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A Novel Fuzzy Logic Control Scheme for FACS-Based Switched Filter Compensation

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***Abstract* – This paper presents a novel switched filter compensator (SFC) scheme for single-phase voltage stabilization and efficient utilization. The SFC is controlled by a novel tri-loop dynamic error driven fuzzy logic controller (FLC). The MATLAB digital simulation models of the proposed SFC scheme have been fully validated for effective power quality (PQ) improvement, dynamic voltage stabilization, and power factor correction. The FACTS-based scheme can be extended to distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific voltage stabilization, reactive compensation requirements, and efficient utilization.**

***Keywords* – Switched Power Filter (SFC), Fuzzy Logic Controller, Nonlinear Loads.**

I. INTRODUCTION

The power quality problem is defined as any variation in voltage, current or frequency that may lead to an equipment failure or malfunction. In a modern electrical distribution/utilization system, there has been a continuous increase of nonlinear loads, such as uninterruptible power supplies, rectifier equipment used in telecommunication networks, domestic appliances, adjustable speed drives, motors, etc. These power-electronic-switched loads are highly nonlinear. Due to their switching non-linearity, the loads can cause severe power quality problems [1].

Harmonics, voltage sag / swell and persistent quasi-steady state harmonics and dynamic switching excursions can result in electric equipment failure, malfunction, hot neutral, ground potential use, fire, and shock hazard in addition to poor power factor and inefficient utilization of electric energy manifested in increase reactive power supply to the hybrid load, poor power factor and severely distorted voltage and current wave- forms. To improve the efficiency, capacitors are employed which also leads to the improvement of power factor of the mains [2].

Passive power filters are traditionally used to reduce harmonic currents because of low cost and simple robust structure. But they provide fixed compensation and create system resonance [3], [4]. The filtering characteristics of passive power filters are determined by the impedance ratio of the supply and the passive filter and are often difficult to design. Shunt active filters are mainly used for providing filtering of harmonics, additional reactive power and/or neutral current reduction in AC networks, regulation of terminal voltage,suppression of voltage flicker, and improvement of voltage balance in three-phase systems [5], [6]. They have the capability of reducing harmonics, but can trigger resonance between an existing passive power filter and the AC supply impedance. They require a large current rating with high tuning bandwidth and may not constitute a cost- effective harmonic filtering solution for dynamic nonlinear loads. Hybrid switched power filters effectively mitigate the problems of passive filters and advantages of active filters and provide cost effective and practical harmonic reduction, particularly for high power switched nonlinear loads. The combination of low cost passive filters and effective control capability of the small rating switched power filter can effectively improve the compensation characteristics of passive filters. This can reduce the rating of the switched power filters, compared to pure shunt and series active filter solutions [7], [8]. Many power filter configurations are proposed in the literature to enhance power quality and to improve power factor [9], [10], [11].

Power generating stations are connected to the electric grid. Multi-zone power control systems can be affected by many variables. Load frequency control of the system variables that the goal is to eliminate the negative effects. For this purpose, the system is controlled with FLC. The two-zone power control system is used for input and output regions separately, one each for the FLC system were used. In this way, tried to control for both systems at the same time [12].

The paper validated a low cost SFC C-type scheme developed to improve the power quality and efficient utilization in smart utilization grid application. The proposed FACTS- based single phase filter utilizes the tri-loop dynamic error driven FLC to control the SFC. The proposed scheme proved success in improving the power quality, enhancing power factor, and full limiting transient over voltage and inrush current conditions. The scheme can be extended to three phase systems.

II. SYSTEM DESCRIPTION

Figure (1) shows single-phase AC utilization system feeding an Arc type load. The proposed novel dynamic error driven tri-loop FLC controller is shown in Figures (4, 5) and is used to reduce the switching transients and current inrushexcursions as well as excursions in the low voltage utilization system for efficient power/energy utilization and power quality enhancement for the arc type load shown in Figure (2). The AC single-phase system includes the following components:

1) Single-phase AC power supply.
2) Capacitor bank as storage media and input conditioning filters C_p, R_S and L_S.
3) Switched filter compensator scheme.
4) DC Arc type Load.

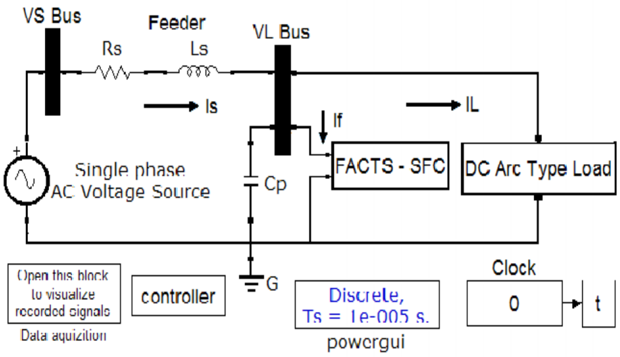

Fig.1. Single-phase electric utilization system.

