Solar PV Fed-Shunt APF to enhancement of Power Quality Issues in Distribution Power System using Adaptive FLC

*** Jyothi Nemmadi [1], Dr.M. Manjula [2]**

*[*1] PhD Scholar, Department of Electrical Engineering, Osmania University, Hyderabad, INDIA,*

[2] Professor, Department of Electrical Engineering, Osmania University, Hyderabad, INDIA

---***---

Abstract: Using an adaptive FLC-based shunt APF, this work proposes a result to Power Quality issues produced by nonlinear loads in distribution power systems with integrated solar energy, such as current fluctuation and THD. This study looks at the use of a s solar PV coordinated shunt APF to work on power quality issues. A type of active power filter called a shunt active power factor (APF) makes use of a shared DC-link voltage source to improve load side parameters like removing even and odd current harmonics. In addition, it exerts additional effort when transferring power to the DC connection voltage from the solar PV system. In this paper, an adaptive FLC to handle PQ issues in grid-connected DG systems, including as harmonic improvement at source & load side. The current reference generator of the active power filter is also described in detail. Applying MATLAB/SIMULINK, the outputs that have been validated were achieved.

Keywords: Shunt APF; Total Harmonic Distortion; Solar PV; Adaptive FLC and MATLAB/Simulink.

1. Introduction

In modern times, electrical energy has taken the crown as the most widely employed power source. Life is unthinkable without access to electricity. Also crucial to the proper functioning of the end user's apparatus are the reliability and consistency of the electricity delivered to them. The commercial and industrial loads often necessitate both continuous high quality and a steady flow of power [1-4]. Consequently, preserving the reliability of the electrical grid is a top priority. The efficiency and reliability of the power supply are greatly influenced by the nonlinear components [5-7]. There are a variety of power quality problems that can be caused by electronic devices. Voltage drops and spikes produced by things like network failures, lightning, and the switching of capacitor banks can all contribute to poor power quality [8]. Computers, laser printers, and rectifiers create reactive and harmonic power when utilized in excess [9]. This type of problem, which could get worse in the future, must be fixed immediately to prevent more damage. For reactive power disturbances and harmonic generation, passive filters have typically been used despite their size, resonance difficulties, and the effect of the source impedance on performance. Active power filters are able to improve the quality of the energy supply [10]. In this Paper the d-q axes current from the load current controls the functioning of the shunt APF, and Solar Fed DC-interface voltage is maintained by an adaptive FLC. This paper discusses the static and dynamic behavior of control circuits under diverse load current and variable voltage situations. When the plant's parameters change, an adaptable FLC is built for it. With static and Dynamic nonlinear loads, the Shunt APF is employed to reduces fluctuations, and harmonics etc.

