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An Improved Power Quality in a Renewable Energy-based Microgrid System Using Adaptive Hybrid UPQC Control Strategy

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Abstract: Due to its ability to integrate renewable energy, improve energy efficiency, and fortify the power system's resilience, microgrids are widely used as regional energy systems. But these advantages do have certain drawbacks in terms of control and Power Quality (PQ). In order to guarantee the proper operation of equipment that is connected and the system's general health, PQ is crucial in microgrids. For microgrids to operate successfully, governing stratagems in concurrence with front-line power electronics devices bid a firm context to knob PQ challenges like Voltage Sag and Swell, Source/Grid current harmonics, Voltage imbalances, Active and Reactive power compensation etc. Multifunctional systems that can integrate clean energy generation and as well as enhance PQ are necessary to meet the demands of complex loads that have the capability of operating in the situation of an unavailable network grid and power electronics devices, which necessitates the need for clean energy. Hence, this paper provides enactment of an adaptive hybrid control strategy based on an Adaptive Leaky Least Mean Square (AL_LMS) algorithm combined with Fuzzy Logic (FL) to the Unified Power Quality Conditioner (UPQC) in a Solar-PV energy based Microgrid system in improving microgrid power quality. The concert of UPQC is assessed by the conventional PI controller and Fuzzy Logic control with MATLAB/SIMULINK software platform, simulation results are conversed with proportionate studies in improving the PQ by minimizing Total Harmonic Distortion (THD), the Voltage Sag & Swell and the result comparison shows the effectiveness of the Fuzzy Logic in coordination with the AL_LMS algorithm resulting improved power quality within the IEEE Power Quality-519 Standards.

Introduction

The detrimental possessions of global warming in addition to fossil fuel emissions appease the practice of Renewable Energy Sources (RES) to replace outmoded fossil fuel energy production (Halkos and Gkampoura, 2020). Widespread adoption of renewable and sustainable energy necessitates the amalgamation of RES for instance solar and wind power into the grid for sustainable development (Mlilo et al., 2021). Today, the microgrid (MG) concept has attracted much attention from system operators to improve operational efficiency and provide a more reliable, sustainable and economical power system, for example, to obtain a number of cost-effective and technological advantages by the large integration of RES based on converters control, such as cheaper energy, fewer carbon emissions, lower operating and maintenance costs (Fazal et al., 2023). A microgrid appears in a central power grid structure as its own regulated unit that connects to a point of common connection (PCC) with the grid. As given in Figure 1 below, the microgrid provides electricity and thermal energy as an agglomeration of micro sources/ distributed generation (DG), storage system, energy control and loads. It operates as a single system, and if there is a problem with the grid, it can be disconnected or independent from the main power system and

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reconnected to the grid when the problem is resolved (Saeed et al., 2021).

grid generates harmonic currents that are in phase opposite to the reactive currents of the load. The integration of RES reduces the power quality at the PCC

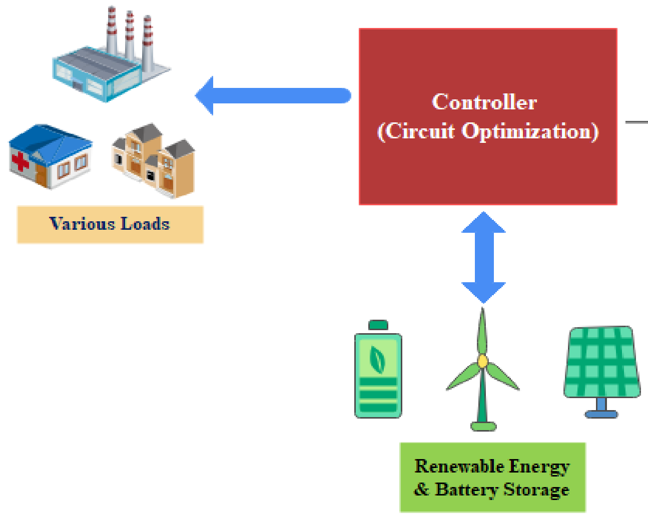

Figure 1. A typical Microgrid Structure.

A grid-interconnected microgrid on the PCC provides reactive and active power compensation. Maximum power monitoring (MPPT) and charge controller can supervise the maximum power of the RES and Charging control of the storage of the energy system (Kiehbadroudinezhad et al., 2022). Microsources must be based on power electronics to afford the necessary flexibility along with reliability. If the electrical system is not flexible enough, it is obligatory to edge the amount of renewable energy associated with the grid. To maintain steady operation throughout transients and changes in AC system parameters, it is crucial to properly operate the power electronics (PE) converter linked to the RES. These devices can instantaneously respond to power quality issues, offering voltage and frequency support, compensating for harmonics, and providing ancillary services (Alam et al., 2020). Power Quality has always been a regular issue, and with the increase in the number of electrical appliances, these issues have increased significantly over the years (Sankaran, 2017). Current drawn by power consuming apparatus passes by the impedance of the electrical system's transmission lines and also reasons a voltage drop, thus affecting the user's voltage distributed. Consequently, voltage quality & current quality both are substantial. It is the customer's responsibility to ensure that the power it purchases from the network is of a high standard, and the utility is accountable for the voltage quality (Sabin et al., 2022).

Currently, a major area of research in industry and academia is the network interaction of RES for improved system performance. In the existence of non-linear loads, a microgrid powered by a RES integrated into the main and introduces harmonic components into the network which must not exceed certain limits (Sudheer et al., 2022). Microgrids minimalize PQ problems in the main grid by connecting active filters and providing reactive power (Q) compensation, harmonic curb and load balancing at the PCC connection (Vijayalakshmi et al., 2022). Since PE converters inject higher harmonics into photovoltaic and wind energy systems, power loss in circuits and interference in communication systems are two major concerns. Several steps must be taken to elevate the PQ in order to guarantee the system's regular operation (Jadeja et al., 2020). More unification of renewable energy to the grid reduces system reliability. An enhanced grid-connected converter control technique using adaptive control to enhance transient performance and repress harmonics in a microgrid where local steady and dynamic AC/DC loads are also coupled to the PCC was proposed in (Baharizadeh et al., 2021). Control strategies improving the power quality of sensitive consumers connected in a microgrid AC bus. In this case, it should include the progress of advanced power electronics towards interfacing ESSs and reduce the impact of RES intermittency and compensate for the existence of harmonic or unbalanced loads, thereby improving microgrid power quality. Controllers for these microgrids must include fast transitions between grid-tied and also islanded operational modes to mitigate the effects of mains outages (Hmad et al., 2023). Several measures have been taken to demonstrate the power quality with RES in a microgrid, for e.g., the implementation of better management & control strategies with the use of various auxiliary equipment.

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The devices based on power electronics technology for refining the PQ in the distribution network, modelling and simulation of these custom power controllers are being anticipated (Bajaj et al., 2020). To mitigate harmonics, several advanced control methods have been proposed in support of inverters in RES systems (Miret et al., 2020; Eroğlu et al., 2021). Flexible Alternating Current Transmission System (FACTS) devices perform a vigorous role in improving a variety of aspects of power quality, say, harmonics, power factor, power fluctuation, voltage drop, etc. in RES connected systems. Several FACTS devices have been projected in the literature to discourse power quality issues in RES systems, namely, Active Power Conditioners (APCs), Automatic Voltage Regulators (AVRs), Distribution Static Synchronous Compensators (DSTATCOMs), Dynamic Voltage Restorers (DVRs) and UPQC belong to the category of FACTS controllers and are amid in enhancing performance of power quality due to the following disturbances: Voltage Swells/Sags, Nonlinearities and Harmonics (Satish et al., 2023; Elmetwaly et al., 2020; Pal and Gupta, 2020; Singh B and Kumar R, 2020).

the authors (Renduchintala, et al., 2021). The use of FL and Pulse Width Modulation (PWM) to enhance PQ using UPQC was described in (Suresh and Gowri Manohar, 2018). For the automatic verdict and categorization of power quality issues, a fuzzy expert system was developed (Beniwal et al., 2021). The paper (Singh et al., 2023) was considered for the purpose of Wavelet Transformation technology aimed at extracting features from waveforms of PQ disturbances in addition classifying them via a combined technique of ANN and FL. In order to regulate a 3-Φ DSTATCOM providing harmonic and reactive power compensation for linear and nonlinear loads, research by (Patel et al., 2019) affords an optimum step size Least Mean Square (LMS) algorithm. In (Devena et al., 2023) used a Variable Leaky LMS (VLLMS) control with an adaptive shunt active filter. By using the suggested method, a non-linear load's harmonic content, power quality, power losses, and power factor can all be improved.