III. ARC FURNACE MODELS

The Arc type melting process is a non-stationary Gaussian-stochastic process, so it is difficult to make an appropriate model for an Arc furnace load. The factors that affect Arc furnace operation are the melting or refining materials, the melting stage, the electrode position; the electrode arm control and the AC supply system voltage and impedance conditions.

Usually an Arc furnace is modelled as an inductor in series with a resistor. However this equivalent circuit is usually inadequate to cover the whole range of volt-ampere behaviour of the furnace and the ensuing impacts on power systems. Many models are set up for the purpose of power quality analyses [13]. In general the models can be classified into: -

- Time domain analysis methods.
- Frequency domain analysis methods.
- Power balance method.

Figure (2) shows the electrical equivalent circuit of the DC Arc type load.

IV. SWITCHED C-TYPE COMPENSATOR (SFC)

The low cost SFC is a switched type filter, used to provide measured filtering in addition to reactive compensation. The SFC is controlled by the on-off timing sequence of the pulse width modulation (PWM) switching pulses that are generated by the novel dynamic tri-loop error driven FLC controller with error-squared. The FLC controller is equipped with a supplementary error-squared fast dynamic compensation loop for fast, effective dynamic response in addition to conventional FLC activation.

The novel SFC scheme is controlled by the modulated PWM switched tuned arm filter through 2 pulse uncontrolled rectifier. The MATLAB model of this scheme structure is shown in Figure (3).

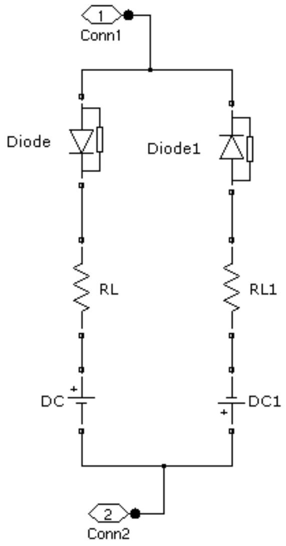

Fig.2. Electrical equivalent circuit of the nonlinear DC Arc type load

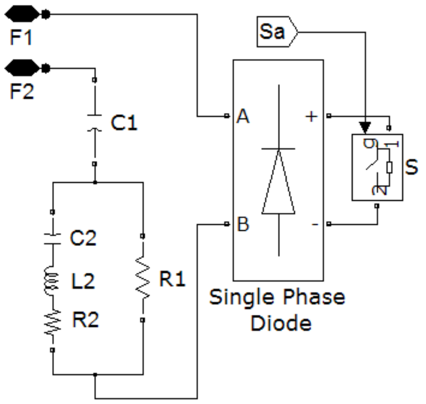

Fig.3. FACTS Switched C-Type filter compensator (SFC) scheme.

V. TRI LOOP ERROR DRIVEN FUZZY LOGIC CONTROLLER

Fuzzy logic (FL) and other audit procedures provide the mathematical model of the system without the need for complex transactions and carry out the audit process. Today, the control system with fuzzy logic control applications has become important. Classical numerical (0-1) is an approach that goes beyond the logic of fuzzy logic multi-level values between the two values as a result of the production control to produce better decisions, thus providing increased performance and efficiency. Figure (4) shows the fuzzy logic control and the basic block structure [14]. Fuzzy logic control basically consists of three components: -

- The Fuzzification Block.
- The Rule Base Assignment Matrix.
- The Defuzzification Output.

They providing the task of perform the final fuzzy input information [12]. Fuzzy values are sent to the rule base unit.

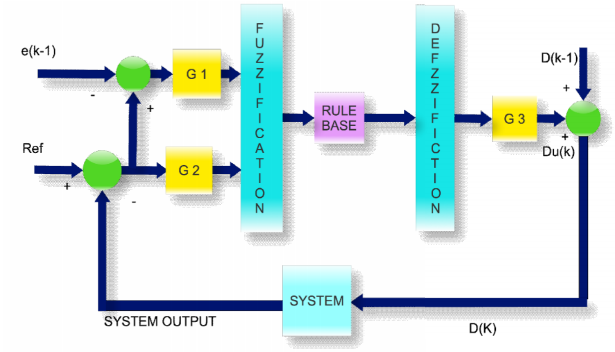

Fig.4. Basic block structure of fuzzy logic control.

There are elements of linguistic control rule base and database. Rules are processed in the fuzzy defuzzification unit to influence the result, which is sent to mark out the next step. Here are produced definitive results. In Figure (4), E(k) the error signal, e(k-1) refers to the change of error in a sampling period. G1, G2, and G3 are gain values. Du(k), clarifying a previous value of unit output and the D(k-1) by gathering with D(k) are obtained and input of the system is given. These variables are created according to the rule base unit rule table. A basic structure of fuzzy controller membership functions has been used. Although the selection is completely arbitrary functions of membership triangle, trapezoid, sinusoid, Cauchy, bell, sigmoid, Gaussian types [12].