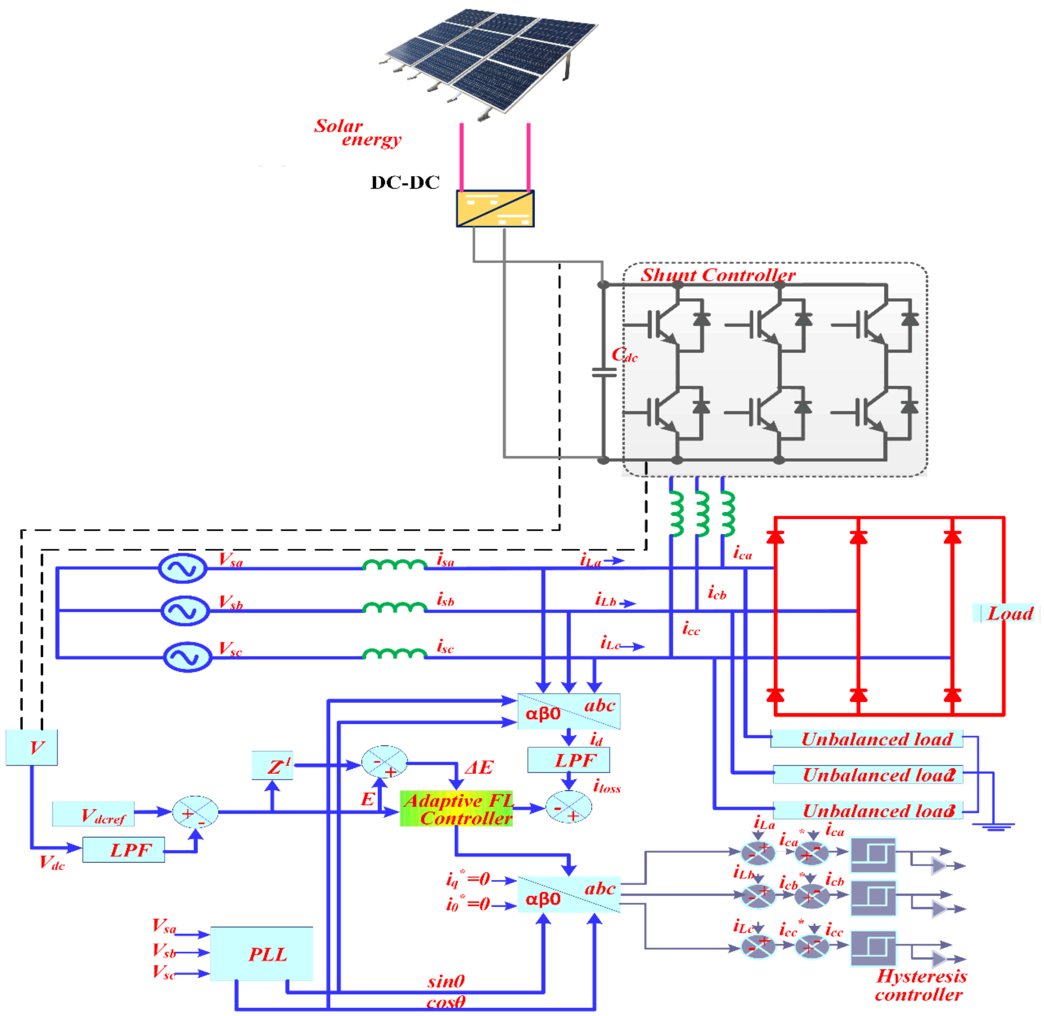

Figure 1. Basic Configuration of Adaptive FLC based Shunt APF

2. Modelling and configuration of System

2.1. Shunt Active Power Filter

Oscillations in the load current can be reduced by connecting a shunt active APF, as seen in Figure 3, which filters a current equal to but opposite to the oscillations. This is accomplished through the use of a shunt system. A shunt active power filter (APF) is essentially a current source that filters a load's resonance with a 180-degree phase shift. The APF's primary duties are to control voltage and filter out harmonics within the nonlinear load and the customer side supply [26]. Its primary application is frequency suppression. The APF involved under reasonable levels of chaos by conforming to the p-q hypothesis [27]. Voltages and currents are converted utilizing these mathematical formulas into the abc coordinate set to the dq coordinate structure.

$$\begin{bmatrix} V_o \\ V_d \\ V_q \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{s,a} \\ V_{s,b} \\ V_{s,c} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_o \\ i_d \\ i_q \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{s,a} \\ i_{s,b} \\ i_{s,c} \end{bmatrix} \quad (2)$$

For calculating the true and reactive elements in (3), the formula provides an initial reference. Because they are both real and reactive components to the interaction among I_L & V_S.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} -V_d & V_q \\ -V_q & -V_d \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (3)$$

$$P_o = V_0 * I_0 \quad (4)$$

$$P = \vec{P} + \tilde{P} \quad (5)$$

$$\begin{bmatrix} i_{cd,r} \\ i_{cq,r} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\vec{P} + \vec{P}_o + \vec{P}_{loss} \\ -Q \end{bmatrix} \quad (6)$$

The specified currents of the "Shunt-APF" in the dq axis are Icd,r and Icq,r. Now are able to observe how the currents are transformed into a 3-φstructure in (7) by applying the equations in Eqn.

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{cd,r} \\ i_{cq,r} \end{bmatrix} \quad (7)$$

The 3-φmethod modifies all abnormalities in the load by deliberately employing three separate current references (Ica,r, Icb,r, and Icc,r). The HCC method analyses the current signal to the reference point signal to produce a switch signal. The performance of the shunt APF method depends on the rate that the contrast occurs and the calibre of the "reference" point signal [15].

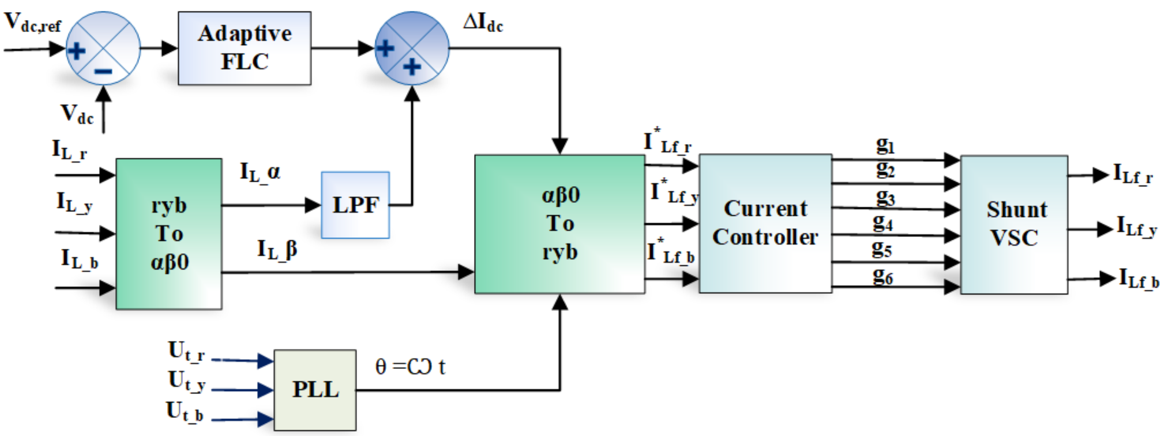

Figure 3. Shunt-APF Configuration.

