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A Novel Intelligent FLC-VLLMS Based Shunt Active Filter for Power Quality Enhancement

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ABSTRACT

The power-quality issues in power distribution system are not new, exponentially increased due to usage non-linear apparatus like power electronics conversion methods. Most of industries and domestic applications, power-electronic converters are highly used for conditioning to attain requisite form of energy with greater efficiency features. But, these conditioning devices produces the harmonic currents and affecting the stable power flow, poor voltage wave-shape, low power-factor, heat losses, affect the loads connected near to common-coupling point. Over the passive schemes, active compensation scheme plays a significant role to mitigate harmonic distortions and furnishing improved power-quality features. In this paper, a Fuzzy controlled Variable Leaky Least-Mean Square control strategy has been proposed to drive the shunt power filter. It mitigates un-even harmonics, power-factor enhancement, exchange of reactive power, and un-balancing loading conditions with good stable performance. A critical analysis of proposed compensation strategy is evaluated under several load conditions verified by using computer simulation tool, simulation results are illustrated with sufficient comparisons.

Key words: Fuzzy-Logic Controller, Power-Quality Enhancement, VLLMS Algorithm, Shunt Active Power Filter, Several Load Conditions.

1. INTRODUCTION

The increased usage of non-linear power-electronic loads creates several Power-Quality (PQ) issues in distribution system such as un-even harmonic current distortions, exchange of reactive power, power-factor control, un-balancing loads, so on. These PQ issues in distribution systems are not modish, but the realization of these concerns has been increased recently by end-user consumers. These non-linear power-electronic conversion loads stimulus the massive injection of harmonic currents with a non-unity power factor furnishes the crucial obstacles at common coupling point (PCC) or load connecting point [1]. These harmonic distortions and unbalanced loading conditions create the high line losses, voltage instability and distortions. When the harmonic current sequences flows towards to upstream level which generates voltage-drop across the source impedance, pertain the distortions in power distribution system.

In general, formal passive filtering techniques are used for harmonic compensation but, it has limited to constant compensation features. As well as, formal passive methods are unable to furnish feasible solutions under variable reactive power control and unbalanced load conditions [2]. The other demerits with passive methods are resonance issues, massive size, high transient response, fixed compensation, etc [3]. To alleviate above-specified issues can be accomplished with the help of Active-Power Filter (APF) which is integrated to system as parallel or series form. The performance of APF is basically relies on estimation of reference current signals which plays a key role in compensation scheme [4]-[6].

Some of well–known DC-link voltage management and reference current estimation methods are explored in Instantaneous Real-Reactive Power theory (IRPT),Synchronous Reference Frame theory (SRFT), etc., [7]-[9]. The above-studied methods are very effective for their ease and simple design but they are inappropriate in furnishing feasible solution. Due to presence of high harmonic distortions, unbalance and reactive power controlling used with rated Voltage-Source Inverter (VSI) as APF. Recently, the usage of soft-computing methods are increased for acquiring good results like Artificial-Neural Networks (ANN) are explored in [10]-[12].

So in this way, the utilization of modern intelligent techniques is used very-often as prime controller in shunt-APF. Like-wise, adaptive sliding-mode techniques have been treated as reference current extraction scheme in a single-phase APF for PQ improvement [13]. An adaptive double-loop sliding-mode controller with recurrent-neural network controller is used for making stable and robust system [14]. Likewise, several signal-processing techniques are most favorable methods like Least-Mean-Square (LMS), a slew-rate of convergence occurred due to constant step-size in [15]-[17], can be conquered by employing time-varied step-size. The error of LMS is considered as cost-function because of unbounded weights and requires high time to response due to stalling effects.

To alleviate the traditional weight updating issues, a variable-leaky LMS algorithm has been proposed in this work where the magnitudes of these weights are varied instantly by using VLLMS weight-updated algorithm. It involves cost-function to enrich the parameter stalling effects, drilling effects, maximizes algorithm extraction and speed. A DC-link control circuit in VLLMS control unit jointly used for mitigation of reactive power and non-linear harmonic current, unbalanced currents, maintain DC-link voltage at requisite level, regulates the PCC/supply-side power-factor becomes ideal. In general, the DC-link controller consists of PI controller, together with these signals from VLLMS furnishes the extraction of reference signal for production of switching pattern to three-phase VSI module.

The significant tuning of PI gains are developed with necessary steps, the PI controller performance is highly relies on these gain settings which is selected through trial and error method [18]. Uncertainly, the PI regulator controls the voltage across DC-link capacitor during parameter variations; sudden load changing attains moderate compensation features, etc., because of improper gain settings. At this scenario, advanced intelligent controller establishes the intelligence knowledge like “machines over the humans”. Several schemes related to advanced intelligence control methods can be examined in analytical methodology related to artificial intelligence search through several possibilities. The Fuzzy-Logic Control (FLC) employed as self-charging intelligent controller accomplishes the subjective decisions with human knowledge which involves fuzzy rule-base and membership functions. In this work, a new self-charging intelligent VLLMS-FLC controller has been developed for enhanced performance of APF for attaining PQ features with good stability index. The performance of VLLMS-FLC controlled APF is verified under various load conditions by using Computer Simulink tool, results are analyzed with better compensation characteristics.