FLC is usually the input variables, control error (e), and the duration of a sampling error change (Δe) form. FLC according to these variables of the rule base unit, a rule table is created. This table is shown in Table (I). Detailed description of the table on the establishment of the rule is presented in [14].

A. Fuzzy Logic Controller MATLAB/Simulink Block Model

The Membership Functions are the basic elements of the fuzzy logic controller. These membership functions are triangular, trapezoidal, sinusoid, Gaussian, bell and sigmoidal types. Triangular membership functions are used in this study [14]. The Input comes from the membership values of space necessary for the weight coefficients of each rule witch are determined based on minimums [12]. After determining the weight coefficients of the required unit of blurring, the rules for multiplying these values are sent to the processed parts.

The Fuzzy Logic Controller uses the exact method of defuzzification unit values to obtain the central areas. FLC systems design courses according to the logic block error feedback and input directly or by reference also is possible to perform data processing. FLC will work to determine whether the limits of membership functions can be determined, as shown in Figure (5).

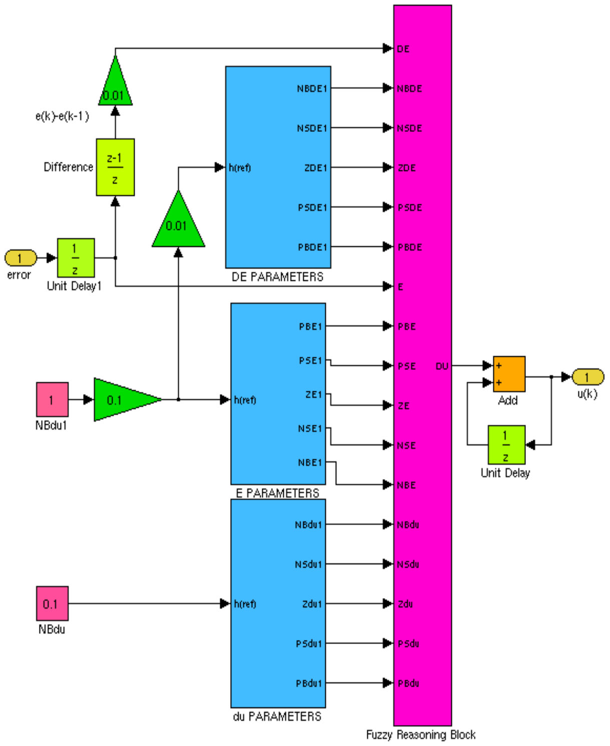

Fig.5. Fuzzy Logic Controller Structure.

Table I: (e-Δe) Rule Assign Matrix (5X5=25).

		Δe				
		NB	NS	Z	PS	P
e	PB	Z	PS	PS	PB	PB
	PS	NS	Z	PS	PS	PB
	Z	NS	NS	Z	PS	PS
	NS	NB	NB	NS	Z	PS
	NB	NB	NS	NS	NS	Z

VI. DIGITAL SIMULATION RESULTS

Digital simulation results using the MATLAB / Simulink / Sim-Power software environment for the proposed FACTS- based SFC scheme under five different study cases are:

A. Normal Operation Case (Without SFC)

The AC single-phase supply feeds a dynamic nonlinear Arc type load without any filtering or reactive compensation. This causes harmonic voltage excursion, inrush current conditions, harmonics, and lower power factor operation. The RMS of voltage, current, power, and power factor waveforms at generator and load buses are depicted in Figures (6, 7) for both source bus and load bus.

B. Controlled Operation Case (With SFC)

The AC single-phase supply feeds a dynamic nonlinear Arc type load by using the modulated/switched power filter; the energy utilization is improved enhanced power quality and reduced total harmonic distortion. The RMS of voltage, current, power, and power factor waveforms at generator and load buses are depicted in Figures (8, 9) for both source bus and load bus.

C. Load Change Case

Changing the load by increasing 50 % of the original load is shown in Figure (1). The RMS of voltage, current, power, and power factor waveforms at generator and load buses are depicted in Figures (10, 11) for both source bus and load bus.

D. Short Circuit Fault Condition Cases

The short circuit (SC) fault is occurred at bus Vs as shown in Figure (1) for a duration of 0.04 sec, from t = 0.3 sec to t = 0.34 sec. The RMS of voltage, current, power, and power factor waveforms at generator and load buses are depicted in Figures (12, 13) for both source bus and load bus.

E. Open Circuit Fault Condition Case

The open circuit (OC) fault is occurred at bus Vs as shown in Figure (1) foradurationof0.02sec, fromt =0.3 sec to t = 0.32 sec. The RMS of voltage, current, power, and power factor waveforms at generator and load buses are depicted in Figures (14, 15) for both source bus and load bus.

