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ANN-SOGI-based Shunt Active Power Filter for Harmonic Mitigation

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ABSTRACT- In this paper introduces a PV based generation system interlinked with shunt active power filter (SAPF) to provide the effective reactive power compensation and mitigation of harmonics. The SAPF is comprised of a photovoltaic generation system, DC link capacitor and voltage source inverter (VSI). The current harmonics caused by nonlinear loads can be greatly reduced with the help of active power filter. To generate the reference current and the regulation of SAPF, the artificial neural network is proposed. The Second Order Generalized Integrator (SOGI) with Artificial Neural Network (ANN) controller is engaged to calculate the reference source current for SAPF. ANN additionally boasts great compatibility for digital implementation, control performance, and lightning-fast dynamic reaction. To demonstrate the effectiveness and superior concert of the proposed methodology, the designed controller is validated with the help of MATLAB simulations.

Keywords: Shunt Active Power Filter, Artificial Neural Network, Voltage Source Inverter, DC link capacitor.

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1. INTRODUCTION

Supplying reliable energy to consumers all over the world is a lucrative business that has long been a focus of academic study and practice standards. Nonlinear loads used in industrial settings worsen harmonic pollution and power quality [1]. Because of the tightly interconnected nature of the power grid, a failure in any part of the network can have far-reaching and undesirable effects on the entire system. Harmonics in electrical current and how to reduce them have become major concerns for many companies in recent years. Equipment longevity is shortened and power quality is degraded due to nonlinear loads that are too high. Industrial facilities are installing power factor improvement devices to boost power reliability. Capacitors are used for this purpose instead of reactors, which would cause the power grid to experience harmonic distortion and resonance. Furthermore, the current drawn by nonlinear loads is not perfectly sinusoidal because the current waveform diverges from a sine wave, which results in distortions in voltage waveforms. It is the harmonics that cause electronic malfunctioning, capacitor overloads, power transformer overheating, an elevated heating impact in electrical devices, and distribution line losses [2-5].

Passive power filtering, active power filtering, and hybrid power filtering are few types of the filtering techniques proposed in the existing literature to reduce harmonics [6]. By using tuned capacitors, reactors, and resistors, the PPF method provides a low-impedance path to harmonics of varying frequencies, reducing the impact of these harmonics [7]. Even though these are inexpensive, one major drawback of employing the PPF is the resonance it causes in the power system. In addition, situations where voltage dips and spikes are present decision for the use of APF [8]. The high cost of running them and the fact that they can't handle low rating loads in industrial settings are their main drawbacks [9].

At the same time, measuring the voltage at the source is crucial for estimating the load's harmonic power consumption. The voltage extracted from the source is essential for compensating the reactive power and harmonics that add complexity to the control scheme [11]. The DC voltage of SAPF is kept at a constant voltage thanks to a DC-link voltage regulator that makes use of a PI controller. Voltage sensors are required for this PI-controlled DC-link voltage regulator in order to collect the necessary voltage-related data. When there is a voltage and current disturbance, the DC-linked capacitor and batteries are activated to stock the surplus energy and supply the necessary power to the load. Due to their limited energy storage capacity, these devices hinder the shunt APF's ability to compensate [12-16]. In the assessment of reference source current signal, the error is to be avoided or else these errors will lead to inaccurate compensation, which is why the control technique used to estimate it is so crucial to the APF's compensation ability [16-18]. A number of researchers have already tried out various control strategies to approximate the shunt active filter's reference current signal [19].

The numerous control strategies including selective harmonic elimination-based pulse width modulation (SHE-PWM), direct

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testing and calculating (DTC) methods, recursive discrete Fourier transformation (RDFT), fast Fourier transformation technique (FFT), Pq0, notch filter, extrapolated integral, synchronous detection algorithm, sine wave multiplication, artificial neural network (ANN), and synchronous detection algorithm are developed by the various researchers to lessening the Total Harmonics Distortion (THD) [20-24].

In the Proposed system, Reference current signal for the shunt PF is generated using second order generalized integrator (SOGI) fed an Artificial Neural Network (ANN). When using the SOGI control algorithm in an SAPF that is interfaced with a Photovoltaic and storage battery. The inverter currents are measured with the help of current sensors placed in the circuit. This allows us to more accurately predict the total amount of energy used by the loads in the distribution system and eliminates the requirement for a PI regulator in the shunt inverter control algorithm. The basic control circuitry, a gate signal for the three-phase voltage source inverter (VSI) switches, is generated by an ANN based SOGI control algorithm. Current-based disturbance compensation is delivered by the Photovoltaic generation based SAPF employing the ANN-based SOGI control algorithm in the distribution system that serves the commercial and residential customers.

The proposed SAPF interconnected photovoltaic system is described in *Section 2*. In *Section 3*, discussed the control strategy for the SAPF. The outcomes of the simulation and experimental validations are shown in the following *Section 4*. The conclusion of the proposed work is presented at the end of the section.