2. PROPOSED VLLMS-FLC DRIVE ACTIVE-POWER FILTER FOR PQ ENHANCEMENT

2.1 Active Power Filter (APF)

The unsatisfactory performance of passive methods administers to explore new compensation schemes for mitigating harmonic distortions, reactive power control by using active-power filter. Generally, APF is integrated either shunt or series to the distribution line to mitigate all current related PQ issues by using DC-link capacitor fed VSI. The VSI based APF’s are recruited for attaining possible solution of harmonics distortions in medium-low power distribution systems and regulation of reactive power in high-mediumrange distribution systems. The proposed APF driving the balanced/unbalanced type both non-linear/linear loads consists of VSI device powered by DC capacitor, filter units, control scheme, gate-drive circuit and sensing elements, etc. The schematic diagram of proposed APF is shown in Figure.1.

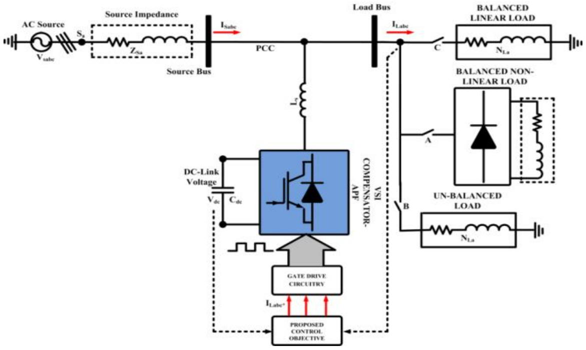


Figure 1: Schematic Diagram of Proposed Shunt-APF

Various elements in proposed APF configuration includes, supply voltage $V_{s.abc}$, load voltage $V_{L.abc}$, supply/PCC current $I_{s.abc}$, line impedance $Z_{s.abc}$, load-current $I_{L.abc}$, in three-phase sequences, respectively. The non-linear load is considered as uncontrolled Rectifier followed with a DC inductive-resistive load. Consequently, the DC-link capacitor C_{dc}, acts as main source of VSI for regulating the voltage and current at PCC level and the DC-link capacitor voltage is V_{dc}, which is regulated by self-charging controller. The main working of shunt connected APF is first sensing the harmonics distortions coming from non-linear load through harmonic analyzers. Based on this harmonic analysis, control circuit extracts the reference signals and forwarded to gate drive circuit produces the switching states to VSI module. The VSI of APF directly injects the in-phase opposite harmonic components to PCC of distribution system to counteract the harmonic distortions coming from non-linear rectifier. As well as shunt-APF can also enhance the reactive power, power-factor, flicker reduction, load balancing, etc.

2.2 Proposed VLLMS Control Scheme

The proposed VLLMS control scheme is generally employed for extraction of active-fundamental component from non-linear load current, the signals can be defined as,

$$y(t) = \sum_{m=1}^{M} A_m \sin(m\omega t + \emptyset_m) \quad (1)$$

$$y(k) = \sum_{m=1}^{M} A_m \sin(m\omega kT) \,.\, cos\emptyset_m + A_m \cos(m\omega kT) .\, sin\emptyset_m \quad (2)$$

The above Eqn. (2) can be re-written in parametric pattern as described as below,

$$y(k) = H(k).\, X_k \quad (3)$$

$$H(k) = [\sin(\omega kT).\cos(\omega kT) \sin(m\omega kT).\cos(m\omega kT)] \quad (4)$$

The vector of un-named parameter is defined as below,

$$X_k = \left[A_{1a}\cos(\emptyset_{1a}) \,.\, A_{1a}\sin \frac{(\emptyset_{1a}) \ldots\ldots\ldots}{A_{ma}\cos(\emptyset_{ma}) \,.\, A_{ma}\sin(\emptyset_{ma})}\right] \quad (5)$$

The proposed VLLMS control scheme is used to estimate the state function which reduces the square of error recursively by adjusting the un-named parameter (X_k) at every sampling time by using Eqn. (6) as described below,

$$\widehat{X_{k+1}} = (1 - 2\mu_k\gamma_k).\widehat{X_k} + 2\mu_k e_k\widehat{y_k}$$
$$\widehat{y_k} = H(k).\widehat{X_k} \quad (6)$$

The square of error signal is defined as

$$e_k = \gamma_k - \widehat{y_k} (7)$$

For attaining good convergence factor of VLLMS, μ_k step-size is varied with respect to noise.

$$\mu_{k+1} = \lambda\mu_k + \gamma_k.R_k^2 (8)$$
$$R_k = \beta.R_{k+1} + (1-\beta).e_k e_{k+1} \quad (9)$$

Where R_k is auto-correlation of e_{k+1} and e_k, it is defined in Eqn. (9), β is the exponential weighting factor and varies $(0 < \beta < 1)$, and $(0 < \lambda < 1)$ and $(\gamma > 0)$ controls the convergence time factor. The variable leakage factor (γ_k) can be varied as,

$$\gamma_{k+1} = \gamma_k - 2\mu_k\rho e_k\hat{y}_k.X_{k-1} \quad (10)$$

After updating of un-named parameter vectors by using VLLMS-controller is described as,

$$i_{c,p} = H_{11} * X_1 (11)$$

The VLLMS control scheme generates the fundamental extracted current signal which is deducted from non-linear load current to acquire reference current signal. The flow-chart representation of VLLMS control algorithm for extraction of fundamental current component is shown in Figure.2.