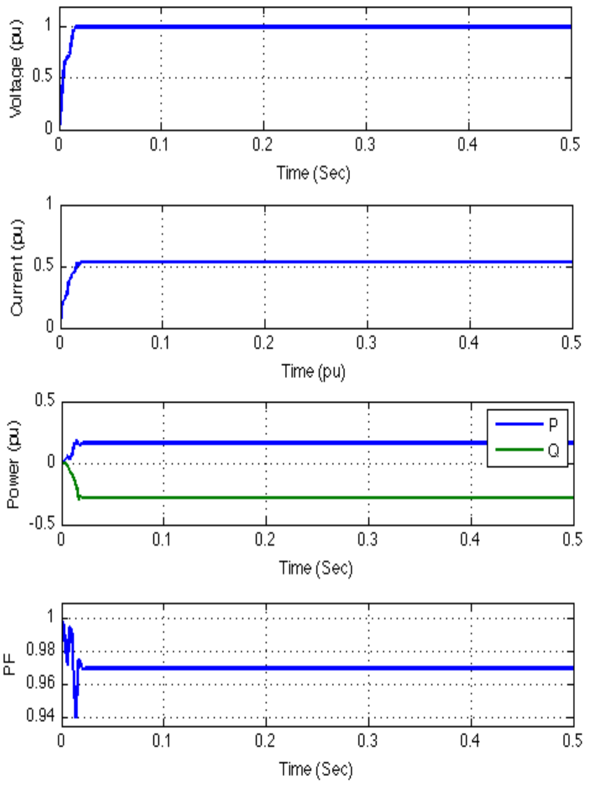

Fig.6. RMS V, I, P, Q, and PF values at AC source bus V_S under normal load operation.

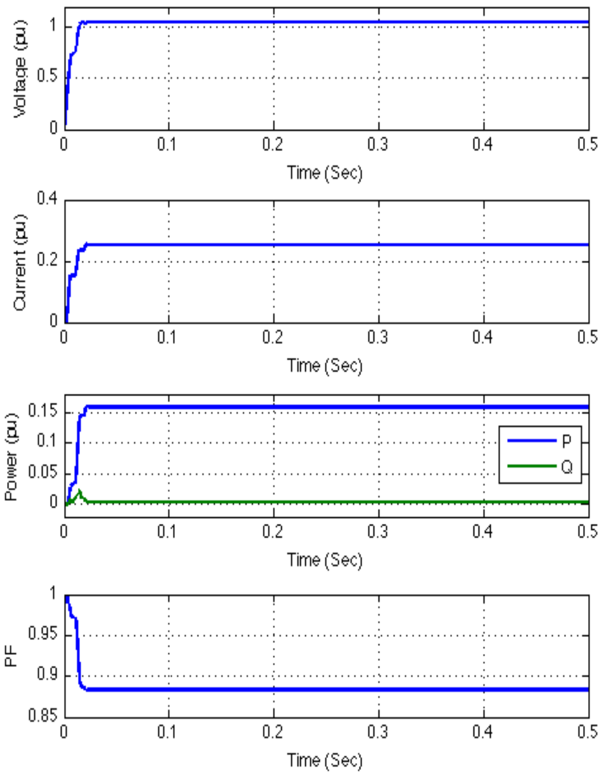

Fig.7. RMSV, I, P, Q, and PF values at AC load bus V_L under normal load operation.

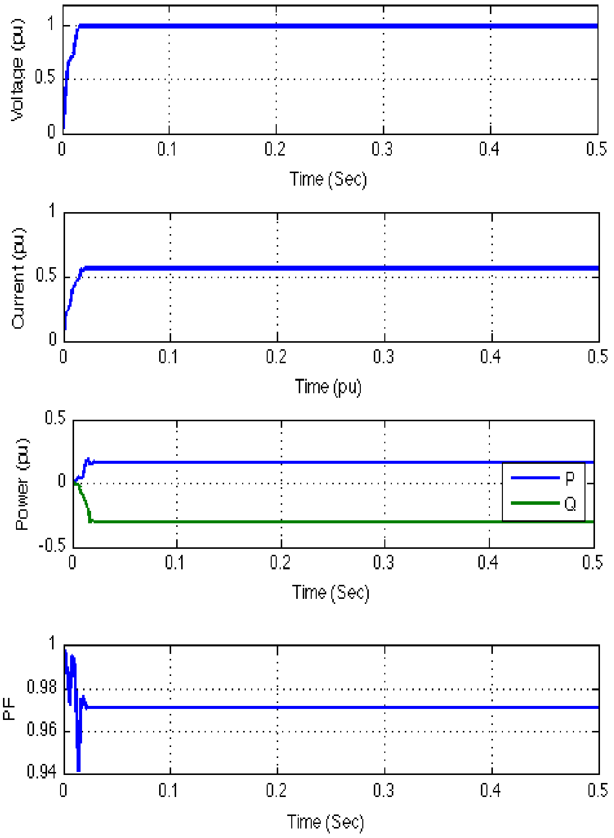

Fig. 8. RMS V, I, P, Q, and PF values at AC source bus V_S with SFC device.