2.2. Solar PV Scheme

PV cell analogous circuit

The quantity of solar panels interconnected in a Photovoltaic system in series and parallel determines voltage, current, short-circuit current, open-circuit voltage. The analogous circuit for photovoltaic cell is shown in **Figure** 3. The crucial elements consist of parallel diode, series resistors, and a current source. The anticipated power is provided by the PV cells that are contemporaneously put together to create PV modules using a mixture of series and parallel. The symbol for number of parallel PV cells is U' p, while symbol for number of series PV cells is U' a. It is possible to depict the correlation between output current, voltage as.

$$I^*_{PV} = N^*_P I^*_G - N^*_P I^*_S \left(exp\left[\frac{q^*}{AKT_C} \left(\frac{v^*_{PV}}{N^*_S} + \frac{R_S I^*_{PV}}{N^*_P} \right) \right] - 1 \right) \quad (8)$$

Photocurrent I* G is created by solar irradiation, as demonstrated below:

$$I^*_G = \left(I^*_{SC} + k_I (T_C - T_{ref}) \right) \frac{s}{1000} \quad (9)$$

According to the correlation shown below, $I^* S$ is the saturation current of a PV cell that changes with temperature:

$$I^*_S = I^*_{rs} \left[\frac{T_C}{T_{ref}} \right]^3 exp\left[\frac{q^* E_g}{AK} \left(\frac{1}{T_{ref}} - \frac{1}{T_C} \right) \right] \quad (10)$$

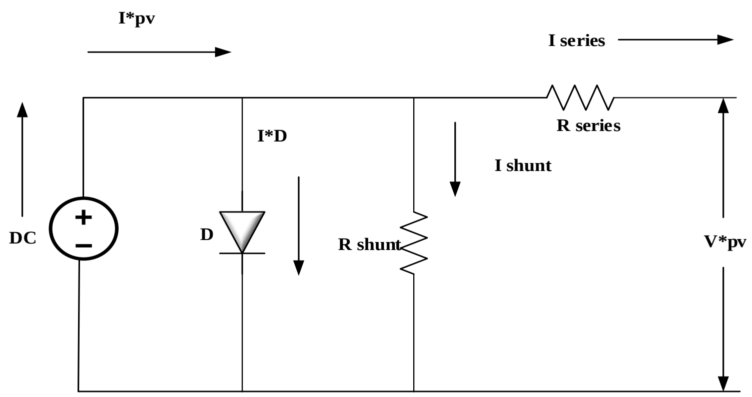

Figure 3. PV cell analogous circuit

3. Control Method

The input for FLC controller is error (V_{dcref}-V_{dc}) and change in error serve as FLC's sources. Fuzzy logic rules are used to adjust the PI controller parameters online in order to achieve the best PI parameters because the inputs are constantly measured and calculated by the FLC [20]. Due to the FLC inputs of the adaptive fuzzy PI controller, the error and change in Error and Output may meet the PI self-calibration requirements at different times. The membership functions of the input variables are depicted in **Figures 4** and **5** respectively. According to **Figures 6 and 7**, respectively, the membership functions for the integral gain Ki and the proportional gain KP are devised. **Figure 8** depicts the suggested control strategy's flowchart.