2.3 Proposed Self-Charging FLC Controller

The DC-link voltage across DC-link capacitor is sustained at predefined level, an extra active-power is to be extracted by shunt-APF filter unit from supply-side to regulate the DC-link capacitor. The energy in DC-link capacitor can be represented as,

$$E_{dc} = \frac{1}{2}C(V_{dc})^2 (12)$$

The DC-link voltage is slightly changing from required voltage (V_{dc}) to reference voltage level (V_{dc}^*), the change of DC-link voltage can be represented as,

$$\Delta E_{dc} = \frac{1}{2}C[(V_{dc}^*)^2 - (V_{dc})^2] (13)$$

The available active power by source side is used to charge the DC capacitor can be described as,

$$E_{ac} = 3(V_{s.rms}.I_{d.rms}\cos(\emptyset)).t (14)$$

Where, $V_{s.rms}$ is instantaneous source voltage, $I_{d.rms}$ is instantaneous current during charging, $\emptyset$ is the angle in between charging current and source voltage, t is the time take to charge the capacitor,

$$E_{ac} = 3\left(\frac{V_s}{\sqrt{2}}.\frac{I_d}{\sqrt{2}}.\frac{T}{2}\right) = \frac{3V_sI_dT}{4} (15)$$

By eliminating the switching losses in VSI module and as per energy conservation law, the below Eqn. (16) defined from Eqn. (14) and Eqn. (15),

$$\Delta E_{dc} = E_{ac}$$
$$\frac{1}{2}C[(V_{dc}^*)^2 - (V_{dc})^2] = \frac{3V_sI_dT}{4}$$
$$I_{d.f} = \frac{2C\left[(V_{dc}^*)^2 - (V_{dc})^2\right]}{3V_sT} \quad (16)$$

To maintain the measured DC-link voltage V_{dc} at reference voltage V_{dc}^* is fed to traditional Proportional-Integral (PI) controller, so it can be computing the requisite DC voltage value through charging current I_d from source side. As well as, it helps to minimize the DC-offset between the measured DC-link voltage and reference DC-link voltage. The outcome error quantities and PI controller at nth instant is represented in below Eqn. (17) and Eqn. (18),

$$V_{dce} = V_{dc}^* - V_{dc} (17)$$
$$\Delta_{id} = \Delta_{idn} - K_p * \left(V_{dce(n)} - V_{de(n-1)}\right) + K_i * \left(V_{de(n)}\right) \quad (18)$$

But, the significant tuning of PI gains are developed with necessary steps, the PI controller performance is highly relies on these gain settings through trial and error method [19]. The PI uncertainly controls the DC capacitor voltage during parameter variations, sudden load interruptions attains reduced compensation features, etc, due to improper gain settings. At this scenario, fuzzy-logic controller is employed as self-charging intelligent controller accomplishes the subjective decisions with human knowledge which involves fuzzy rule-base and membership functions. The schematic diagram of proposed self-charging FLC-VLLMS control scheme is depicted in Figure.3.

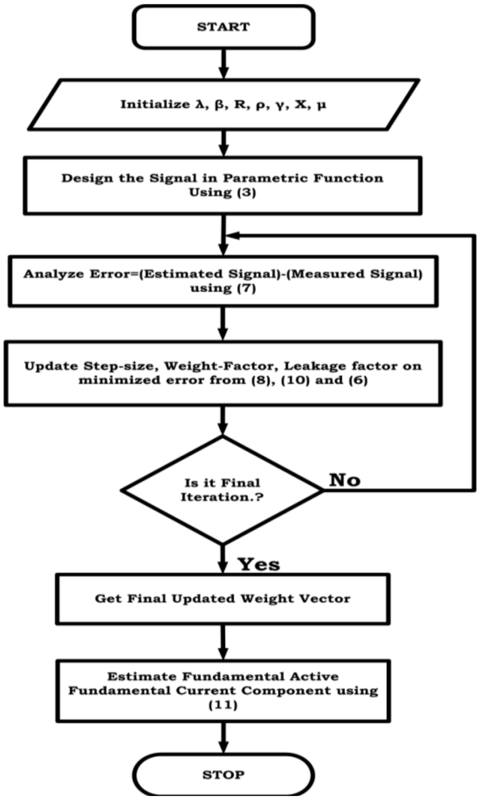


Figure 2: Flow chart model of the Fundamental Active Current Estimation using VLLMS Control Algorithm

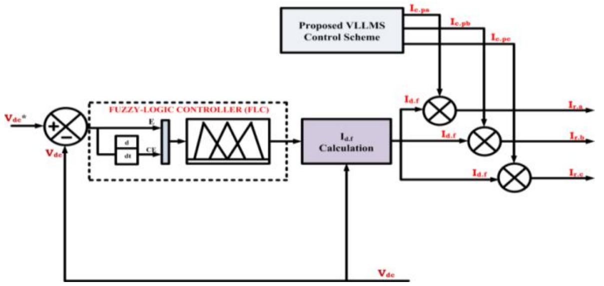


Figure.3: Schematic Diagram of Proposed FLC-VLLMS Control Scheme

In FLC controller, a triangular membership functions are used to define the error and change-in error values because of simple transformation and linear function [20]-[23]. All the membership functions are converted into fuzzy-sets by employing fuzzier classification for developing the requisite decisions as fuzzy rule-sets to furnish feasible error-free outputs and re-converted into crisp-sets by employing centroid technique through fuzzy de-fuzzier process. The knowledge base acts as the heart of the FLC controller which consists of inference unit, this mechanism develops the signals based on fuzzy-logic operations as If-Then rules.