Hence, this paper delves regarding with hybrid control strategy for Solar-PV coordinated microgrid using the AL_LMS algorithm combined with FL control to the

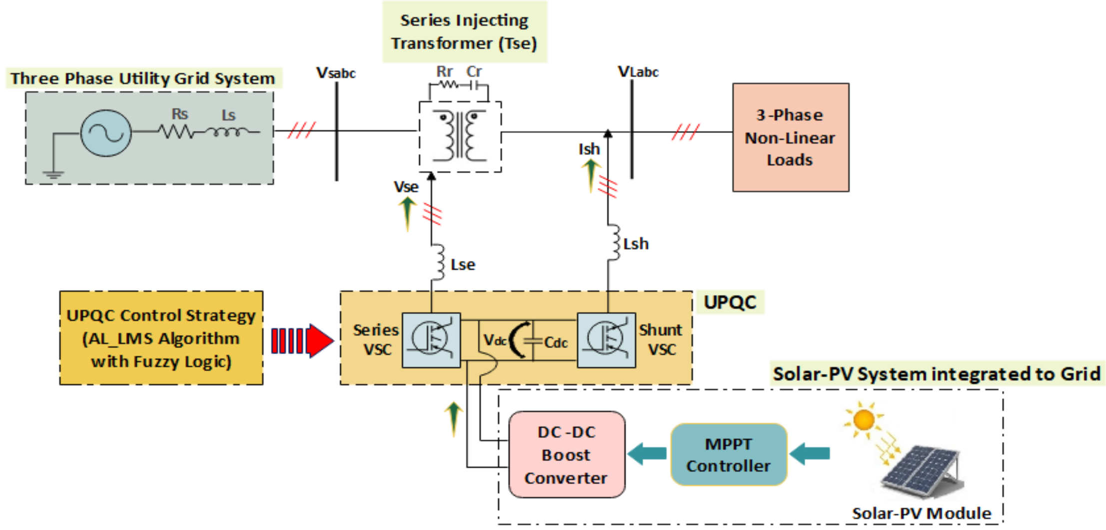

Figure 2. Proposed Solar-PV fed UPQC System Model.

Microgrid Power Quality governing strategies are often implemented using a combination of rule-based, model-based, and optimization-based techniques (Resener et al., 2020). Artificial intelligence (AI) is one of the foremost fields that have gained popularity during this decade for its ability to solve complex problems in complex situations (Trivedi et al., 2022; Abdulkader et al., 2023). These AI approaches like Artificial Neural Networks (ANN) (Venkata Anjani Kumar and Damodar Reddy, 2023), Fuzzy Logic (FL) and Genetic Algorithms (GA) etc. be inured effectively improve PQ and achieve good performances. The usage of FL method in microgrid energy systems built on cutting-edge power conditioning technology, including UPQC is presented by UPQC for the PQ enhancement. The format of this document is as follows: The main system architecture is discussed in Section-II. The procedure of the UPQC control mechanism is elucidated in Section-III. Section-IV suggests controlling examination and explanations of MATLAB/Simulink results for power quality conditions, and Section-V states the conclusions of the paper.

Proposed System Description

The Figure 2 depicts the schematic representation of a proposed system model comprising of Solar-PV fed UPQC in a Grid-Connected (GC) mode. V_{Sabc} and V_{Labc} indicate the 3-Φ source and load voltages respectively. A coupled inductor (L_{se}) and a 3-Φ series injection

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transformer (T_{se}) are used to link the series VSC component of UPQC in series with the distribution grid. The Shunt VSC component has joined in parallel to the load point over the interface inductor (L_{sh}) and a capacitor (C_{dc}) links amongst the two compensators. To cutout the high-frequency constituent of voltage as a result of switching of VSCs, Ripple filters (R_r & C_r) are used. A Solar-PV module is linked through a reverse blocking diode across the DC-link capacitor. A Non-Linear (R-L) load is connected using the 3-Φ diode bridge rectifier to the circuit (Chilakapati and Manohar, 2023).

Table 1 below contains a tabulation of the system's parameters.

Table 1. Parameters values of the Proposed System

Parameters	Value
Supply Voltage (V_s)	415 V (L-L)
Coupling inductors (L_{se} and L_{sh})	1.5mH
DC-link capacitor (C_{dc})	8000 µF
DC-link Voltage (V_{dc})	700 V
Gains of Shunt VSC (Kp and Ki)	2 and 0.1
Gains of Series VSC (Kp and Ki)	4 and 800
Solar-PV voltage and current at MPP	700V, 60A
Non-linear load	15 KW, 7.2 KVA

used for adaptive adjustment of the reference signals provided to the UPQC to minimize the error. By using a learning rate (µ) and the error signal, the algorithm modifies the reference signals, which determines the adaptation rate. The adapted reference signals generated by the algorithm are used to control the UPQC's operations. This comprises generating appropriate compensation signals to correct the power quality problems. The process continues in a feedback loop, with the UPQC continuously adjusting its control signals based on the changing electrical conditions in the system (Ray et al., 2022).

Control Method for Shunt VSC

The proposed controller representation of shunt VSC is shown in Figure 3. The aim of the strategy is to produce balanced sinusoidal source current while controlling DC-link voltage. The first step is to sense the instantaneous phase voltages (V_{sa}, V_{sb} and V_{sc}) at PCC for all the phases. The phase voltages are then used to compute the phase-amplitude (V_{sp}) of PCC voltage (Alhafadhi and The., 2022) as given in equation 1.

$$V_{sp} = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (1)$$

The source voltage's in-phase unit templates are defined with the formula as in equation 2.

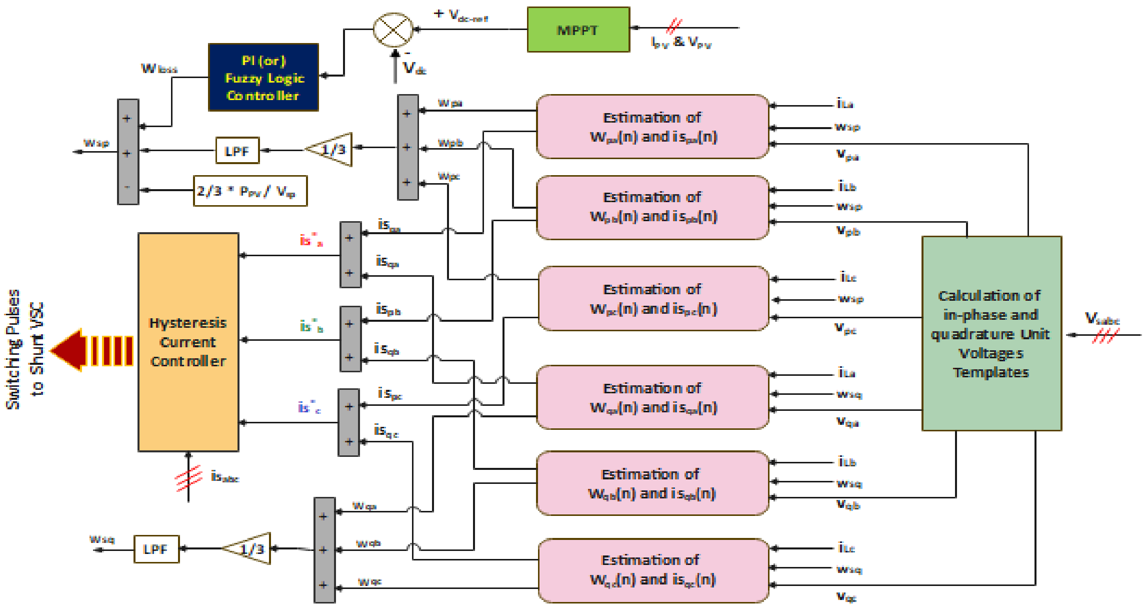

Figure 3. Proposed schematic control diagram of shunt VSC.

$$v_{pa} = \frac{v_{sa}}{V_{sp}};\quad v_{pb} = \frac{v_{sb}}{V_{sp}};\quad v_{pc} = \frac{v_{sc}}{V_{sp}} \;\ldots\ldots\ldots\; (2)$$

By means of in-phase unit templates, the voltage quadrature unit templates are calculated as in equation 3.

$$v_{qa} = \frac{-v_{pb}+v_{pc}}{\sqrt{3}};\quad v_{qb} = \frac{\sqrt{3}}{2}v_{pa} + \frac{1}{2\sqrt{3}}(v_{pb}-v_{pc});$$

$$v_{qc} = -\frac{\sqrt{3}}{2}v_{pa} + \frac{1}{2\sqrt{3}}(v_{pb}-v_{pc}) \;\ldots\ldots\ldots\ldots\; (3)$$

W.r.t the control technique, the grid in addition to the PV array both supply the load active power requirement. In keeping the constant voltage over DC-link, the grid also