2. SYSTEM DESCRIPTION

The shunt APF circuitry with a Photovoltaic (PV) generating system is shown in *figure 1*. All of the linear and nonlinear loads are serviced by the grid-connected SPV power generating system that utilizes shunt APF. The consumer load is connected in parallel with the three-phase VSI through the interfacing inductor (Lf). The PV power generating system keeps the DC link of the shunt APF running so that it can continuously providing the compensation for changes in load current or current disturbances. The PV array, along with the high and low DC-DC converters for the battery bank, make up the PV power generation system. The DC-DC step up converter is employed to keep the shunt inverter's DC bus voltage stable.

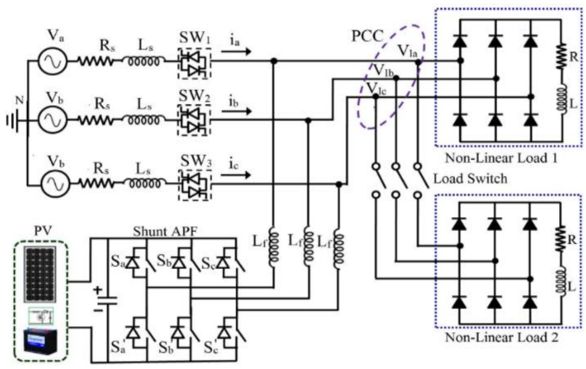

Figure 1: Proposed Shunt Active Filter Circuit

When the PV power generating system is producing more electricity than is needed, the excess can be sent to a battery via the power conditioning circuitry, and the battery can then be used to supply electricity when the PV system is not producing enough electricity. Nonlinear loading is provided by an unregulated diode rectifier consisting of a resistor and an inductor connected at their point of common coupling (PCC). The current transformer is used to measure the current drawn by the nonlinear load.

2.1 Photovoltaic Generating System

The PV system array, storage battery, DC-DC boost converters contributes the photovoltaic power generation. To achieve the highest output during the time of decreasing solar irradiance, the DC-DC converter incorporates the maximum power point tracking (MPPT) function for enhancing the voltage capability. The maximum power point tracking (MPPT) control circuitry for the SPV array and DC-DC converter is depicted in *figure 2*

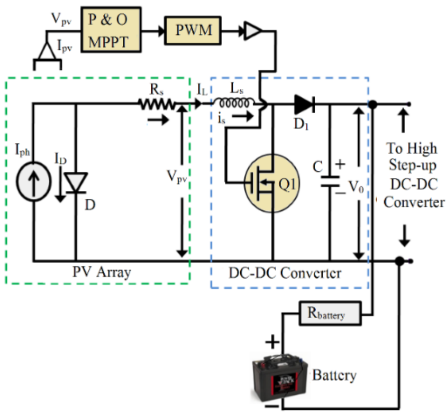

Figure 2: Circuit diagram of PV System with MPPT

2.1.1 Operation modes of Photovoltaic System

There will be three distinct modes of operation for the planned photovoltaic system with battery is interfaced shunt APF. There are three different modes are given below:

Mode 1: Photovoltaic (PV) power Generation
The PV power generating mode kicks in during the day, or whenever there is enough solar irradiation to generate sufficient electricity. The photovoltaic is connected to SAPF is used here to smooth out harmonics and store the excessive power in a battery for later use.

Mode 2: Battery Backup
When solar energy is unavailable, such as at night or on cloudy days, the battery backup mode is activated. The harmonics and reactive power are balanced by a battery-supported SAPF. In order to ensure that compensation is maintained without interruption, the battery backup mode uses a DC-DC boost converter.

Mode 3: Uninterrupted Supply
The critical/sensitive loads are reliably supplied by the Photovoltaic based SAPF system even when the voltage is out. In such cases, the Battery based PV generating system provides

the load power. Through the operation of the semiconductor switches, the utility grid is unplugged.

3. MATHEMATICAL MODELLING FOR PROPOSED SHUNT ACTIVE FILTER

The non-sinusoidal currents is generated by nonlinear load, for the purpose of modelling, the phase 'b' is considered for deriving the equation as follows

$$i_{lb}(t) = \sum_{g=1}^{¥} i_{L_{b,g}} \mathrm{Sin}(g\omega t+f_g) \quad (1)$$

$$i_{lb}(t) = \sum_{g=1}^{\infty} i_{L_{b,1}} Sin(\omega t + \phi_1) + \sum_{g=1}^{\infty} i_{L_{b,g}} Sin(g\omega t + \phi_g)$$
(2)

Where g is harmonic order, ϕ_g is harmonics phase angle and ω is angular frequency.