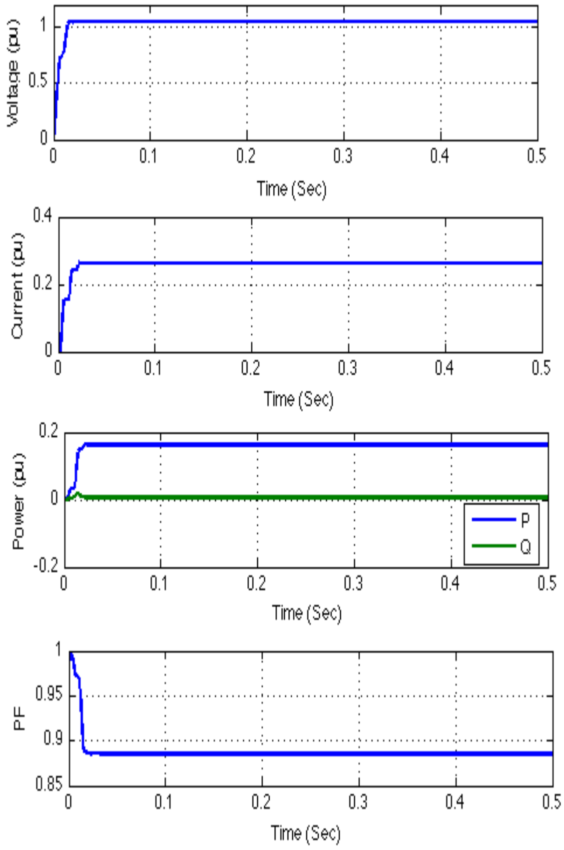

Fig.9. RMS V, I, P, Q, and PF values at AC load bus V_L with SFC device.

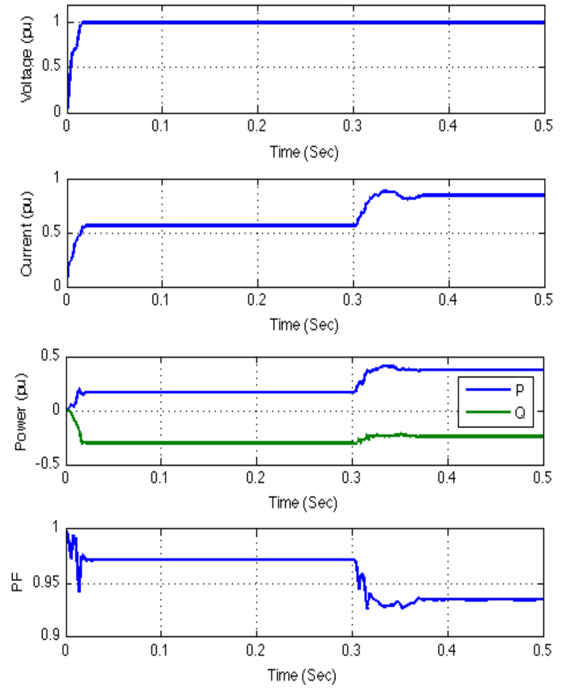

Fig.10. RMS V, I, P, Q, and PF values at AC source bus V_S under loadvariations.

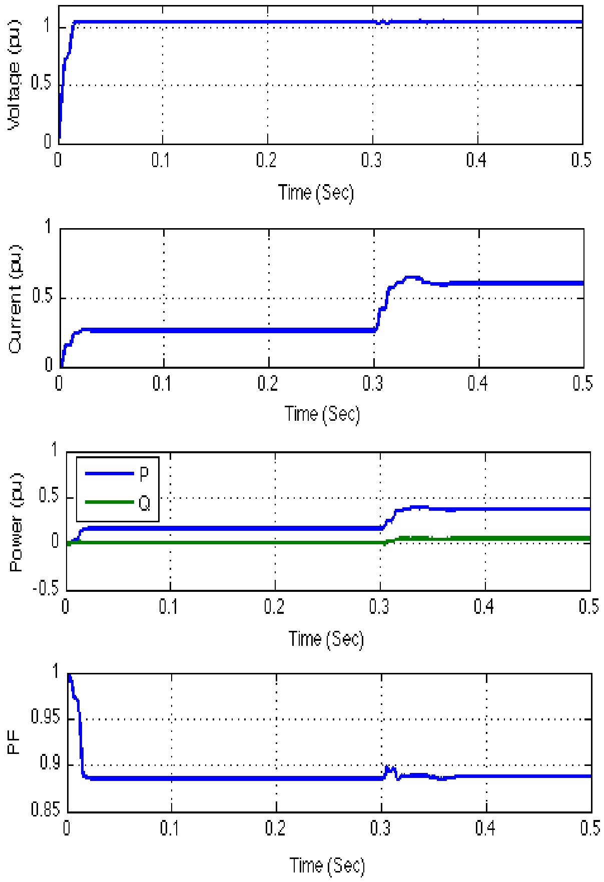

Fig.11. RMS V, I, P, Q, and PF values at AC load bus V_L under load variations.