Proposed UPQC Control Methodologies

In this paper, a hybrid control approach of AL_LMS algorithm (Chilakapati and Manohar, 2023) combined with FL is discussed to estimate the reference's voltage and current meant for operating both series and shunt compensators of UPQC. This algorithm computes the variance amongst the desired (ideal) values and the measured values of these parameters such that the difference indicates the error in the power quality and is

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affords the UPQC's internal losses. The predicted DC-link voltage (V_{dcref}) given by MPPT of Solar-PV output is correlated to the measured DC-link capacitor voltage (V_{dc}), and then error signal (E_{dc}) attained, which is given for PI or Fuzzy controller so as to minimize the error. Thus, the loss component (W_{loss}) required is obtained and expressed by equations 4 and 5, illustrated in Figure 4 below.

$$E_{dc}(t) = V_{dcref}(t) - V_{dc}(t) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

$$W_{loss}(t+1) = W_{loss}(t) + K_p * [E_{dc}(t+1) - E_{dc}(t)] + K_i * E_{dc}(t+1)] \quad \ldots\ldots\ldots\ldots\ldots (5)$$

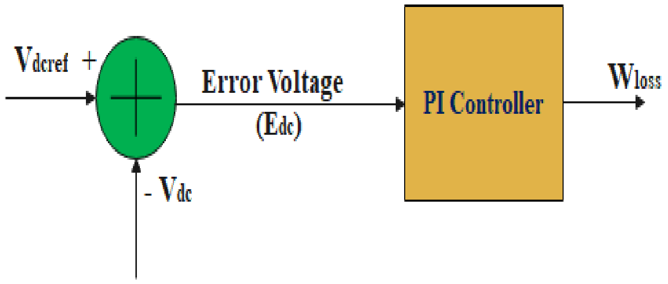

Figure 4. AL_LMS algorithm with PI Controller in Shunt VSC.

The fraction of active current supplied by Solar-PV array (W_{PV}) is specified by equation 6.

$$W_{pv} = \frac{2}{3} * \frac{P_{PV}}{V_{sp}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Now, with help of basic weight update expressions (Bag et al., 2020) of the algorithm, the fundamental constituent of phase 'a' active load current can be determined as described in equations 7 – 10 below.

$$W_{pa}(t+1) = W_{pa}(t)[\,1 - 2\mu_{pa}(t) * \lambda_{pa}(t)] + 2\mu_{pa}(t) * E_{pa}(t) * v_{pa}(t) \quad \ldots\ldots\ldots\ldots\ldots (7)$$

$$\lambda_{pa}(t+1) = \lambda_{pa}(t) - [2\mu_{pa}(t) * \rho * E_{pa}(t) * v_{pa}(t) * W_{pa}(t-1)] \quad \ldots\ldots\ldots\ldots\ldots (8)$$

$$\mu_{pa}(t+1) = [\alpha * \mu_{pa}(t)] + [\lambda_{pa}(t) * R_{pa}^2(t)] \ldots.. (9)$$

$$R_{pa}(t) = [\beta * R_{pa}(t-1)] + [(1-\beta) * E_{pa}(t) * E_{pa}(t-1)] \quad \ldots\ldots\ldots\ldots\ldots (10)$$

And the predicted error will be now as

$$E_{pa}(t) = i_{La}(t) - v_{pa}(t) * W_{pa}(t) \ldots\ldots\ldots\ldots (11)$$

Where 'i_{La}' is load current of phase 'a'. In a similar way, at any time instant, weights of active components (W_{pb} and W_{pc}), leakage factors (λ_{pb} and λ_{pc}), step size (μ_{pb} and μ_{pc}), error autocorrelation (R_{pb}, R_{pc}) and predicted errors (E_{pb}, E_{pc}) can be updated similarly to the phases 'b' and 'c' for the shunt VSC. Hence, weighted average of the fundamental active component (W_{pave}) is specified as in equation 12.

$$W_{pave} = \frac{W_{pa}(t) + W_{pb}(t) + W_{pc}(t)}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

From (5), (6) and (12), the reference grid current's total weight of active component (W_{sp}) and active components of reference grid currents (i_{spa}, i_{spb} and i_{spc}) are computed as in equations 13 and 14.

$$W_{sp} = W_{pave} + W_{loss} - W_{PV} \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$i_{spa} = W_{sp} * v_{pa};\ i_{spb} = W_{sp} * v_{pb};\ i_{spc} = W_{sp} * v_{pc} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

In the same way, load current's reactive components are obtained by having quadrature unit vector voltage templates and corresponding updated weights related towards reactive current components and are expressed as in equation (15).

$$i_{sqa} = W_{sq} * v_{qa};\ i_{sqb} = W_{sq} * v_{qb};\ i_{sqc} = W_{sq} * v_{qc} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Here, weight average of fundamental reactive constituents is equal to the weight of over-all reactive components (W_{sq}). Thus, by means of summing up of both the above obtained components in equations 14 and 15, the extracted resulting reference source currents are attained and expressed as in equation 16.

$$i^*_{sa} = i_{spa} + i_{sqa};\ i^*_{sb} = i_{spb} + i_{sqb};\ i^*_{sc} = i_{spc} + i_{sqc} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Henceforth, comparing the resultant reference (i^*_{sa}, i^*_{sb} and i^*_{sc}) and measured (i_{sa}, i_{sb} and i_{sc}) network source currents and also the attained erroneous signals are enumerated to the Hysteresis Current Controller (HCC) towards engendering the estimated switching signals for shunt VSC.

Control Method for Series VSC

The control objective of this VSC is in obtaining the nominal magnitude and pure sinusoidal load voltages. The reference load voltages are evaluated using the proposed AL_LMS algorithm as described and illustrated in Figure 5 below. The 3-Φ load currents (i_{La}, i_{Lb} and i_{Lc}) are sensed for calculating the magnitude (I_{Lp}) and the load current unit templates are given by equations 17 and 18 respectively.

$$I_{Lp} = \sqrt{\frac{2}{3}(i_{La}^2 + i_{Lb}^2 + i_{Lc}^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

$$u_{pa} = \frac{i_{La}}{I_{Lp}};\ u_{pc} = \frac{i_{Lc}}{I_{Lp}};\ u_{pc} = \frac{i_{Lc}}{I_{Lp}} \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

These in-phase unit templates are used in computing the quadrature current unit templates and are given as in equation 19.

$$u_{qa} = \frac{-u_{pb} + u_{pc}}{\sqrt{3}};\ u_{qb} = \frac{\sqrt{3} * u_{pa}}{2} + \frac{1}{2\sqrt{3}}(u_{pb} - u_{pc});$$

$$u_{qc} = -\frac{\sqrt{3} * u_{pa}}{2} + \frac{1}{2\sqrt{3}}(u_{pb} - u_{pc}) \quad \ldots\ldots\ldots\ldots\ldots (19)$$

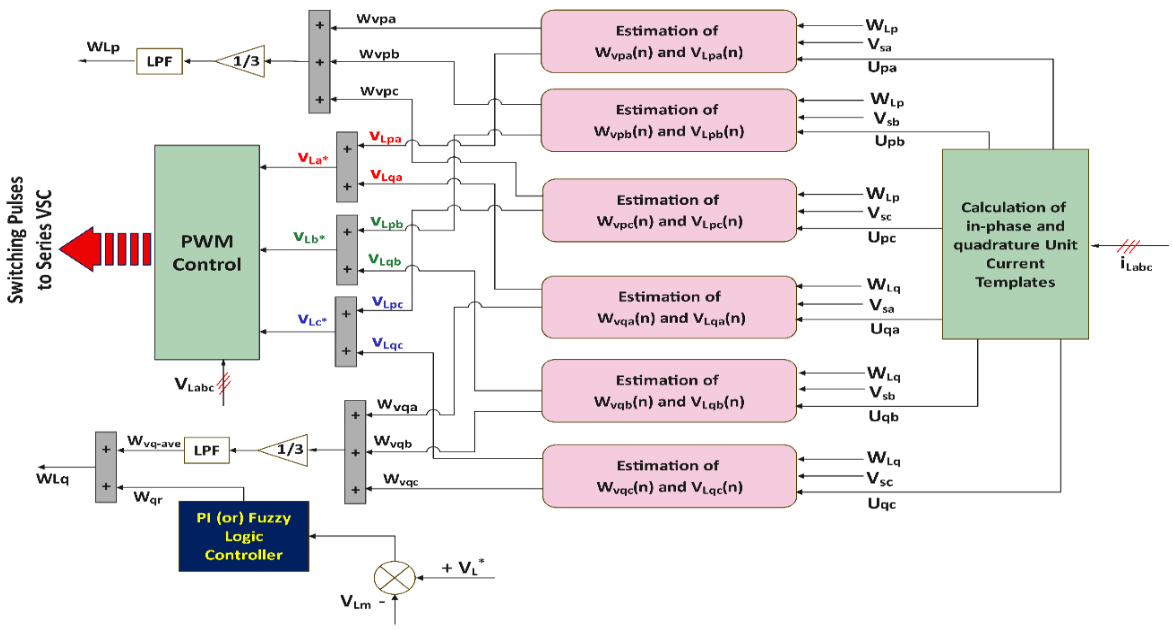

Figure 5. Proposed schematic control diagram of Series VSC

Now, by means of basic weighted updated expressions, load voltage weighted in-phase component (W_{vpa}) of phase 'a' is computed by equations 20 – 24 as follows;