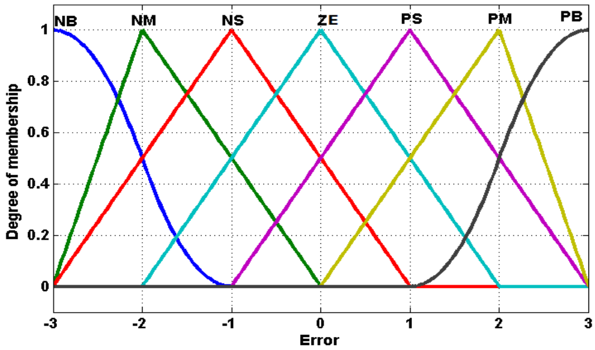

Figure 4. Membership functions of Error

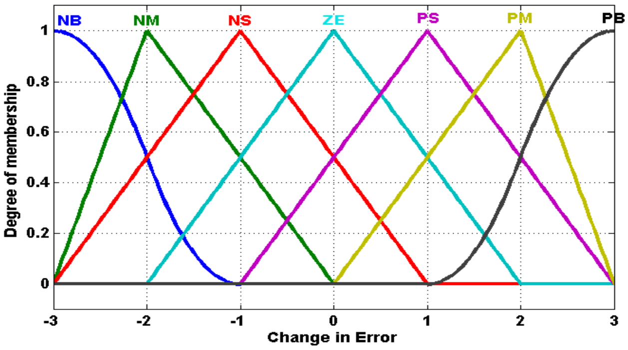

Figure 5. Membership functions of change in Error

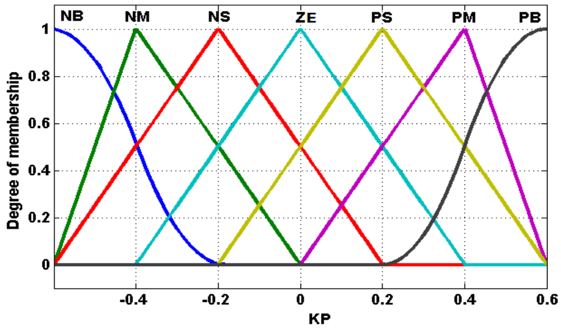

Figure 6. Membership functions of K_P

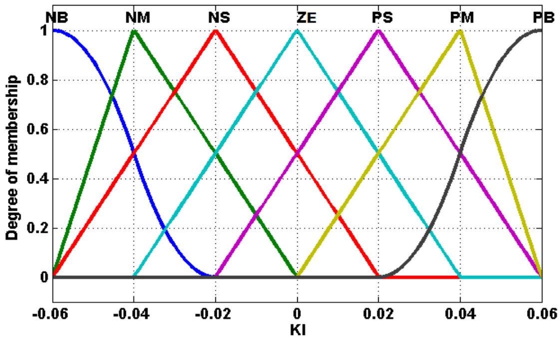

Figure 7. Membership functions of K_I

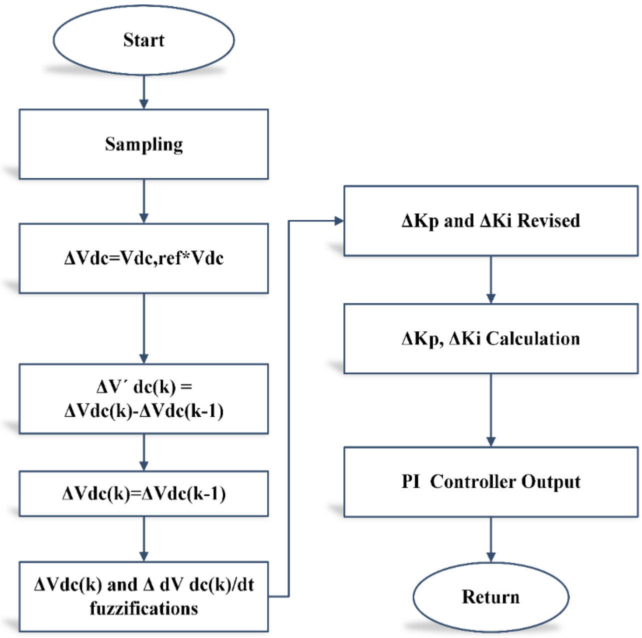

Figure .8 Flow chart for Adaptive FLC strategy

3.1. Learning part

Performance input is part of an adaptive controller's learning process. The performance index generates optimal states to produce optimal constraint states based on fuzzy inference by awarding credits or rewards to individual control actions that add to the current performance. In order to achieve the best results, there should be no loss of power in the output control signal, which could be due to harmonics, voltage distortion, current distortion, etc. By enlarging the FLC's inference table to include the voltages and currents on the source and source sides, we can also use the same membership functions for these variables as in the earlier approach. Table 1 displays a rule table for the control diagram modification FLC and FLC.