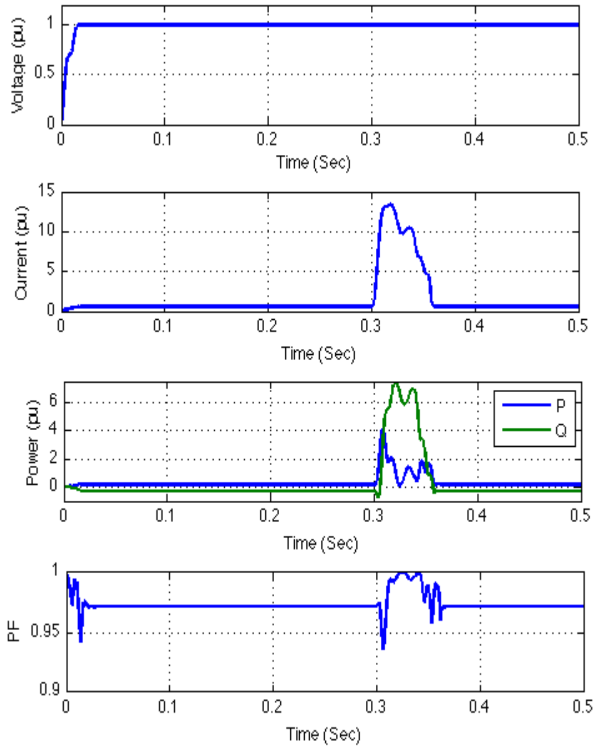

Fig.12. The RMS V, I, P, Q, and PF at AC source bus V_S under short circuit (SC) fault.

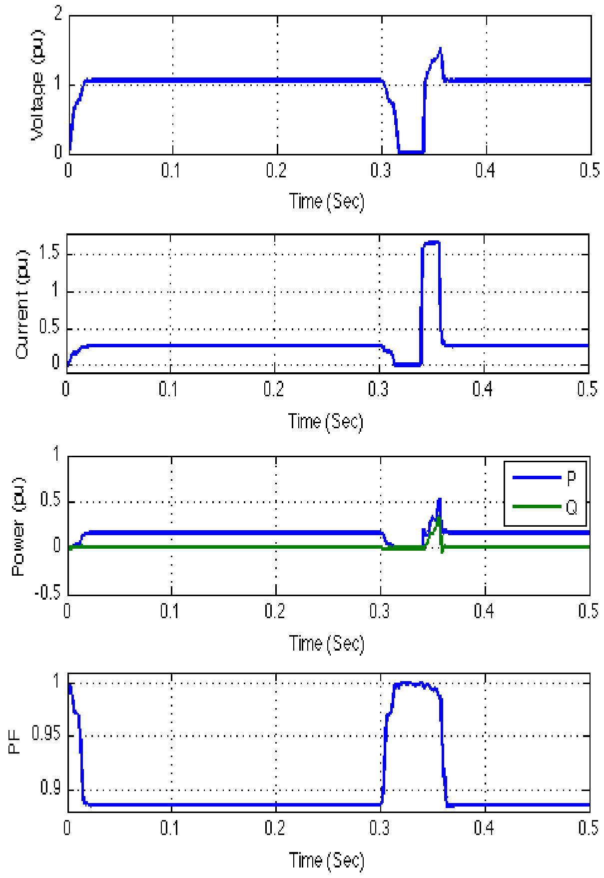

Fig.13. The RMS V, I, P, Q, and PF at AC load bus V_L under short circuit (SC) fault.

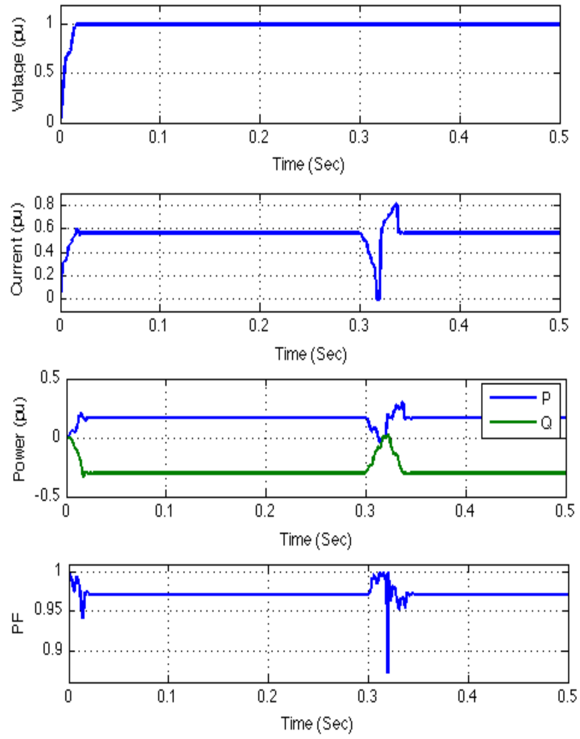

Fig.14. The RMS V, I, P, Q, and PF at AC source bus V_L under open circuit (OC) fault.

