: Fuzzy controller

III. EXISTING SYSTEM

There are two technical challenges which exist in H-bridge cascaded STATCOM[1] to date. First, the control method for the current loop is an important factor influencing the compensation performance. However, many nonideal factors, such as the limited bandwidth of the output current loop, the time delay induced by the signal detecting circuit, and the reference command current generation process, will deteriorate the compensation effect. Second, H-bridge cascaded STATCOM is a complicated system with many H-bridge cells in each phase, so the dc capacitor voltage imbalance issue which caused by different active power losses among the cells, different switching patterns for different cells, parameter variations of active and passive components inside cells will influence the reliability of the system and even lead to the collapse of the system. Hence, lots of researches have focused on seeking the solutions to these problems.

IV.PROPOSED SYSTEM

This paper presents a transformerless static synchronous compensator (STATCOM) system based on multilevel H-bridge converter with delta configuration. In this paper, a fuzzy logic controller is designed for static synchronous compensator (STATCOM) to enhance interconnected power system stability. The power frequency model for STATCOM with conventional PI (Proportional Integral) controller is presented first. Fuzzy logic controller in then designed for main controller of the STATCOM. This paper investigates the application of a rule based fuzzy logic control technique for controlling a STATCOM at steady and transient condition. The control strategy is evaluated by simulation programs and the comparison indicates the fuzzy logic based STATCOM gives improved performance compared with PI STATCOM controller based techniqueIn this paper, a new nonlinear control method based on PBC theory which can guarantee Lyapunov function dynamic stability is proposed to control the current loop. It performs satisfactorily to improve the steady and dynamic response. For dc capacitor voltage balancing control, by designing a proportional resonant (PR) controller for overall voltage control, the control effect is improved, compared with the traditional PI controller. Furthermore, it finds its new application in H-bridge cascaded STATCOM for clustered balancing control and using fuzzy controller . It realizes the excellent dynamic compensation for the outside disturbance. By shifting the modulation wave vertically for individual balancing control.

V. CONTROL BLOCK DIAGRAM

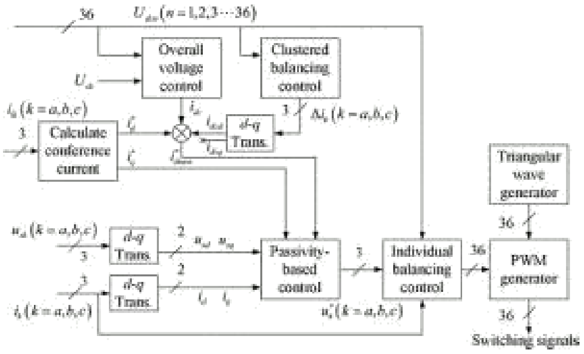


Fig. 2. Control block diagram for the 10 kV 2 MVA H-bridge cascaded STATCOM.

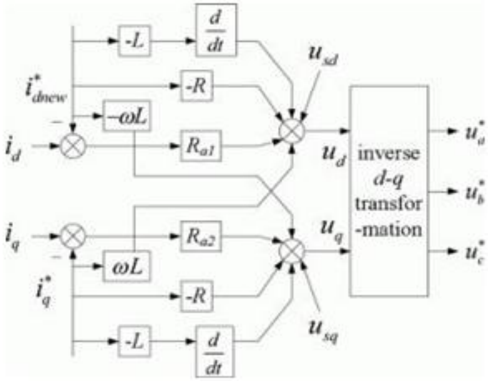


Fig. 3. Block diagram of PBC.

Advantages:

1. Quick response speed and Small volume,
2. High efficiency and minimal interaction with the supply grid and
3. Its individual phase controllability.

Applications:

1. A PBC theory based nonlinear controller is first used in STATCOM with this cascaded structure for the current loop control, and the viability is verified by the simulation results.
2. The PR controller is designed for overall voltage control and the simulation result proves that it has better performance in terms of response time and damping profile compared with the PI controller.
3. The ADRC is first used in H-bridge cascaded STATCOM for clustered balancing control and the simulation results verify that it can realize excellent dynamic compensation for the outside disturbance.