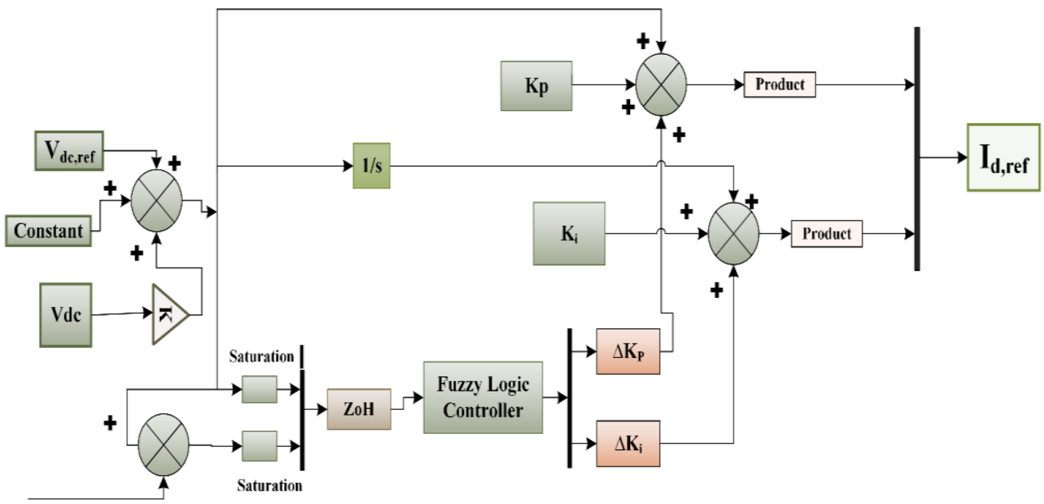

Figure 9. Control diagram adaptive FLC

Table 1. Rule table for FLC

Error / Change In Error	PS	PB	ZE	NS	NB
PB	PB	PB	PB	PS	ZE
PS	PB	PB	PS	ZE	NS
ZE	PS	PB	ZE	NS	NB
NS	ZE	PS	NS	NB	NB
NB	NS	ZE	NB	NB	NB

The Shunt APF based ADFLC is used to adjust for load current harmonics. By adjusting the DC interface voltage, the determined value of the reference currents can be calculated. A reference value is connected to the voltage to summing point. The error signal is currently maintained by an FLC, which ensures that the signal is tracked with a constant error of zero. Under d-q, FLC is added to the d-axis to control the active current component and keep the DC interconnection voltage constant. The current regulator adjusts this small amount of active current that is controlled by the FLC to maintain a constant DC interface voltage. The control diagram for the ADFLC-based Shunt APF is shown in **Figure 9**. It is shown that the proposed adaptive fuzzy logic control method can attenuate the effects of outside disturbances and inaccurate approximations to a certain level. It joins fluffy framework properties, criticism linearization procedures, versatile control plans, and ideal control hypothesis to take care of following control plan issues for nonlinear frameworks with restricted obscure or dubious boundaries and unsettling influences.

4. Simulation Results

The **Figure.10** and **Figure .11** dipicts the Source current, filter current and load current with FLC and Adaptive FLC respectively.it obseved the by adaptive the proposed controller the source current beconme stable sinusioadal current and fluctuation are reduced.

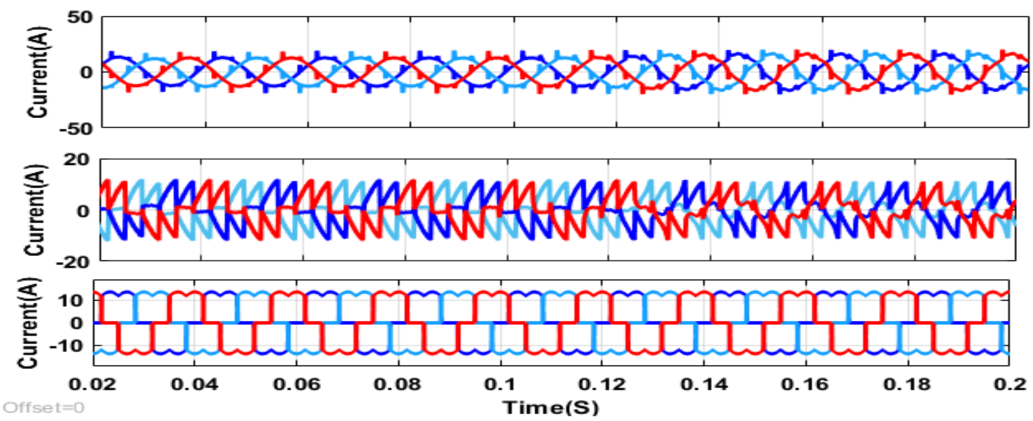

Figure.10. Results of Source current during distortion with FLC

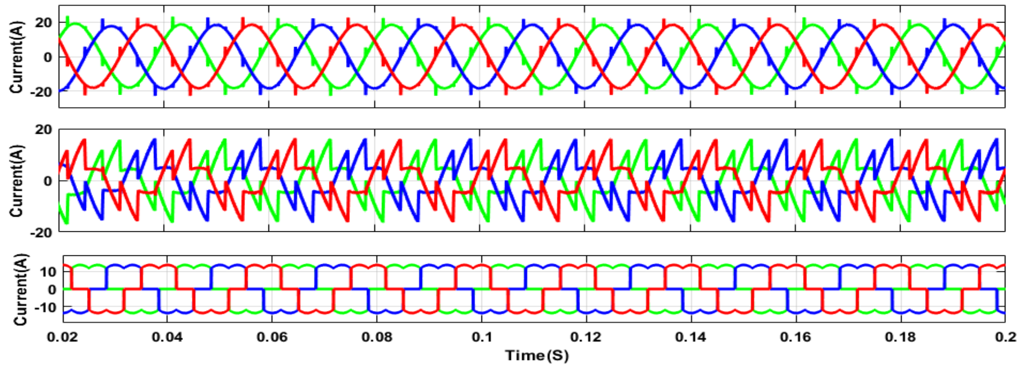

Figure.11. Results I_s and I_l with adaptive FLC

During distortion following implementation of Adaptive FLC simulation results for V_S and I_S are given in **Figure 12.** and **13. Figure 12** depicts the Source Voltage and Source Current with FLC and **Figure 13.** depicts the V_S and I_S with Adaptive FLC.It examine the with Adaptive FLC Source voltage maintained stable magnitude compared to FLC and also Distortions reduced of source Current.