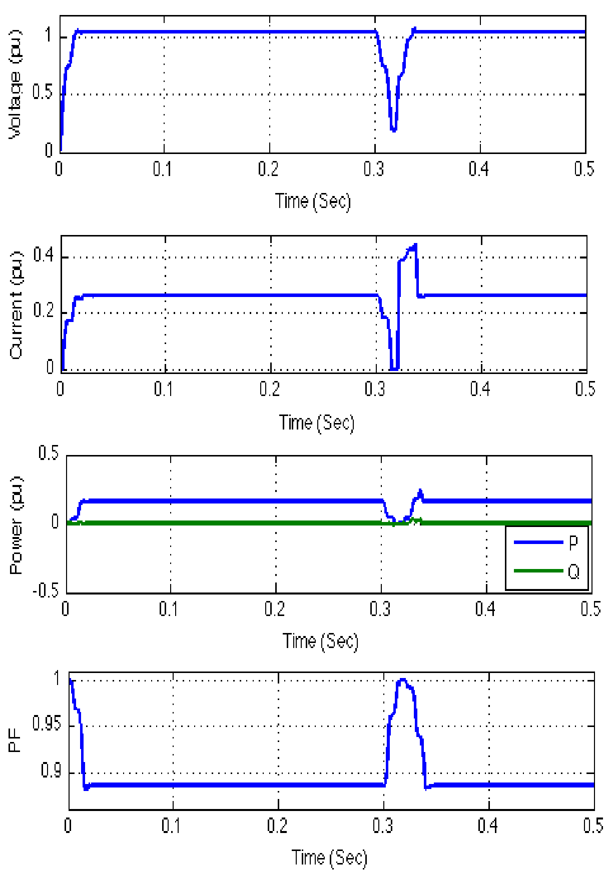

Fig. 15. The RMS V, I, P, Q, and PF at AC load bus V_L under open circuit (OC) fault.

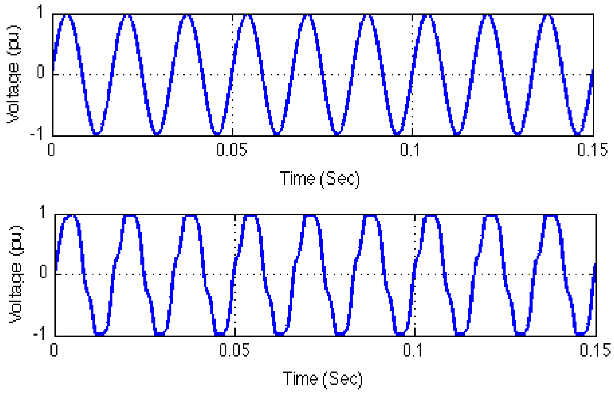

Fig.16. The Voltage waveforms at the AC source and the load.

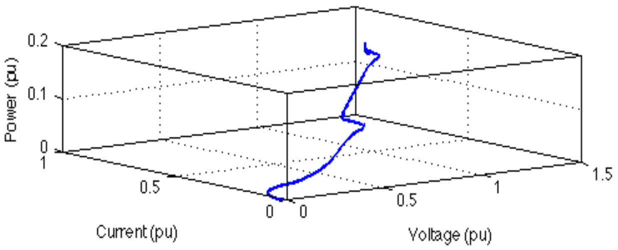

Fig.17. RMS voltage, current, and power (V-I-P) at the AC source V_S.

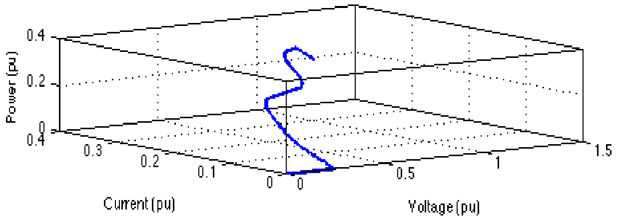

Fig.18. RMS voltage, current, and power (V-I-P) at the AC load V_S.