$$W_{vpa}(t+1) = W_{vpa}(t)\left[1 - 2\mu_{vpa}(t) * \lambda_{vpa}(t)\right] + [2\mu_{vpa}(t) * E_{vpa}(t) * u_{pa}(t) \quad \text{..................} (20)$$

$$\lambda_{vpa}(t+1) = \lambda_{vpa}(t) - \left[2\mu_{vpa}(t) * \rho * E_{vpa}(t)\right] * [u_{pa}(t) * W_{vpa}(t-1)] \quad \text{..................} (21)$$

$$\mu_{vpa}(t+1) = [\alpha * \mu_{vpa}(t)] + [\lambda_{vpa}(t) * R^2_{vpa}(t)] ..(22)$$

$$R_{vpa}(t) = \left[\beta * R_{vpa}(t-1)\right] + [(1-\beta) * E_{vpa}(t) * E_{vpa}(t-1)] \quad \text{..................} (23)$$

And error predicted will be obtained as

$$E_{vpa}(t) = V_{sa}(t) - u_{pa}(t) * W_{vqa}(t) \quad \text{.........} (24)$$

Where, V_{sa} is the source voltage of phase 'a'. Likewise, at any instantaneous, in-phase weights component (W_{vpb} and W_{vpc}), leakage factors (λ_{vpb} and λ_{vpc}), step size (μ_{vpb} and μ_{vpc}), error auto correlation (R_{vpb} and R_{vpc}) and error prediction (E_{vpb} and E_{vpc}) can be similarly updated in the phases 'b' and 'c' of series VSC. The in-phase component weighted average (W_{vpave}) is calculated as in equation 25.

$$W_{vpave} = \frac{W_{vpa}(t) + W_{vpb}(t) + W_{vpc}(t)}{3} = W_{Lp} \text{ -----}(25)$$

The components of in-phase reference load voltage are measured as in equation 26.

$$V_{Lpa} = W_{Lp} * u_{pa};\ V_{Lpb} = W_{Lp} * u_{pb};\ V_{Lpc} = W_{Lp} * u_{pc} \quad \text{..................} (26)$$

In the same way, the load voltage's quadrature component weights (W_{vqa}, W_{vqb} and W_{vqc}) using proposed algorithm are attained. Then, the reactive component weighted average is given by equation 27.

$$W_{vqave} = \frac{W_{vqa}(t) + W_{vqb}(t) + W_{vqc}(t)}{3} \quad \text{...........} (27)$$

Now, a loss component (W_{qr}) is taken here into account for the regulation of the load voltage and stated as in equation 28.

$$W_{qr}(t+1) = W_{qr}(t) + K_{pq} * [E_{ac}(t+1) - E_{ac}(t)] + K_{iq} * E_{dc}(t+1) \quad \text{....................} (28)$$

By comparison of the magnitudes of measured load voltages (V_{La}, V_{Lb} and V_{Lc}) and rated load voltage (V^*_L), produces an error signal and it is been fed to a PI or Fuzzy Controller for keeping load voltage's magnitude at desired value as given by the below equations 29 and 30 and shown in Figure 6 below.

$$V_{Lm} = \sqrt{\frac{2}{3}\left(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2\right)} \quad \text{....................} (29)$$

$$E_{ac}(t) = V_L^*(t) - V_{Lm}(t) \quad \text{...................} (30)$$

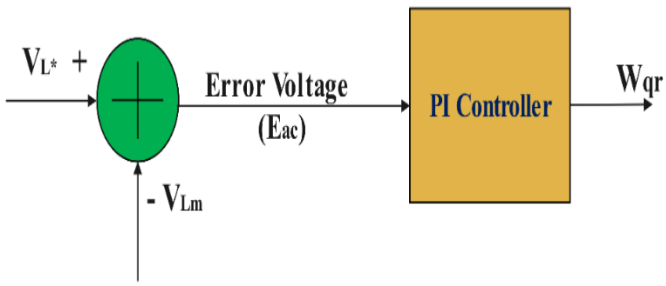

Figure 6. Error Reduction using PI Controller in Series VSC.

The over-all quadrature component weight (W_{Lq}) of reference voltage of the load is expressed as in equation 31.

$$W_{Lq} = W_{vqave} + W_{qr} \quad \text{..................} (31)$$

The over-all quadrature components of reference voltage of the load are specified by equation 32.

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$$V_{Lqa} = W_{Lq} * u_{qa}; V_{Lqb} = W_{Lq} * u_{qb}; V_{Lqc} = W_{Lq} * u_{qc} \quad \ldots\ldots\ldots\ldots\ldots\ldots (32)$$

Thus, the considerable reference load voltages for all the three phases are given as equation 33.

$$V^*_{La} = V_{Lpa} + V_{Lqa};\ V^*_{Lb} = V_{Lpb} + V_{Lqb}; V^*_{Lc} = V_{Lpc} + V_{Lqc} \quad \ldots\ldots\ldots\ldots\ldots\ldots (33)$$

At last, by comparing the reference and measured load voltages, the variance is fed to a PWM generator to produce switching pulses to the series VSC. Hence, the operation of UPQC is done for the enhancement of power quality.

THEN rule (Srilakshmi et al., 2023) while the inference engine decides how the fuzzy logic operation is carried out as depicted in following Figures 7 & 8.

Five linguistic variables are present in both the inputs and output. The membership functions employed stands Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) as shown in Rule Editor of Figure 8 and the rule base in Table 2 below.

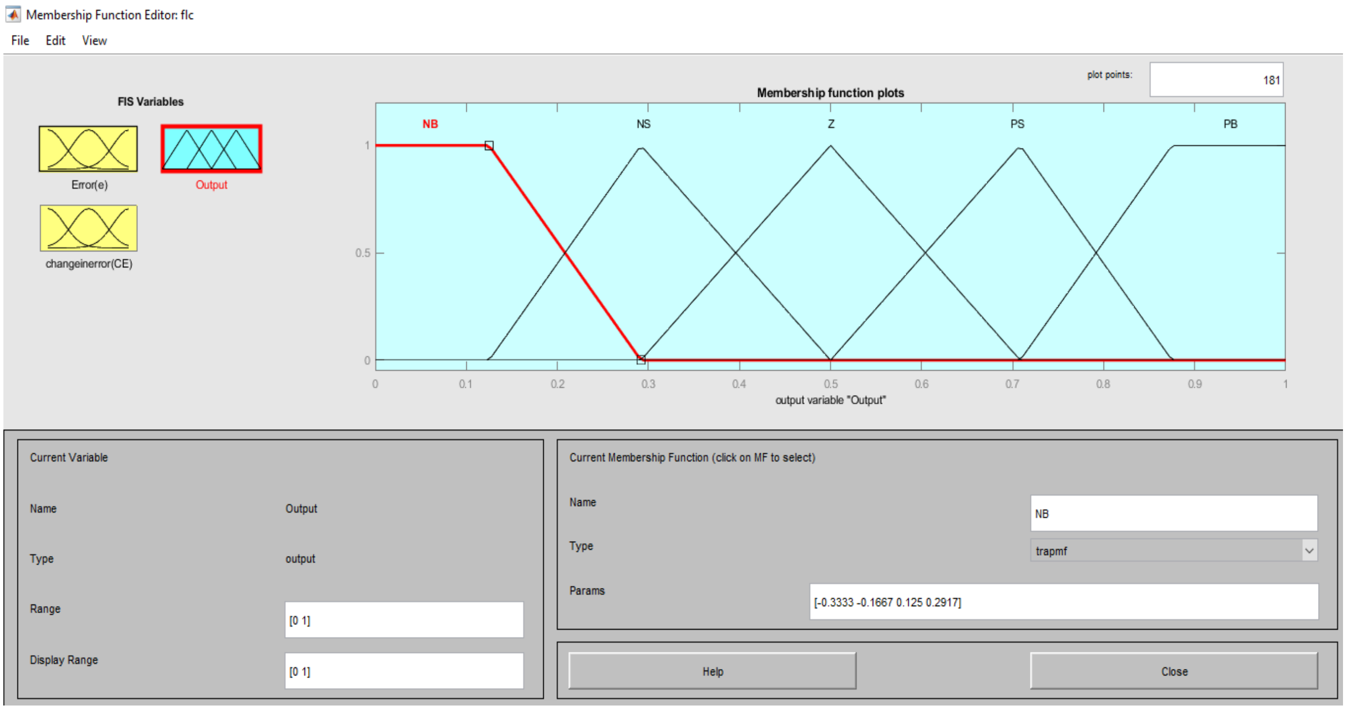

Figure 7. Fuzzy Membership Function Editor window of Inputs and Output.