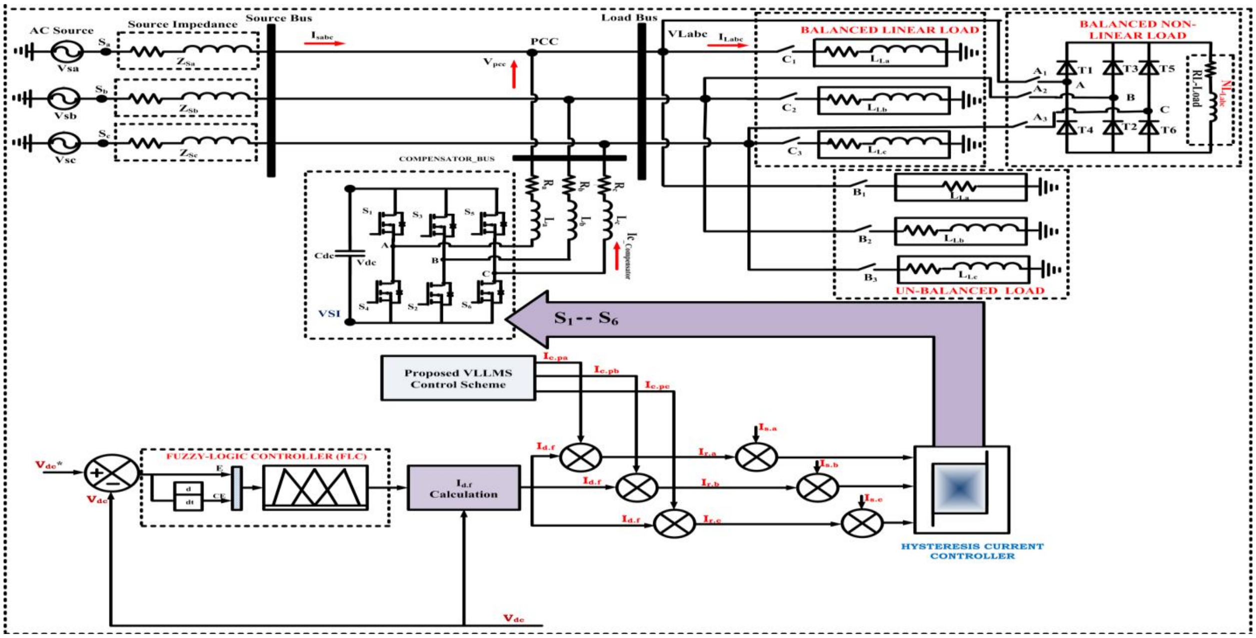


Figure 4: Over-all Proposed Schematic Model of FLC-VLLMS Controlled APF for PQ Enhancement

The over-all proposed schematic model of FLC-VLLMS controlled APF for PQ enhancement is depicted in Figure.4.The superlative features of FLC are manifested of symbolic representation of inference system with an expertise knowledge base. The FLC controller is used in many automation and industrial applications to achieve high-strength, model-free, robust performance, high stability index, based on working as theme of universe-approximate with rule-base functions. The fuzzy membership-functions are represented as Positive-Large (P.L), Positive-Medium (P.M), Positive-Small (P.S), Negative-Small (N.S), Negative -Medium (N.M), Negative-Large (N.L) and Zero (Z.E), respectively. The fuzzy membership functions and fuzzy rule-setsis depicted in Figure.5 and Table.1.

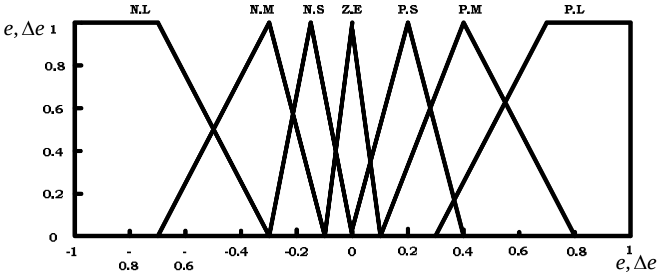


Figure 5: FLC Membership Functions

The proposed FLC controller provides measured fundamental current (I_{dm}) with low error quantities and the VLLMS unit furnishes the active fundamental current component $(I_{d.f})$ are assimilated to produce the final reference current component$(I_{ref.abc})$. The final reference current is compared with actual supply/PCC current which produces the switching states to activate the VSI module through Hysteresis Current Controller (HCC) with certain band-limits. These band-limits are the boundary limits for controlling the compensation current between the upper/lower bands which are recognized to ON/OFF states to VSI for eliminating the harmonics, reactive-power control, power-factor correction, etc.

Table 1: FLC Rule-Sets

e Δe	**N.L**	**N.M**	**N.S**	**Z.E**	**P.S**	**P.M**	**PL**
N.L	N.L	N.L	N.L	N.L	N.M	N.S	Z.E
N.M	N.L	N.L	N.L	N.M	N.S	Z.E	P.S
N.S	N.L	N.L	N.M	N.S	Z.E	P.S	P.M
Z.E	N.L	N.M	N.S	Z.E	P.S	P.M	P.B
P.S	N.M	N.S	Z.E	P.S	P.M	P.B	P.B
P.M	N.S	Z.E	P.S	P.M	P.B	P.B	P.B
P.L	Z.E	N.M	N.S	Z.E	P.S	P.M	P.B

Moreover, the actual supply/PCC currents are continuously swinging inside the lower/upper band limits followed by reference current produced by FLC-VLLMS control scheme. As well as, the proposed FLC-VLLMS control scheme regulates the dynamic response of entire system and attains high stability index, low THD profile, so on.

3. MATLAB/SIMULINK RESULTS & ANALYSIS

The performance analysis of proposed FLC-VLLMS controlled SAPF for PQ enhancement is carried on various load conditions by using Matlab/Simulink platform, and the system specifications are illustrated in Table.2.