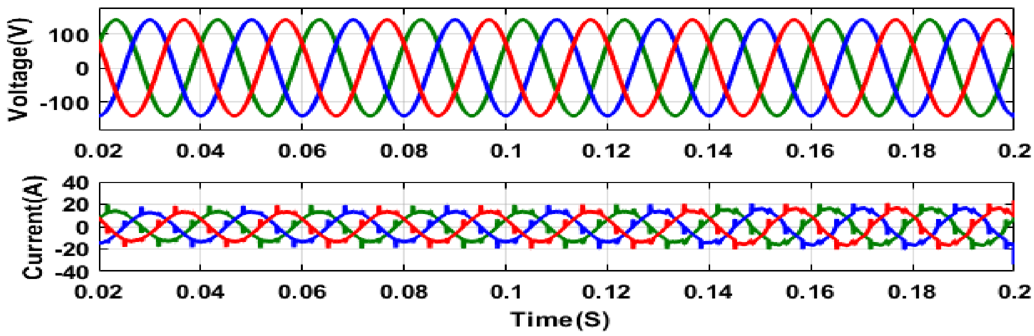

Figure 12. Result of V_s and I_s with FLC

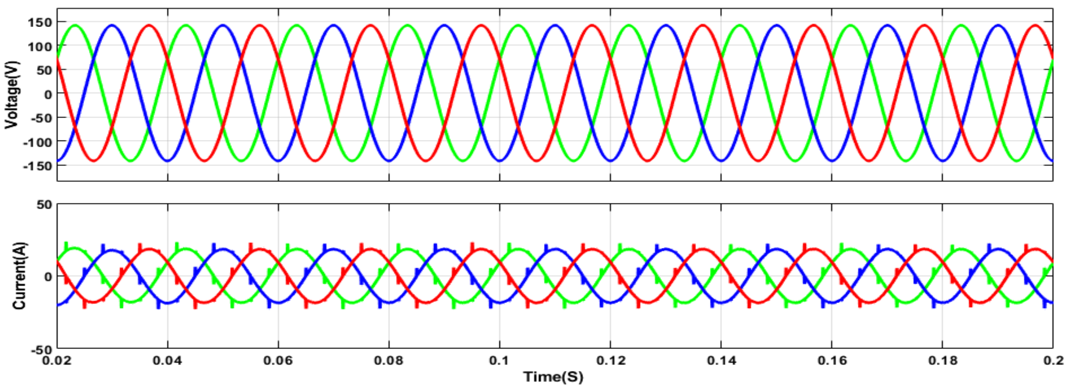

Figure 13. Result of V_s and I_s with Adaptive FLC

During distortion following implementation of Adaptive FLC simulation results for V_S and I_S are given in Fig.14 and 15. Fig.14 depicts the V_L and I_L with FLC and Fig.13 depicts the V_L and I_L with Adaptive FLC.It examine the with Adaptive FLC load voltage maintained stable magnitude compared to FLC and also Distortions reduced of load Current.