Fuzzy Logic Control

In order to capture human knowledge and produce arbitrary decisions, FL controllers are enabled by knowledge systems such as fuzzy membership functions and fuzzy rule bases. Learning methods have been integrated into the system in an attempt to improve its performance aspects through the adaptation of rule-based systems and/or fuzzy controllers' membership functions (Bhavani and Shanmukha Rao, 2019) The fuzzy controller's fundamental component is a knowledge system made up of fuzzy rule bases and information units which offers language variables. The fuzzy logic controller's operation and the fuzzy rule's function are characterized by the database-related system, and the controller's performance is significantly impacted by the heuristic knowledge rules. The fuzzy logic controller's output is decided by the knowledge base using the IF-

Table 2. Rule Base of Membership Functions.

e \ Δe	NB	NS	Z	PS	PB
NB	NB	NB	Z	NS	Z
NS	NB	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

Here, in this research, a FL control generates the ideal switching states by feeding the compensator with a voltage/current reference signal. The overall compensating features are increased when the suggested AL_LMS algorithm is combined with a FL that controls UPQC's series and shunt VSCs. The actual as well as reference components of current and voltage imperfections are compared to determine the error, which is then used as input for the FL controller as shown in the below Figures 9 and 10.

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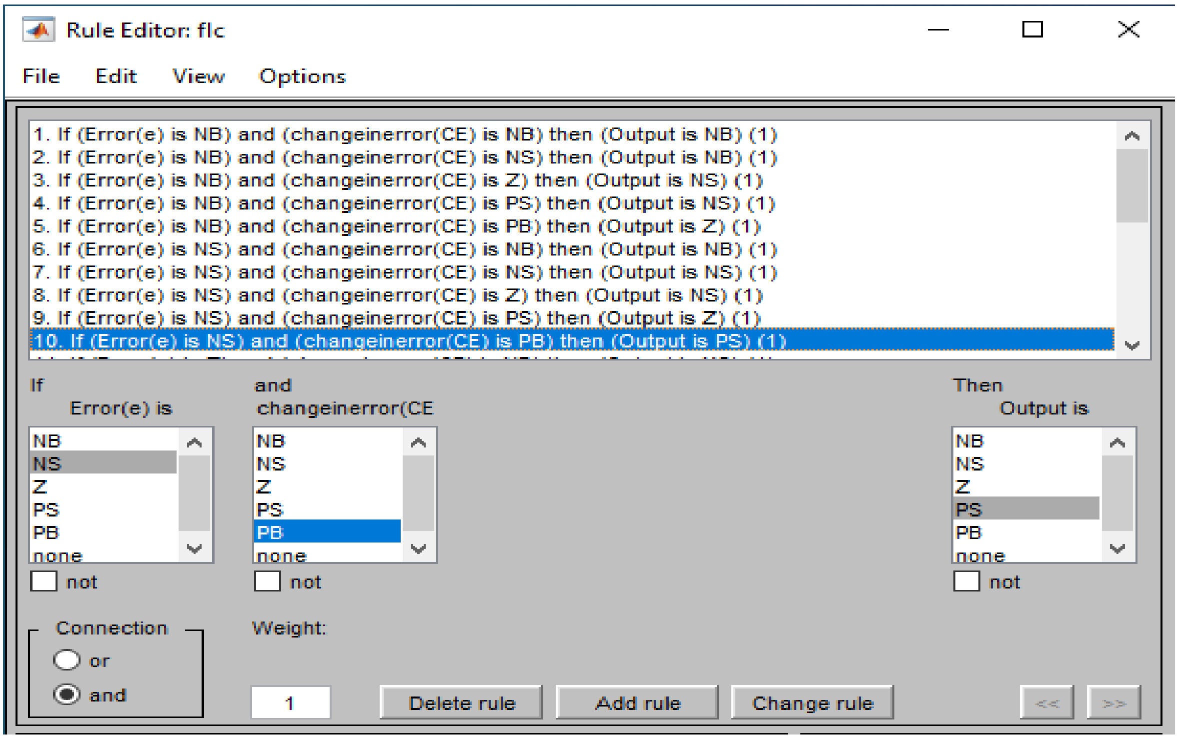

Figure 8. Fuzzy Rule Editor.

Triangular functions are applied to all membership functions such as error, change in error, and output because of basic control functions and the linearity principle. The fuzzification process converts these membership functions into fuzzy data, which may be used as a rule-based system for producing output signals and making wise judgements. The centroid method of the defuzzification process then converts this fuzzy data back into crisp data.

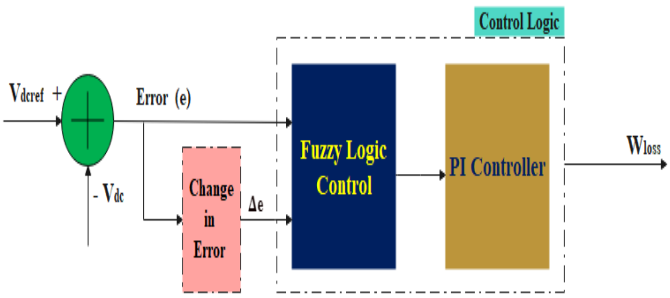

Figure 9. Proposed DC-link Control with Fuzzy Logic in Shunt VSC.

The shunt compensator's control schematic is shown in Figure 9 above. The scheme's goal is to regulate the DC bus voltage while providing a sinusoidally balanced source current. Because non-linear loads are involved, the shunt compensator reduces harmonics in the current while maintaining the DC-link voltage. Given below in Figure 10, is the control schematic for a series compensator. Getting a nominally magnitude, completely sinusoidal voltage across the load is the scheme's objective. In addition to removing sag/swell-related distortions from the voltage waveform, the series compensator ensures the level of voltage at the load terminal.

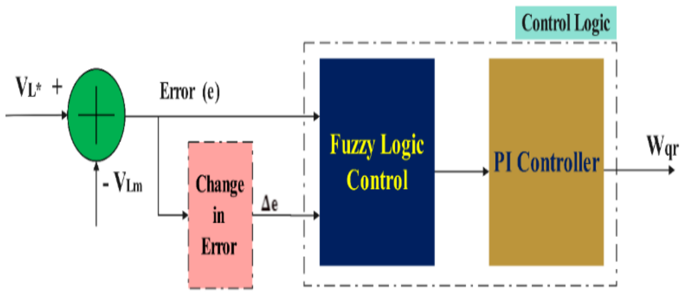

Figure 10. Proposed Load Voltage Control with Fuzzy Logic in Series VSC.

Results and Discussions

Performance of Shunt VSC for Non-Linear Loads

The system is investigated for non-linear load condition with AL_LMS algorithm using PI and Fuzzy Controllers. From the Figure 11, it can be observed that before t=0.04Sec, the harmonics due to non-linear load are reflected into the network source current. At t=0.04Sec, the shunt VSC of UPQC compensates the non-linearities injected into the network source current and hence resulting in sinusoidal grid current while upholding the DC-link voltage constant. By using AL_LMS algorithm using PI controller, the shunt VSC of UPQC compensates the non-linearities present in the network source current and made sinusoidal which is personified in above figure 12. The %THD of grid/source current obtained is 3.49%.