Table 2: System Specifications

Parameters	**Values**
Supply Voltage	V_s-220V_{rms}, Fs-50Hz
Supply Side Impedance	0.1+j0.282Ω
Non-Linear Load Side Impedance	2+3jΩ
DC-Link Capacitor	V_{dc}-1500µF
Filter Modules	R-0.001; L-10mH
PI Regulator Gain Values	Kp-0.7; Ki-0.4

3.1 Non-Presence of Shunt-APF

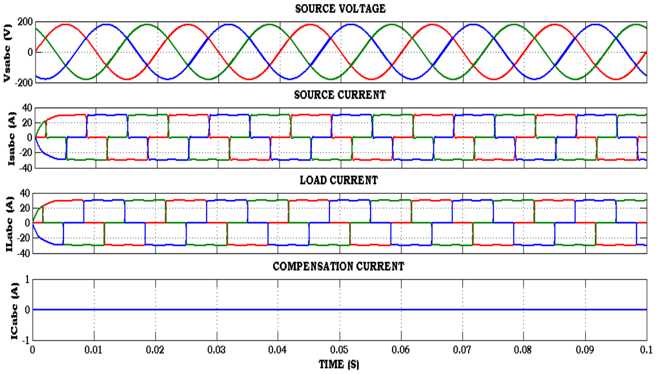


Figure.6: Simulation Results of Distribution System without Shunt-APF

Figure.6. shows the simulation results of distribution system without non-presence of SAPF, includes (a) Supply Voltage, (b) Supply Current, (c) Non-Linear Load Current, (d) APF Compensation Current, respectively. The three-phase power distribution system is driving by three-phase regulated supply as 220V_{rms}, 50Hz frequency. The load is considered as non-linear balanced load defined as three-phase diode-bridge rectifier, it generates greater harmonic distortions in supply currents. As well as, affecting the other loads integrated near to supply/PCC and proliferate the power-quality in entire distribution system. The harmonic currents distortions disturbs the frequency components in system and produces more heat losses, damaging the loads connected at supply/PCC side. The source current is same as non-linear load current under non-presence of APF, thus both currents are represented as same.

3.2 Performance of APF Fed by Traditional PI-VLLMS Controller under Linear Balanced Load

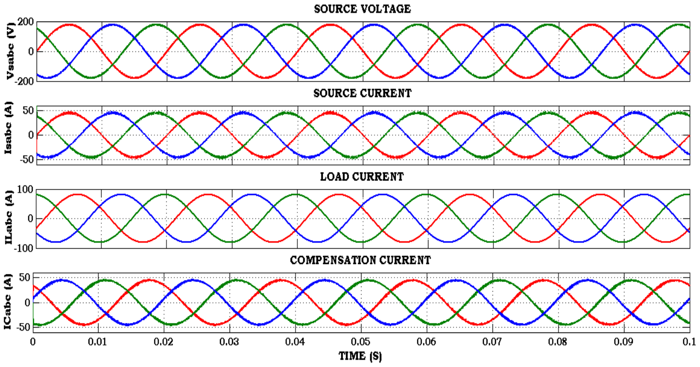


Figure 7: Simulation Results of Distribution System with Traditional PI-VLLMS Controlled Shunt-APF under Linear Balanced Load

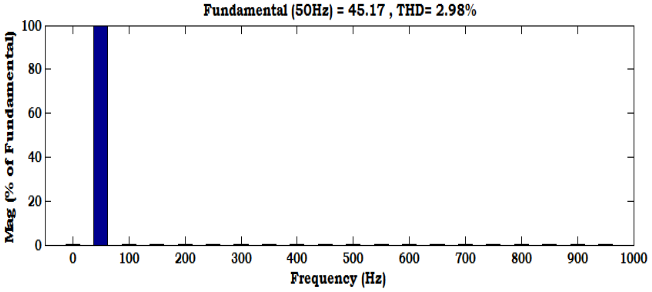


Figure 8: Harmonic Spectrum analysis of Supply Current

Figure.7. shows the simulation results of distribution system with presence of traditional PI-VLLMS fed SAPF under linear balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V_{rms}, 50Hz frequency. The load is considered as linear balanced load defined as three-phase RL-load; then the supply/PCC current is maintained as sinusoidal and constant nature. The harmonic spectrum analysis of supply current acquires 2.98%, which is complying with IEEE-519 standards as shown in Figure.8.

3.3 Performance of APF Fed by Traditional PI-VLLMS Controller under Linear Un-Balanced Load

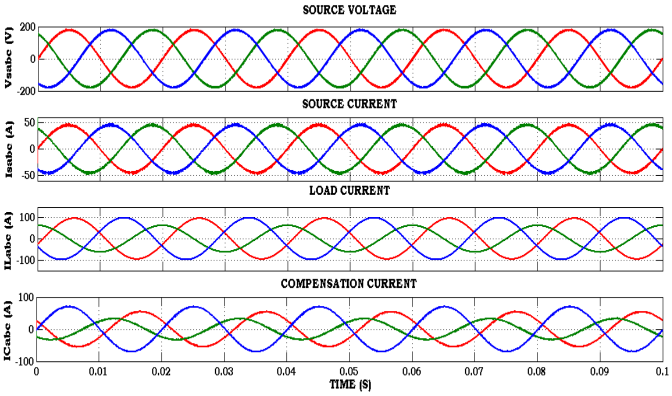


Figure 9: Simulation Results of Distribution System with Traditional PI-VLLMS Controlled Shunt-APF under Linear Un-Balanced Load