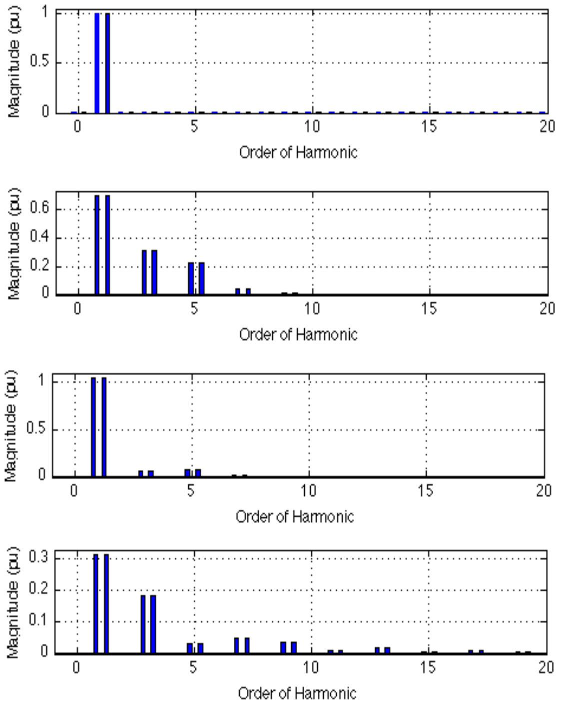

Fig.19. Fourier FFT Frequency Spectra of V and I waveforms at the both source and loud buses.

VII. CONCLUSION

This paper presents an FLC scheme for FACTS-based SFC. The SFC is controlled by a dynamic tri-loop error driven FLC controller. The digital simulation model of the SFC scheme is validated for effective power quality improvement, voltage stabilization, and power factor correction. The FACTS-based filter compensator scheme can be extended to other AC smart grid distributed/ dispersed renewable generation interface and electric utilization systems. It can be easily modified for other specific reactive compensation requirements, voltage stabilization and power factor efficient utilization. Switched filter topology variations and other flexible dynamic control techniques can also be utilized in renewable energy generation with smart grid using distributed interface.

REFERENCES

[1] J. Arrillaga, D. Bradley, and P. Bodger, *Power system harmonics*. Wiley Online Library, 1985.

[2] D. Sabinand A. Sundaram,“Qualityenhances,”*IEEE Spectr-um*, vol.33, no. 2, pp. 34-41, 1996.

[3] Sharaf, H. Huang, and L. Chang, “Power quality and nonlinear load voltage stabilization using error-driven switched passive power filter,” in *Industrial Electronics, ISIE’95. Proceedings of the IEEE International Symposium on*, vol. 2. IEEE, 1995, pp. 616-621.

[4] M. Rastogi, N. Mohan, and A. Edris, “Hybrid-active filtering of harmonic currents in power systems,” *Power Delivery, IEEE Transactions on*, vol. 10, no. 4, pp. 1994-2000, 1995.

[5] H.FujitaandH.Akagi,“Apracticalapproachtoharmoniccompensation in power systems-series connection of passive and active filters,” *Industry Applications, IEEE Transactions on*, vol. 27, no. 6, pp. 1020-1025, 1991.

[6] Sharaf, C. Guo, and H. Huang, “Distribution/utilization system voltage stabilization and power quality enhancement using intelligent smart filter,” *UPEC95*, 1995.

[7] M. Aredes, K. Heumann, and E. Watanabe, “An universal active power line conditioner,” *Power Delivery, IEEE Transactions on*, vol. 13, no. 2, pp. 545-551, 1998.

[8] H. Fujita, T.Yamasaki, and H. Akagi, “A hybrid active filter for damping of harmonic resonance in industrial power systems,” *Power Electronics, IEEE Transactions on*, vol. 15, no. 2, pp. 215-222, 2000.

[9] A. Sharaf and G. Wang, “Wind energy system voltage and energy enhancement using low cost dynamic capacitor compensation scheme,” in *Proceedings of the IEEE International Conference on Electrical, Electronic and Computer Engineering*, 2004, pp. 804-807.

[10] A. Sharaf, “A facts based dynamic capacitor scheme for voltage compensation and power quality enhancement,” in *Industrial Electronics, 2006 IEEE International Symposium on*, vol. 2. IEEE, 2006, pp. 1200-1205.

[11] A. Sharaf and R. Chhetri, “A novel dynamic capacitor compensator/green plug scheme for 3phase-4 wire utilization loads,” in *Electrical and Computer Engineering, 2006. CCECE’06. Canadian Conference on*. IEEE, 2006, pp. 454-459.

[12] H. Zenk, O. Zenk, and A. S. Akpinar, “Two different power control sys- tem load-frequency analysis using fuzzy logic controller,” *Innovations in Intelligent Systems and Applications (INISTA), 2011 International Symposium on*, pp. 465–469, 2011.

[13] I. Vervenne, K. Van Reuse, and R. Belmans, “Electric arc furnace modelling from a power quality point of view,” in *Electrical Power Quality and Utilisation, 2007. EPQU 2007. 9th International Conference on*. IEEE, 2007, pp. 1-6.

[14] I. Altas and A. Sharaf, “A generalized direct approach for designing fuzzy logic controllers in matlab/simulinkgui environment,” *International Journal of Information Technology and Intelligent Computing*, 2007.