VI EXPERIMENTAL RESULTS

Without fuzzy

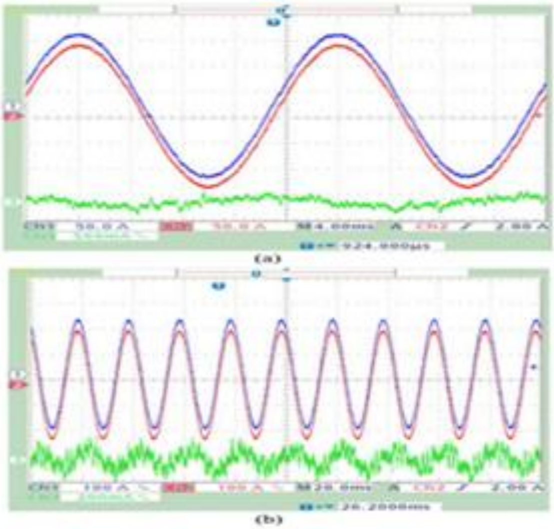


Fig. 4. Experimental results verify the effect of PBC in steady-state process. (a) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid. (b) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid.

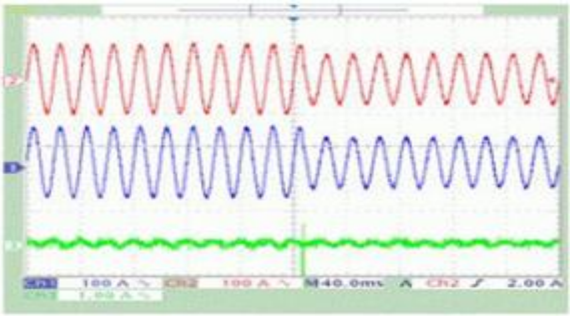


Fig. 5. Experimental results show the dynamic performance of STATCOM in the dynamic process. Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid.

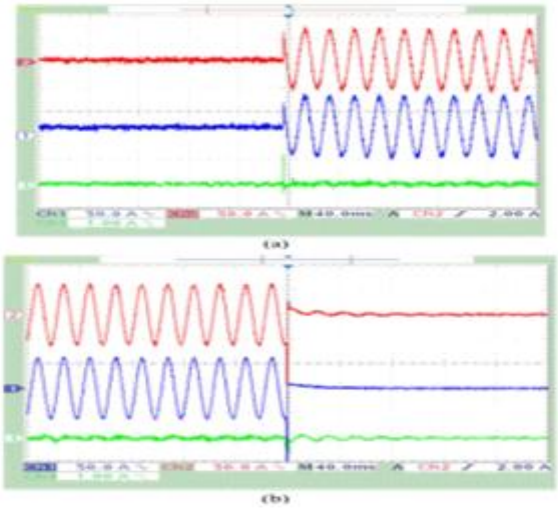


Fig. 6. Experimental results in the startup process and stopping process. (a) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid. (b) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid.

With fuzzy

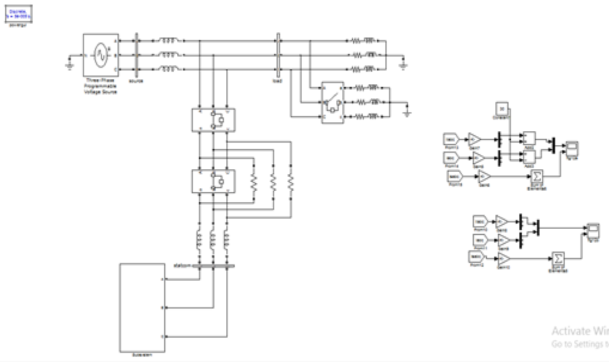


Fig.7: Block diagram of the Actual 10 kV 2 MVA H-bridge cascaded STATCOM.