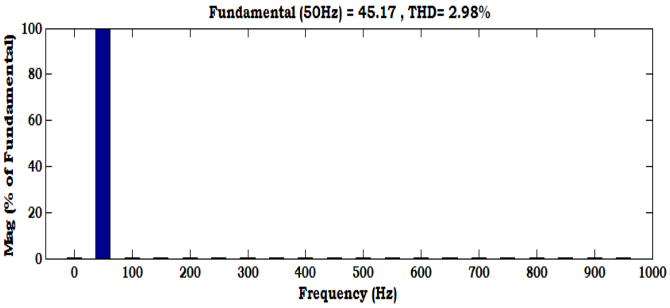


Figure 10: Harmonic Spectrum analysis of Supply Current

Figure.9. shows the simulation results of distribution system with presence of traditional PI-VLLMS fed SAPF under linear un-balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V$_{rms}$, 50Hz frequency. The load is considered as linear un-balanced load defined as three-phase un-balanced RL-load values, but the load current is unbalanced nature. The traditional PI-VLLMS fed SAPF injects compensation currents into distribution system, which regulates the supply currents as sinusoidal, balanced and linear nature. The harmonic spectrum analysis of supply current acquires 2.98%, which is complying with IEEE-519 standards as shown in Figure.10.

3.4 Performance of APF Fed by Traditional PI-VLLMS Controller under Non-Linear Balanced Load

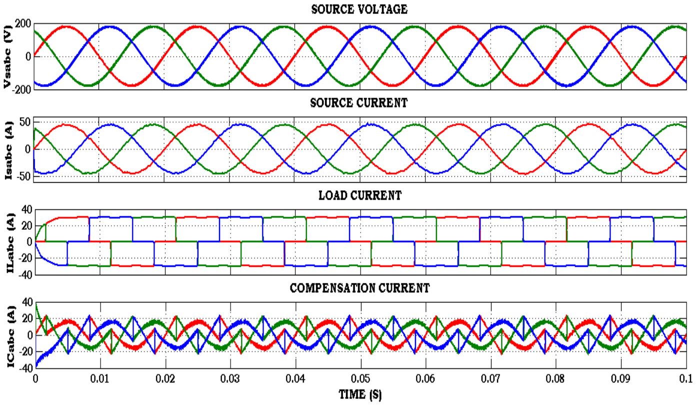
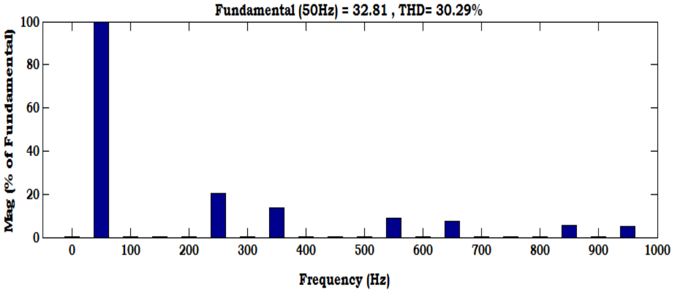
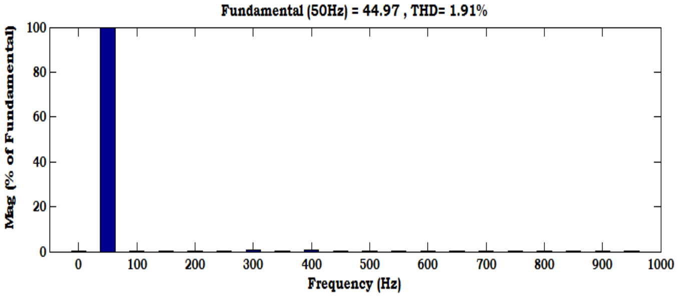


Figure 11: Simulation Results of Distribution System with Traditional PI-VLLMS Controlled Shunt-APF under Non-Linear Balanced Load



(a) Harmonic Spectrum analysis of Supply Current without SAPF



(b) Harmonic Spectrum analysis of Supply Current with PI-VLLMS Fed SAPF

Figure 12: Harmonic Spectrum analysis of Supply Current with and without SAPF

Figure.11. shows the simulation results of distribution system with presence of traditional PI-VLLMS fed SAPF under non-linear balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V$_{rms}$, 50Hz frequency. The load is considered as non-linear balanced load defined as three-phase diode-bridge rectifier, it generates greater harmonic distortions in supply currents. As well as, affecting the other loads integrated near to supply/PCC and proliferate the power-quality in entire distribution system. The harmonic currents distortions disturbs the frequency components in system and produces more heat losses, damaging the loads connected at supply/PCC side. The traditional PI-VLLMS fed SAPF injects requisite compensation currents into PCC of distribution system, which regulates the supply currents as sinusoidal, balanced, low harmonic content and linear nature. The harmonic spectrum analysis of supply current with and without SAPF is 30.29%, 1.91%, which is well-complying with IEEE-519 standards as shown in Figure.12.