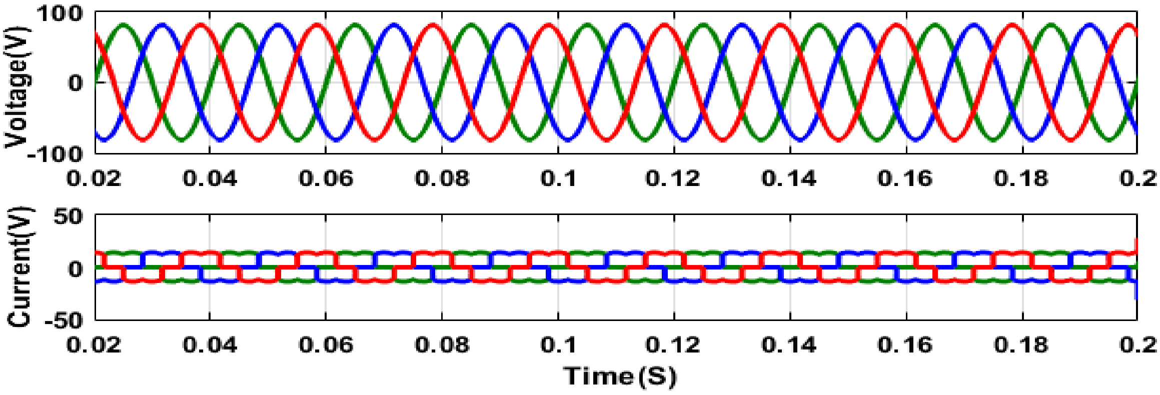

Figure 14 Results of load voltage and Current during distortion with FLC

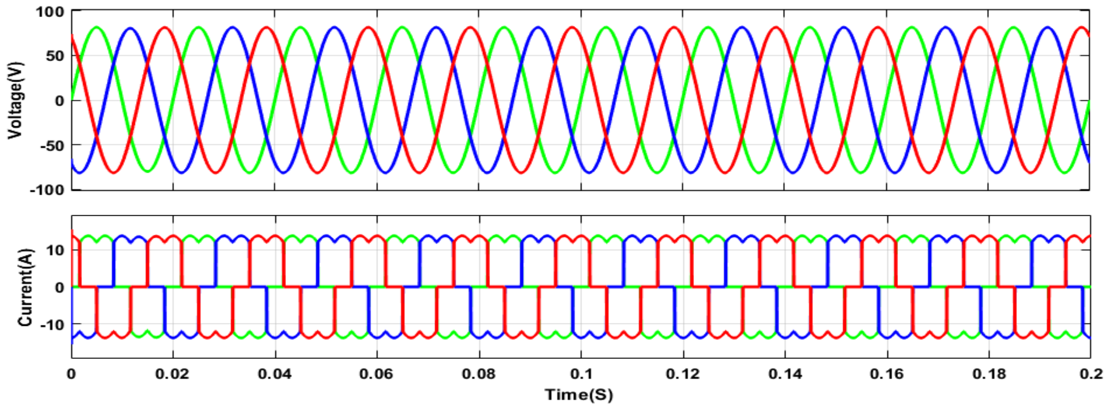

Figure 15. Results of load voltage and current during distortion with adaptive FLC

Table .2. THD values for I_S, V_S, I_L and V_L with certain controllers

	Parameters & THD variations			
Controllers	for I_S	for V_S	for I_L	for V_L
Shunt APF with FLC	8.35%	4.21%	8.21%	11.5%
Shunt APF with Adaptive FLC	5.14%	3.60%	6.15%	7.32%

5. Conclusion

In order to improve the P.Q issues and V_{DC}-Link parameter, which have been identified as major issues in the power quality industry, this study offers a adaptive FLC based Shunt APF. The two controllers that make up shunt APF's operation are the FLC, Adaptive FLC is established with MATLAB/Simulink, and then the simulation results are studied. THD values are computed for each controller and compared to one another. The results show that using a Adaptive FL controller, the source Voltage THD values are 3.60% and the source Current THD values are 5.14%. The success of this controller's compensation for all parameters is further demonstrated. Therefore, the adaptive FLC is the most efficient of proposed solutions. The following are some of the benefits of the suggested controller: During voltage distortion, stable voltage regulation was accomplished. When compared to the previous scheme, VSI and power supply losses are significantly reduced. The current system with Shunt APF has the capacity to tackle numerous PQ challenges.

References

1. Ray, Pragnyashree, Pravat Kumar Ray, and Santanu Kumar Dash. "Power quality enhancement and power flow analysis of a PV integrated UPQC system in a distribution network." IEEE Transactions on Industry Applications 58, no. 1 (2021): 201-211.

2. Patel, Harsh D., Priyank Gandhi, and Pranav Darji. "PV-Array-Integrated UPQC for Power Quality Enhancement and PV Power Injection." In Recent Advances in Power Electronics and Drives: Select Proceedings of EPREC 2021, pp. 433-449. Singapore: Springer Nature Singapore, 2022.

3. Krishna, D., M. Sasikala, and R. Kiranmayi. "FOPI and FOFL Controller Based UPQC for Mitigation of Power Quality Problems in Distribution Power System." Journal of Electrical Engineering & Technology 17, no. 3 (2022): 1543-1554.

4. Mishra, Ankit, Sushil Chauhan, P. Karuppanan, and Manmath Suryavanshi. "Pv based shunt active harmonic filter for power quality improvement." In 2021 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS), pp. 905-910. IEEE, 2021.

5. Krishna, D., M. Sasikala, and V. Ganesh. "Fractional order fuzzy logic based upqc for improvement of power quality in distribution power system." International Journal of Recent Technology and Engineering (IJRTE) 7, no. 6 (2019): 1405-1410.

6. Senguttuvan, S., and M. Vijayakumar. "Solar photovoltaic system interfaced shunt active power filter for enhancement of power quality in three-phase distribution system." Journal of Circuits, systems and computers 27, no. 11 (2018): 1850166.

7. Babu, Narendra, Josep M. Guerrero, Pierluigi Siano, Rangababu Peesapati, and Gayadhar Panda. "An improved adaptive control strategy in grid-tied PV system with active power filter for power quality enhancement." IEEE Systems Journal 15, no. 2 (2020): 2859-2870.

8. Krishna, D., M. Sasikala, and V. Ganesh. "Adaptive FLC-based UPQC in distribution power systems for power quality problems." International Journal of Ambient Energy 43, no. 1 (2022): 1719-1729.