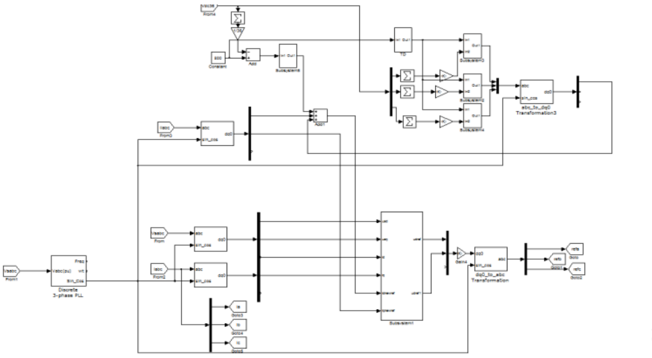


Fig.8: Block diagram of the FLC based control system

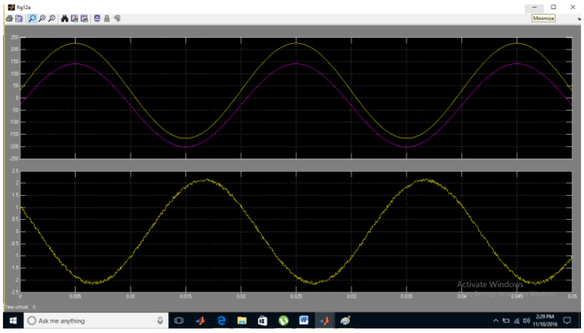
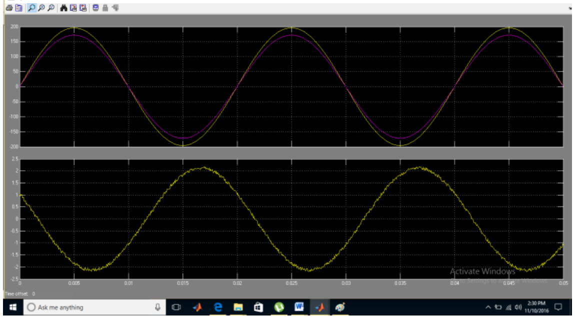


Fig.9-(a)



9-(b)

Fig9 (a,b):Experimental results verify the FLC in steady state process a) reactive current, compensating current; b) residual current of grid, compensating current

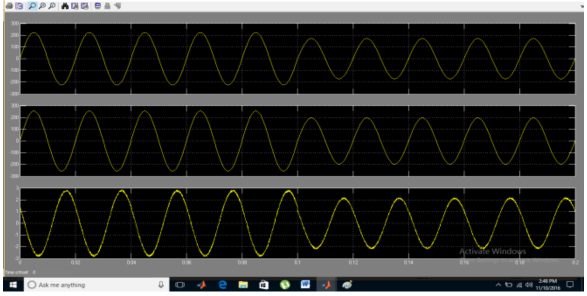


Fig.10: Experimental results verify the FLC in dynamic process reactive current; compensating current; residual current of grid.

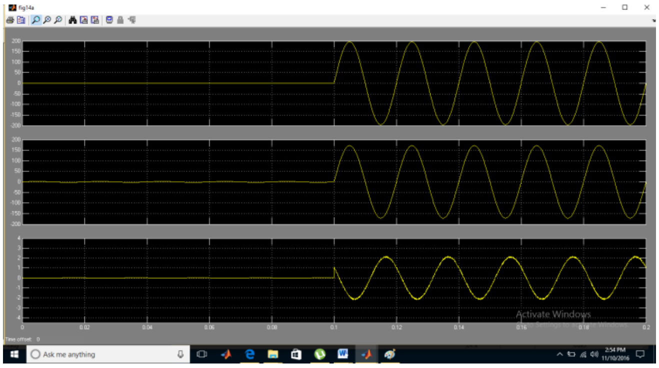


Fig.11-(a)