3.5 Performance of APF Fed by Traditional PI-VLLMS Controller under Non-Linear Un-Balanced Load

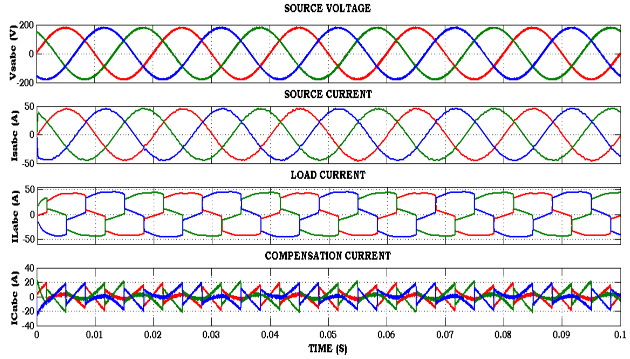
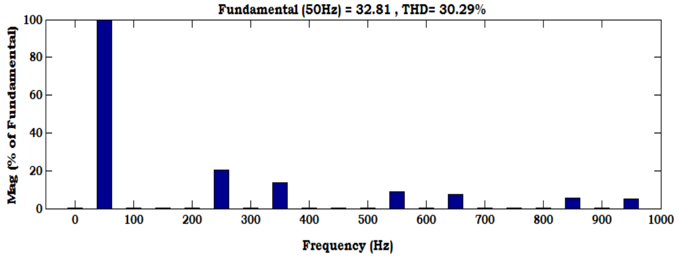
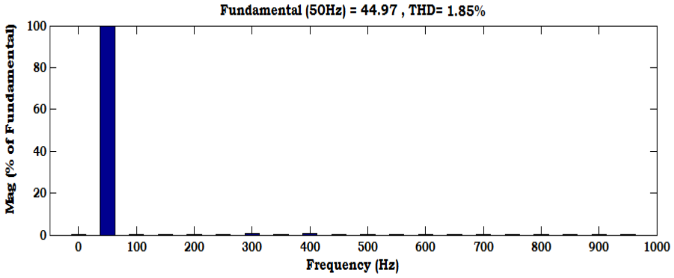


Figure 13: Simulation Results of Distribution System with Traditional PI-VLLMS Controlled Shunt-APF under Non-Linear Un-Balanced Load



(a) Harmonic Spectrum analysis of Supply Current without SAPF



(b) Harmonic Spectrum analysis of Supply Current with PI-VLLMS Fed SAPF

Figure 14: Harmonic Spectrum analysis of Supply Current with and without PI-SAPF under Non-Linear Un-Balanced Load

Figure.13. shows the simulation results of distribution system with presence of traditional PI-VLLMS fed SAPF under non-linear un-balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V$_{rms}$, 50Hz frequency. The load is considered as non-linear un-balanced load defined as three-phase diode-bridge rectifier with unbalanced RL-load; it generates greater harmonic distortions and unbalanced nature in supply currents. As well as, affecting the other loads integrated near to supply/PCC and proliferate the power-quality in entire distribution system. The unbalanced and harmonic currents distortions disturbs the frequency components in system and produces more heat losses, damaging the loads connected at supply/PCC side. The traditional PI-VLLMS fed SAPF injects requisite compensation currents into PCC of distribution system, which regulates the supply currents as sinusoidal, balanced, low harmonic content and linear nature. The harmonic spectrum analysis of supply current with and without SAPF is 30.29%, 1.89%, which is well-complying with IEEE-519 standards as shown in Figure.14.

3.6 Performance of APF Fed by Proposed FLC-VLLMS Controller under Non-Linear Balanced Load

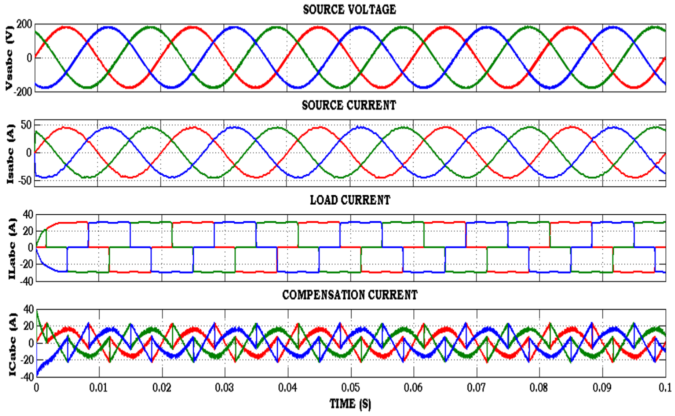


Figure 15: Simulation Results of Distribution System with Proposed FLC-VLLMS Controlled Shunt-APF under Non-Linear Balanced Load

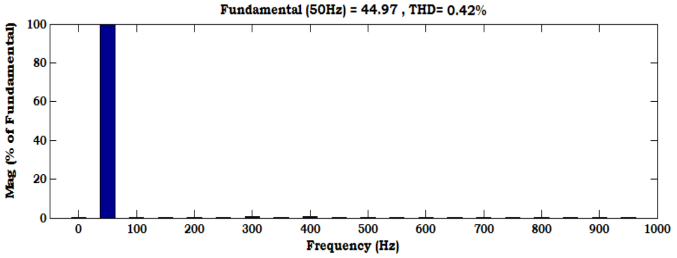


Figure 16: Harmonic Spectrum analysis of Supply Current with FLC-VLLMS Fed SAPF under Non-Linear Balanced Load

Figure.15. shows the simulation results of distribution system with presence of FLC-VLLMS fed SAPF under non-linear balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V$_{rms}$, 50Hz frequency. The load is considered as non-linear balanced load defined as three-phase diode-bridge rectifier, it generates greater harmonic distortions in supply currents. As well as, affecting the other loads integrated near to supply/PCC and proliferate the power-quality in entire distribution system. The harmonic currents distortions disturbs the frequency components in system and produces more heat losses, damaging the loads connected at supply/PCC side. The proposed FLC-VLLMS fed SAPF injects requisite compensation currents into PCC of distribution system, which regulates the supply currents as sinusoidal, balanced, low harmonic content and linear nature. The harmonic spectrum analysis of supply current with FLC-VLLMS fed SAPF is 0.42%, which is well-complying with IEEE-519 standards as shown in Figure.16.