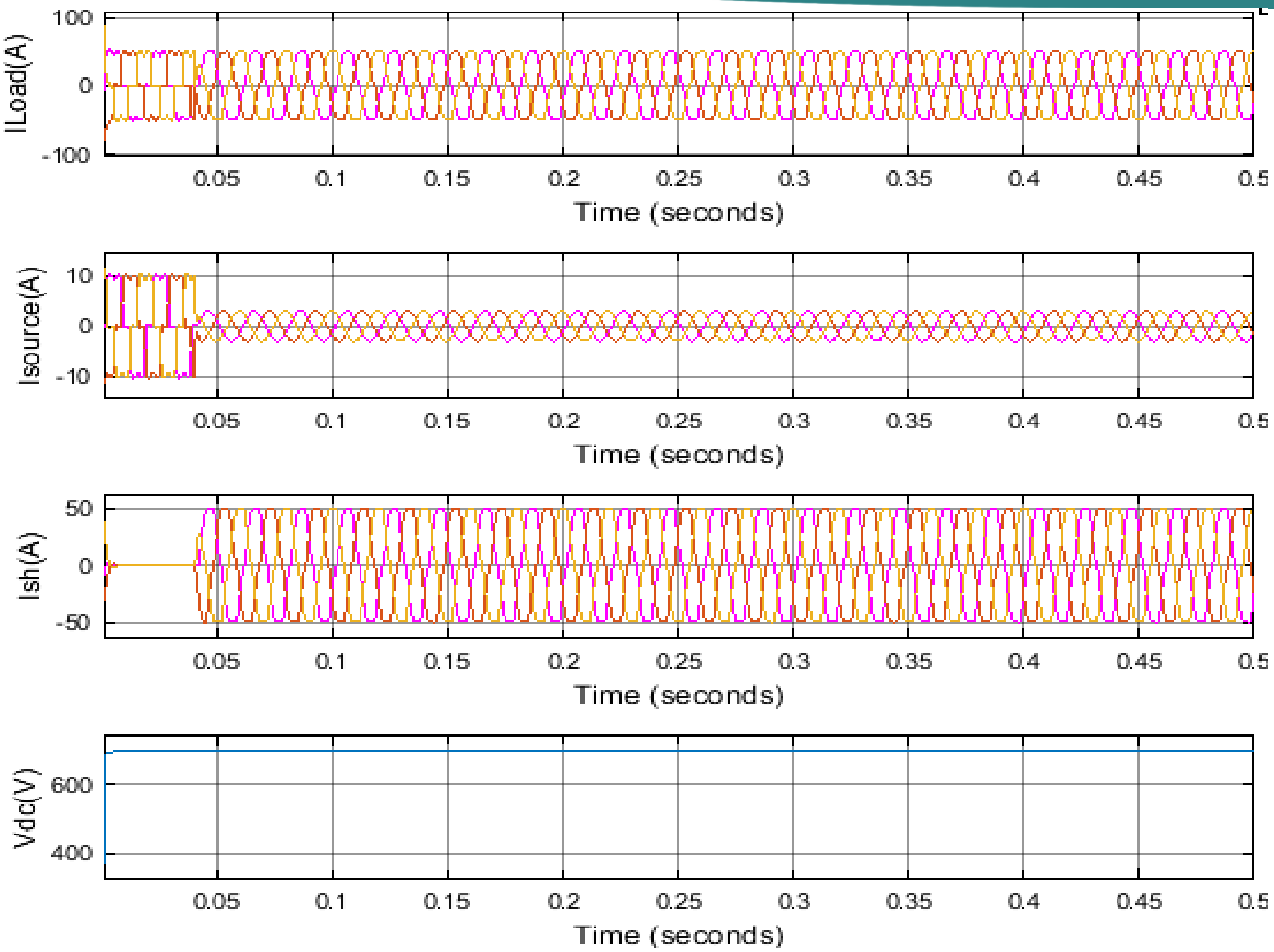

Figure 11. Performance of Shunt VSC by AL_LMS algorithm with PI Controller.

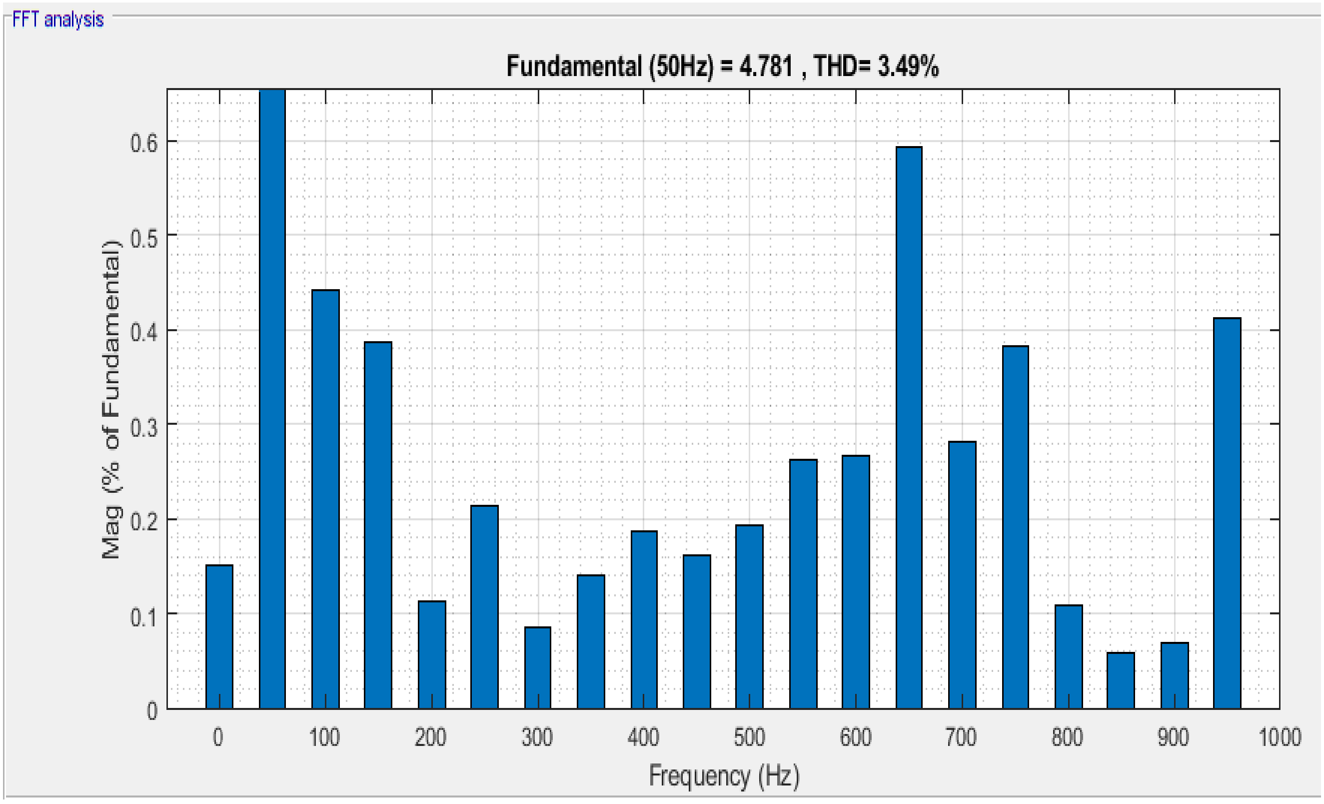

Figure 12. %THD for source current by AL_LMS algorithm with PI Controller.

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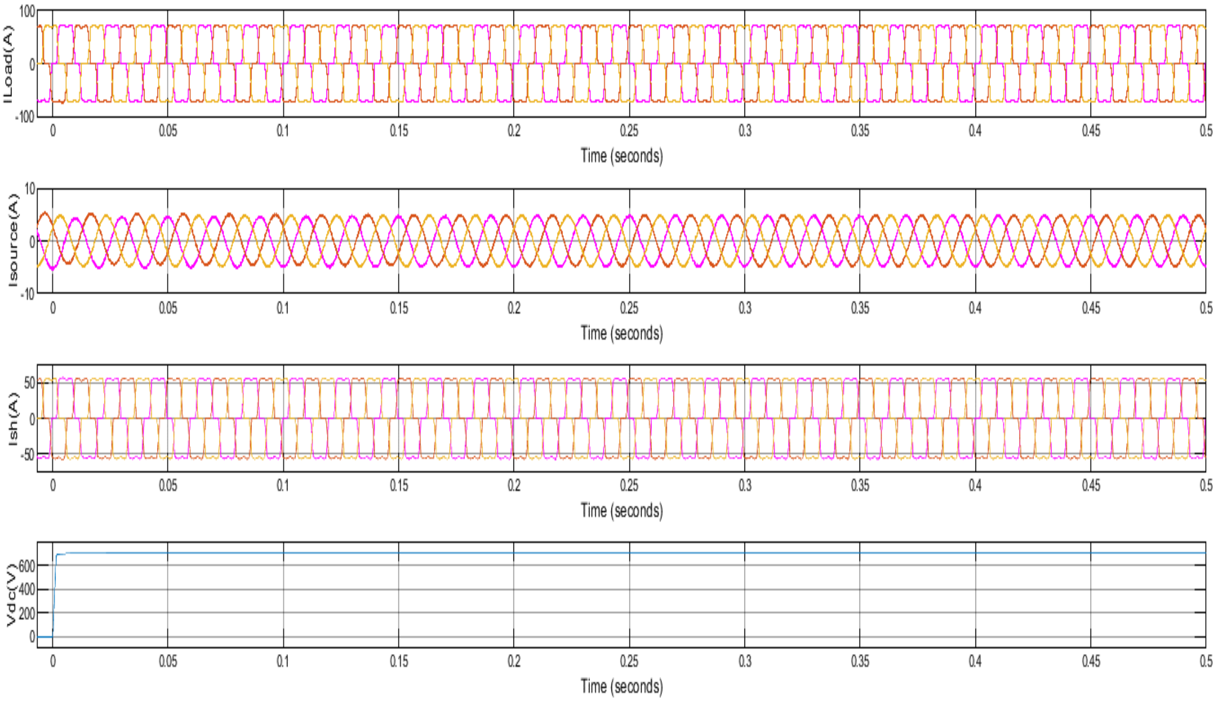