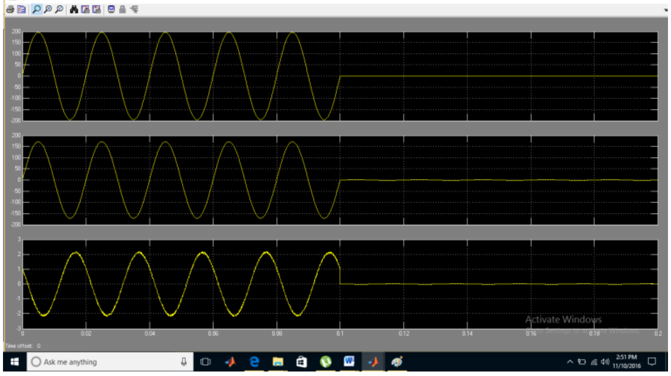


Fig.11-(b)

Fig.11(a,b): Experimental results verify the FLC in start up and stopping process reactive current; compensating current; residual current of grid.

VII RESULTS AND ANALYSIS

This paper has analyzed the fundamentals of STATCOM based on multilevel H-bridge converter with delta configuration. And then, the actual H-bridge cascaded STATCOM rated at 10 kV 2 MVA is constructed and the novel control methods are also proposed in detail. The proposed method has the following characteristics.

1. Fuzzy controller based rule sets are usefull for accuracy in reducing oscillations.
2. A PBC theory-based nonlinear controller is first used in STATCOM with this cascaded structure for the current loop control, and the viability is verified by the experimental results.
3. The PR controller is designed for overall voltage control and the experimental result proves that it has better performance in terms

of response time and damping profile compared with the PI controller.

4. The ADRC is first used in H-bridge cascaded STATCOM for clustered balancing control and the experimental results verify that it can realize excellent dynamic compensation for the outside disturbance.
5. The individual balancing control method which is realized by shifting the modulation wave vertically can be easily implemented in the FPGA.

The experimental results have confirmed that the proposed methods are feasible and effective. In addition, the findings of this study can be extended to the control of any multilevel voltage source converter, especially those with H-bridge cascaded structure.

ADVANTAGES

1 Found very effective cost and optimal solution to remove instability of power system and to become healthy power system.

2 Fuzzy controllers self-adjust the controller gain values dynamically during disturbances so that the performance always matches a desired response, regardless of the change of operating condition.

VIII CONCLUSION

This paper gives an application of fuzzy logic controller for the design of STATCOM.Fuzzy logic technique used in PI controller which tune gain values. Simulation (MATLAB/SIMULINK) output shows that PI and Fuzzy control method gives power factor correction, reactive power compensation and voltage regulation. Fuzzy controller with fixed gain values not reach desired response when operating condition changes. So the output response is also poor. To address the challenge, this paper proposes a new control model based on fuzzy technique improves performance provide reactive power compensation and power factor correction achieved. By achieving these two factors voltage profile improved and overall system performance improved. Future studies in Harmonic mitigation performed using STATCOM with PI control method and performance can be improved by ICOS algorithm. In most of the research paper they only used fuzzy or just simply neural network but ANFIS system gives better power quality improvement using SATCOM The results clearly shows that in all the cases there is improved performance by the FLC based STATCOM compared to PI controller based STATCOM. This is possible due to its capacity to deal with power system uncertain environment more efficiently.

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A. Roosta was born in Shiraz, Iran. He received his B.S from Shahid-chamran University, M.S from Tehran Universiy and P.hD degree from INPG (France)respectively. Currently, he is an Assistant Professor with the Shiraz University of Technology. His interests include power system dynamics and nonlinear fuzzy control of power systems

T. Niknam was born in Shiraz, Iran. He received his B.S, M.S and PhD degrees from Shiraz University and Sharif University of Technology respectively.
Currently, he is an Assistant Professor with the Shiraz University of Technology. His interests include power system restructuring, impact of DGs on power system, power Electronics, optimization methods, and evolutionary algorithms.

Binbin Li was born in 1989. He received the B.S. and M.S. degrees in electrical engineering from the Harbin Institute of Technology, Harbin, China, in 2010 and 2012, respectively, where he is currently working toward the Ph.D. degree.His research interests include high-power electronics,multilevel converters, control algorithms, and pulse width modulation techniques.