3.7 Performance of APF Fed by Proposed FLC-VLLMS Controller under Non-Linear Un-Balanced Load

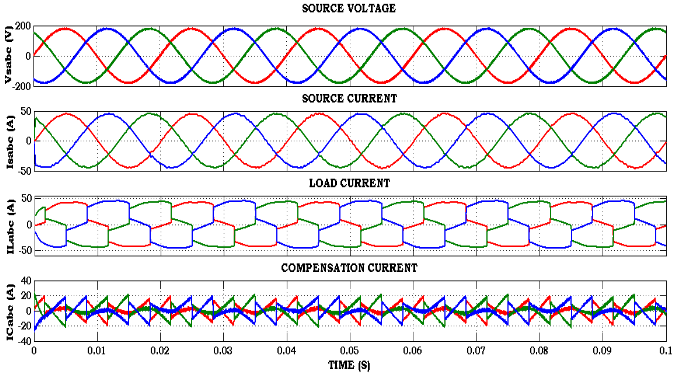


Figure 17: Simulation Results of Distribution System with Proposed FLC-VLLMS Controlled Shunt-APF under Non-Linear Un-Balanced Load

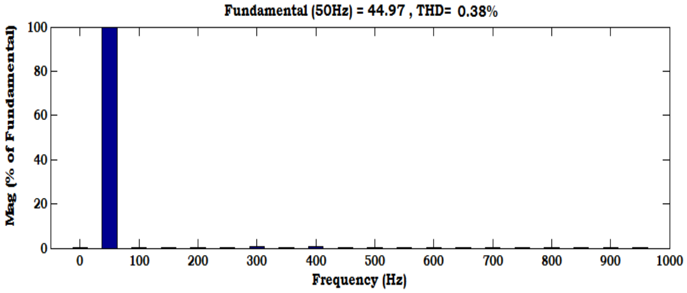


Figure 18: Harmonic Spectrum analysis of Supply Current with FLC-VLLMS Fed SAPF under Non-Linear Un-Balanced Load

Figure.17. shows the simulation results of distribution system with presence of FLC-VLLMS fed SAPF under non-linear un-balanced load. The three-phase power distribution system is driving by three-phase regulated supply as 220V_{rms}, 50Hz frequency. The load is considered as non-linear un-balanced load defined as three-phase diode-bridge rectifier with unbalanced RL-load; it generates greater harmonic distortions and unbalanced nature in supply currents. As well as, affecting the other loads integrated near to supply/PCC and proliferate the power-quality in entire distribution system. The unbalanced and harmonic currents distortions disturbs the frequency components in system and produces more heat losses, damaging the loads connected at supply/PCC side. The proposed FLC-VLLMS fed SAPF injects requisite compensation currents into PCC of distribution system, which regulates the supply currents as sinusoidal, balanced, low harmonic content and linear nature. The harmonic spectrum analysis of supply current with FLC-VLLMS fed SAPF is 0.38%, which is well-complying with IEEE-519 standards as shown in Figure.18. The THD comparison of SAPF performance under several control schemes and various load conditions are illustrated in Table.3. Under both load conditions, the proposed FLC-VLLMS controller performance is very effective to enhance the PQ feature in distribution system over the traditional PI-VLLMS control scheme.

Table 3 :THD Comparison of SAPF under Several Control Schemes and Various Load Conditions

THD (%)	**Traditional PI-VLLMS Control Scheme**	**Proposed FLC-VLLMS Control Scheme**
Source Current (Without SAPF)	30.29%	30.29%
Source Current (Under Balanced Non-Linear Load)	1.91%	0.42%
Source Current (Under Un-Balanced Non-Linear Load)	1.85%	0.38%

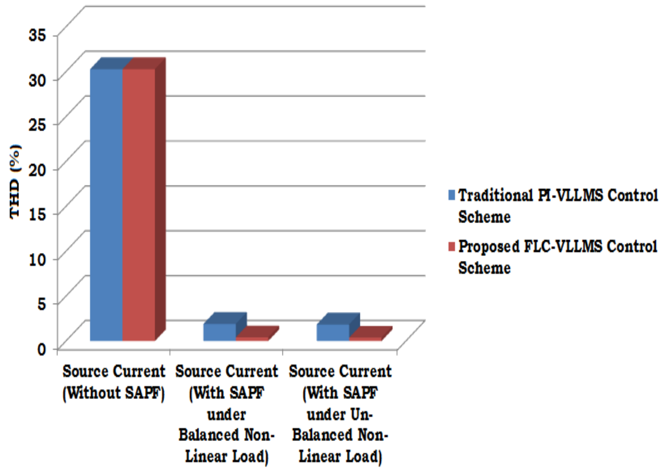


Figure 19: Graphical Representation of SAPF Performance under Several Control Schemes and Various Load Conditions

Current harmonics in source currents generated from non-linear load are compensated using five-level DSTATCOM controlled by IRP algorithm. A transformation from three-coordinates to two-coordinate terminology of voltage and load current is the base step. Meanwhile, the DC-link power loss is measured by differential value of set and actual DC-Link voltages using PI / Fuzzy controllers. Fuzzy controller transforms the input data to fuzzier data and relates to rule base set (as in Table.1). Error signal is de-fuzzier and generates reference signal. Inverse transformation of reference signals generates gate pulses to inverter circuit.

4. CONCLUSION

In this work, a new self-charging FLC-VLLMS controlled SAPF has been developed for enhancing PQ characteristics in a three-phase power distribution network. The feasible operation of proposed SAPF is totally relies on self-charging FLC-VLLMS control algorithm which extracts the fundamental reference current signals. The performance of SAPF has been validatedin both PI-VLLMS and FLC-VLLMS controllers and several load conditions by using computer-simulation tool. Over the traditional PI-VLLMS controller, the proposed FLC-VLLMS controller generates good and enhanced PQ compensation characteristics with greater stability index, good THD profile well comply with IEEE-519/1992 standards.

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