Figure 13. Performance of Shunt VSC for Non-linear load with Fuzzy Logic

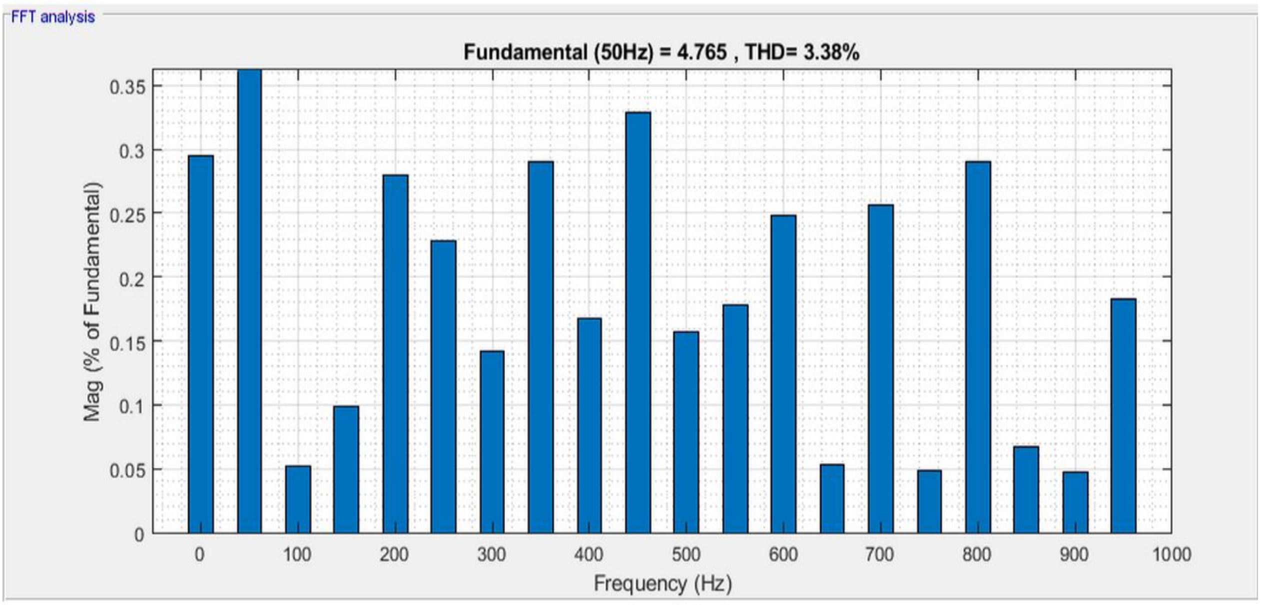

Figure 14. %THD for source current by AL_LMS algorithm with Fuzzy Logic Control

By using AL_LMS algorithm using PI controller, the shunt VSC of UPQC compensates the non-linearities present in the network source current and made sinusoidal which is personified in above figure 12. The %THD of grid/source current obtained is 3.49%.

Furthermore, the non-linearities in the source current and load current are further reduced by using Fuzzy Logic co-ordinated AL_LMS algorithm. As given away in Figure 13, at t=0.04Sec, the shunt VSC of UPQC compensates the non-linearities injected into the network source current and hence resulting in sinusoidal grid current while maintaining the constant DC-link voltage.

Figure 14 shows the %THD of grid/source current with Fuzzy Logic. Compared to PI controller %THD obtained in the source network current is 3.38% as of 3.49% using PI controller in co-ordination with AL_LMS algorithm. Thus, it can be proved that enhancement of power quality is superior by using the proposed AL_LMS algorithm with Fuzzy Logic.

Performance of Series VSC for Voltage Sag and Swell

The concert of series component of UPQC using proposed AL_LMS algorithm with PI and Fuzzy controllers for voltage sag and swell conditions is

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depicted in the graph below. At t=0.1Sec, a 0.5 P.U. sag and at t=0.3Sec, a 1.2 P.U swell has created which can be mitigated by series VSC of UPQC and results rated load voltage as given away in figure 15.

depicted in the graph below. At t=0.1Sec, a 0.5 P.U. sag and at t=0.3Sec, a 1.2 P.U swell has created which can be mitigated by series VSC of UPQC and results rated load voltage.

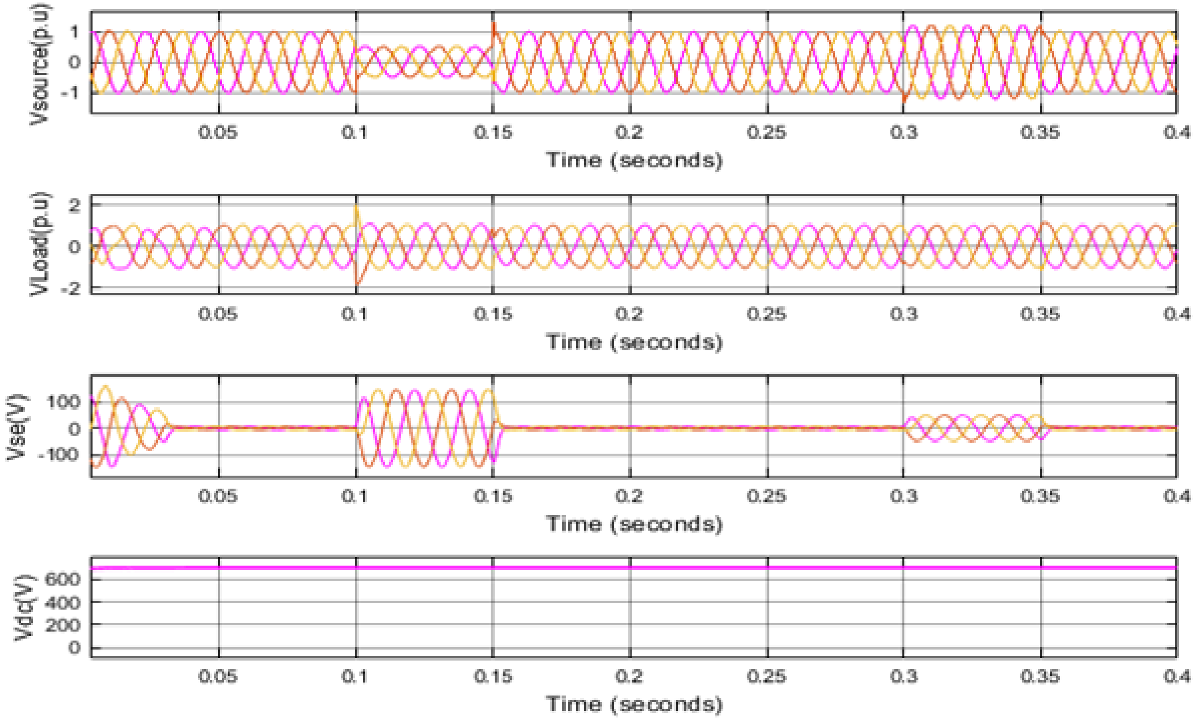

Figure 15. Voltage Sag and Swell compensation by AL_LMS algorithm with PI Controller.