9. Ali, Ayesha, Ateeq Ur Rehman, Ahmad Almogren, Elsayed Tag Eldin, and Muhammad Kaleem. "Application of Deep Learning Gated Recurrent Unit in Hybrid Shunt Active Power Filter for Power Quality Enhancement." Energies 15, no. 20 (2022): 7553.

10. Gade, Swati, Rahul Agrawal, and Ravindra Munje. "Recent Trends in Power Quality Improvement: Review of the Unified Power Quality Conditioner." ECTI Transactions on Electrical Engineering, Electronics, and Communications 19, no. 3 (2021): 268-288.

11. Ahmed, Toqeer, Asad Waqar, Rajvikram Madurai Elavarasan, Junaid Imtiaz, Manoharan Premkumar, and Umashankar Subramaniam. "Analysis of fractional order sliding mode control in a d-statcom integrated power distribution system." IEEE Access 9 (2021): 70337-70352.

12. Muhtadi, Abir, Dilip Pandit, Nga Nguyen, and Joydeep Mitra. "Distributed energy resources based microgrid: Review of architecture, control, and reliability." IEEE Transactions on Industry Applications 57, no. 3 (2021): 2223-2235.

13. JeraldineViji, A., R. Priya, and B. Pushpa. "PV Combined ZSI-DVR with Fuzzy Logic Controller for Power Quality Improvement." In 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), pp. 1-6. IEEE, 2021.

14. Yavari, Mojtaba, Sayyed Hossein Edjtahed, and Seyed Abbas Taher. "A non-linear controller design for UPQC in distribution systems." Alexandria engineering journal 57, no. 4 (2018): 3387-3404.

15. Al-Ammar, Essam A., Azhar Ul-Haq, Ahsan Iqbal, Marium Jalal, and Almas Anjum. "SRF based versatile control technique for DVR to mitigate voltage sag problem in distribution system." Ain Shams Engineering Journal 11, no. 1 (2020): 99-108.

16. Yang, Dongsheng, Zhanchao Ma, Xiaoting Gao, Zhuang Ma, and Enchang Cui. "Control strategy of intergrated photovoltaic-UPQC System for DC-Bus voltage stability and voltage sags compensation." Energies 12, no. 20 (2019): 4009.

17. Mohanty, Asit, Sandipan Patra, and Prakash K. Ray. "Robust fuzzy-sliding mode based UPFC controller for transient stability analysis in autonomous wind-diesel-PV hybrid system." IET Generation, Transmission & Distribution 10, no. 5 (2016): 1248-1257.

18. Das, Balaram, Pratap K. Panigrahi, Soumya R. Das, Debani P. Mishra, and Surender Reddy Salkuti. "Power quality improvement in a photovoltaic based microgrid integrated network using multilevel inverter." International Journal of Emerging Electric Power Systems 23, no. 2 (2022): 197-209.

19. Rajarajan, R., and R. Prakash. "A reformed adaptive frequency passiveness control for unified power quality compensator with model parameter ability to improve power quality." Microprocessors and Microsystems 73 (2020): 102984.

20. Srilakshmi, Koganti, Canavoy Narahari Sujatha, Praveen Kumar Balachandran, Lucian Mihet-Popa, and Naluguru Udaya Kumar. "Optimal Design of an Artificial Intelligence Controller for Solar-Battery Integrated UPQC in Three Phase Distribution Networks." Sustainability 14, no. 21 (2022): 13992.

21. Qashou, Akram, Sufian Yousef, Abdallah A. Smadi, and Amani A. AlOmari. "Distribution system power quality compensation using a HSeAPF based on SRF and SMC features." International Journal of System Assurance Engineering and Management 12, no. 5 (2021): 976-989.

22. Sarita, Kumari, Sachin Kumar, Aanchal Singh S. Vardhan, Rajvikram Madurai Elavarasan, R. K. Saket, G. M. Shafiullah, and Eklas Hossain. "Power enhancement with grid stabilization of renewable energy-based generation system using UPQC-FLC-EVA technique." IEEE Access 8 (2020): 207443-207464.

23. Kumar, Ravinder, and Hari Om Bansal. "Shunt active power filter: Current status of control techniques and its integration to renewable energy sources." Sustainable Cities and Society 42 (2018): 574-592.

24. Kumar, Ravinder, Hari Om Bansal, and Dinesh Kumar. "Improving power quality and load profile using PV-Battery-SAPF system with metaheuristic tuning and its HIL validation." International Transactions on Electrical Energy Systems 30, no. 5 (2020): e12335.

25. Sharma, Jayant, C. K. Sundarabalan, R. Sitharthan, C. Balasundar, and N. S. Srinath. "Power quality enhancement in microgrid using adaptive affine projection controlled medium voltage distribution static compensator." Sustainable Energy Technologies and Assessments 52 (2022): 102185.