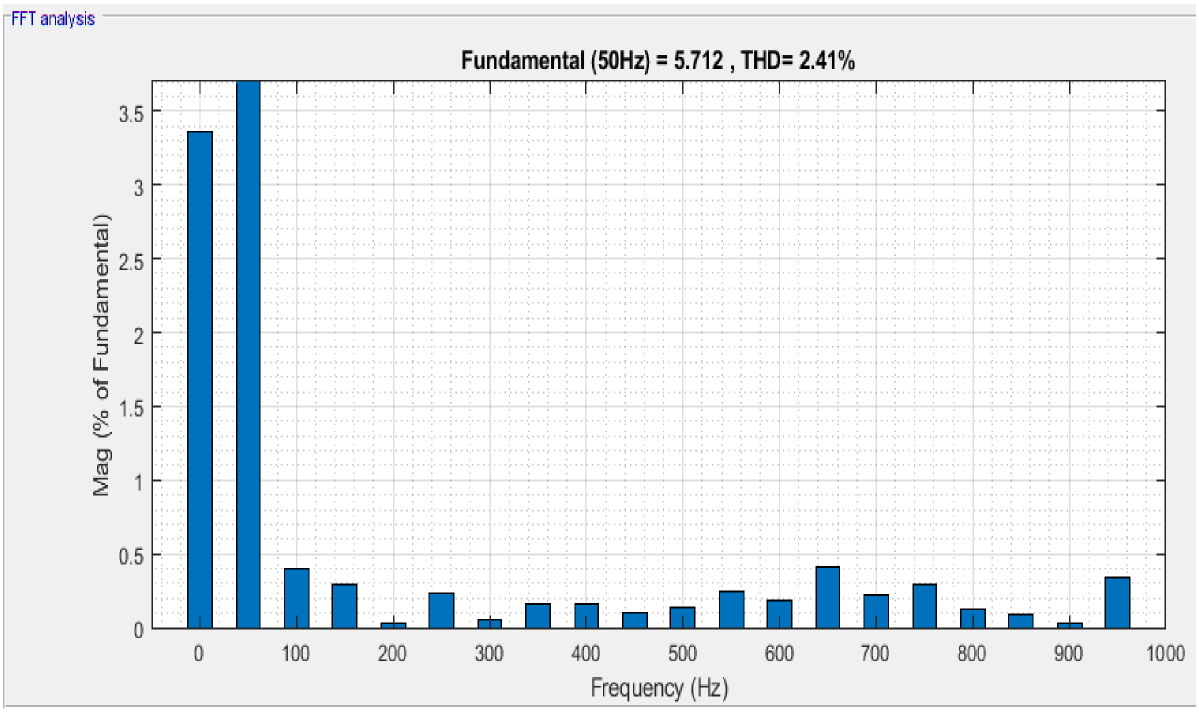

Figure 16. Load Voltage %THD with AL_LMS algorithm with PI Controller.

The %THD of load voltage using PI controller-based AL_LMS algorithm applied to UPQC is obtained as 2.41% as depicted in figure 16. Further, it is investigated with proposed method by Fuzzy Logic control for better enhancement of quality, as made known below. The performance of series component of UPQC using Fuzzified control for voltage sag and swell conditions is

It can be viewed in figures 17 & 18 that the proposed Fuzzy logic with AL_LMS algorithm better compensates voltage sag and swell with improved performance of %THD. The obtained %THD of load voltage is 2.29% as compared to conventional PI controller of 2.41% as illustrated in figure 18 below. Thus, it can be evidenced that enhancement of power quality is superior by using

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the proposed AL_LMS algorithm with Fuzzy Logic technique than that of traditional PI controller, where the comparison is been provided in Table 3.

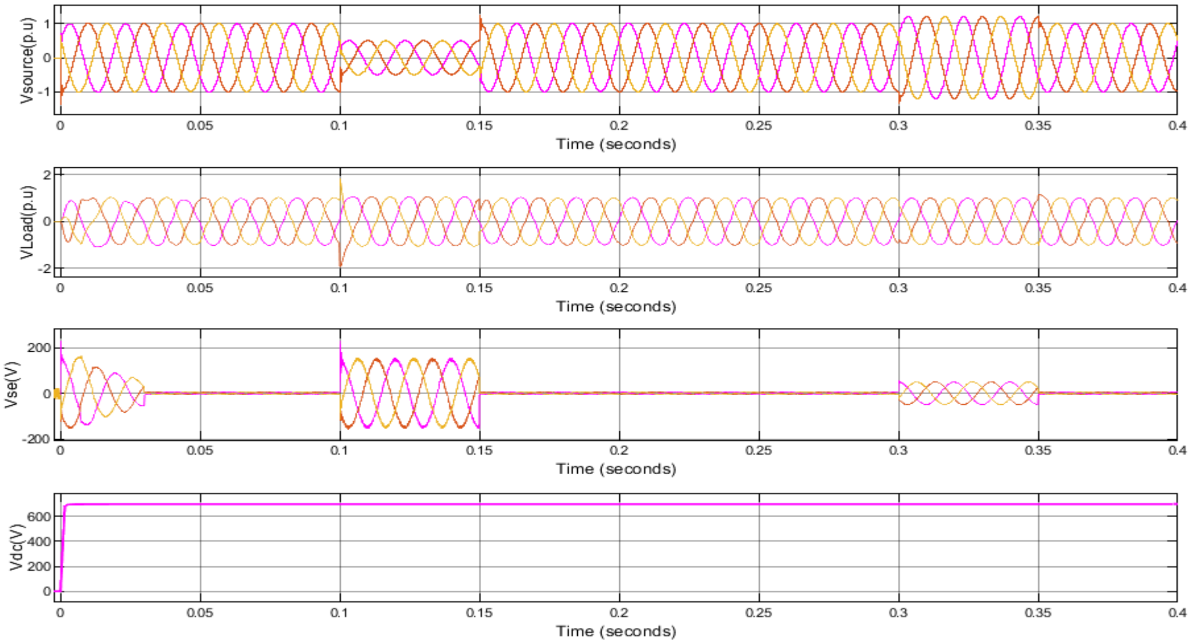

Figure 17. Voltage Sag & Swell compensation with Fuzzy Logic control.

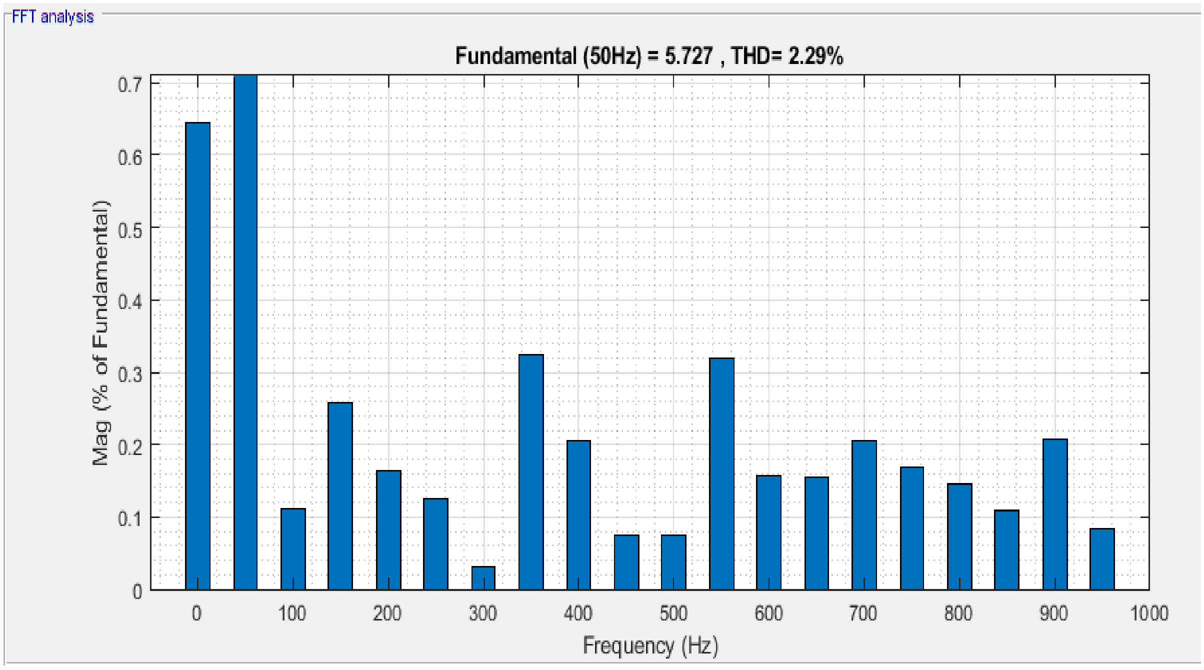

Figure 18. %THD of Load Voltage by AL_LMS algorithm with Fuzzy Logic control.

Table 3. %THD comparison of UPQC Control Strategies.

S.No.	Proposed AL_LMS Algorithm		
	Parameter/ Controller	Source/Grid Current (Non-linearities)	Load Voltage (Sag and Swell)
1	**With PI Controller**	3.49%	2.41%
2	**With Fuzzy Controller**	3.38%	2.29%

Conclusion

In the proposed research, the power quality is enhanced by using UPQC for a Solar-PV integrated Microgrid system in a grid connected mode. The control strategy used to a UPQC is a hybrid approach implemented with Adaptive Leaky LMS (AL_LMS) algorithm in co-ordination of both PI controller and Fuzzy Logic control. The performance of shunt and series VSC's of UPQC are studied and executed in MATLAB/Simulation environment for AL_LMS algorithm. The shunt VSC compensates for Non-linearities in the source/grid current and obtained %THD is improved to 3.38% with Fuzzy Logic when compared with that of 3.49% in PI Controller.

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Also, the series VSC of UPQC compensates the source's voltage sag and swell and thus, obtaining the rated load voltage. As of the results obtained, it is evident that the Fuzzy controller effectively mitigates the power quality problems of source voltage with %THD of 2.29% than that of 2.41% as compared to PI controller. Furthermore, the study can be implemented with soft computing/Optimization techniques in order to tune the controller for getting better power quality enhancement.

Conflict of Interest

The authors declare no conflict of interest.

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