The load current will often contain the fundamental and harmonic components.

$$i_{Lb} = i_{L_{b,1}} + \sum_{g=2}^{\infty\Sigma} i_{L_{b,g}} \quad (3)$$

The proposed SAPF effectively dampens out all harmonic currents. In order to provide efficient compensation, the shunt APF's control algorithm must determine the appropriate reference currents for compensation. The phase '*b*' compensation current is expressed as

$$i_{cg} = \sum_{g=2}^{\infty} i_{c,g} = -(i_{cb,3} + i_{cb,5} + i_{cb,7} + i_{cb,9} + ... + i_{cb,n}) \quad (4)$$

As a result of VSI's compensatory current injection, current-based disturbances at the PCC are reduced. And hence the current at the source will evolve into a sinusoid.

$$i_{sb} = i_{L_{b,1}} + \sum_{g=2}^{\infty} i_{L_{b,g}} - \sum_{g=2}^{\infty} i_{C_{b,g}} = i_{L_{b,1}} + i_{L_{b,g}} \quad (5)$$

The source current for the phase 'b' is expressed as

$$i_{sb} = i_1 \, sin(\,\omega t + \phi_1) \quad (6)$$

As a result, we can compute the source reference compensation current as:

$$i_{sb}^* = i_{sb} \, sin(\,\omega t) \quad (7)$$

$$i_{ca} = \text{Reference source current } (i_{sb}^*) - \text{Load current}(i_{Lb}) \quad (8)$$

A PI controller is often used to calculate the reference current with respect to source. The voltage-associated data is essential for the PI regulator to perform as expected. The voltage sensor, then, must be integrated into the power conditioning circuitry for this reason. SOGI estimates the reference current signal using load current and compensation current as feedback signals. Without considering the voltage sensor, the SOGI algorithm provides the estimation of the source reference current to the shunt APF.

The second order generalized integrator is derived for estimating the compensation current with below mentioned function.

$$F_1(S) = \frac{i_{Lb\alpha}(s)}{i_{Lb}(s)} = \frac{k\omega s}{s^2 + k\omega s + \omega^2} \quad (9)$$

$$F_2(S) = \frac{i_{Lb\beta}(s)}{i_{Lb}(s)} = \frac{k\omega^2}{s^2 + k\omega + \omega^2} \quad (10)$$

In this case, we set the angular frequency to a constant 304 rad/s. In practice, the transfer function given in *equation (9) & (10)*, F1 is applied as a band pass filter, while function F2 is applied as a low pass filter in SOGI. On the fundamental harmonic of the input signal, the transfer function displays a perfect phase and amplitude match between the input and received signals. Therefore, the acquired signal is considered as the standard value of source current.

$$i_{Lb\alpha} = i_{sa}^* = I_{sa} \, sin(\omega t) \quad (11)$$

At this time, the signal received from the transfer function F2(s) is 900 out of phase with the signal generated by the transfer function F2(s). As soon as the necessary current from the reference source is calculated, the reference current for compensation can be attained accurately. After gathering data on the reference and the measured compensation current, the error in the compensation current can be computed.

$$\Delta i_{cb} = i_{cb}^* - i_{cb} \quad (12)$$

At the point of common coupling, the compensation current is injected with the help of the ANN-based SOGI algorithm. The ANN receives its input signal from the compensation current error. A hysteresis band comparator receives the signal from the ANN and uses it to create the gate pulses for the VSI. The active filter's compensation current is controlled by an Artificial neural network (ANN) based SOGI algorithm.

When it comes to quickly identifying distorted signals, an artificial neural network controller is unique in effectiveness. In the presence of parametric variation, the standard controller fails to function. It's a network of smart neurons that can pick up new information and adapt to its surroundings. Through manipulation of the weight value, neurons can be programmed to carry out a specific task. Their training involves the minimization of mean squared error (MSE) using the Levenberg-Marquardt Back Propagation (LMBP) algorithm.

It consists of a single neuron in the input layer, twenty in the hidden layer, and another single neuron in the output layer. The neural network has two inputs, twenty layers of hidden neurons, and one output layer. The error in the compensation current, denoted by *e(n)*, and the change in the error over time, denoted by de(n), i^*_{cabc} represents the current reference value used in compensation and i_{cabc} denotes the measured actual compensation current. For realizing the enhanced compensation results, the weights of ANN is to be adjusted to minimize the current based distortion. *Table 1* shows the data of proposed ANN controller. The switching pulses were generated by the

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hysteresis comparator, which compared the reference current with the measured current.

Table 1: ANN Parameters

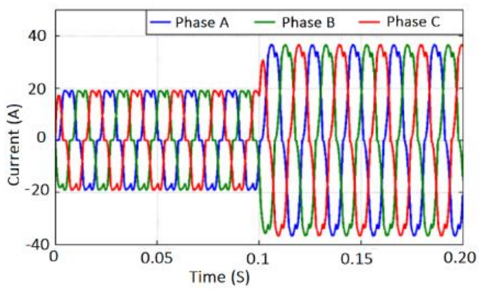
Parameters	Values
Maximum epochs	600
No of neurons in hidden layer	20
Performance goal	0.001
Learning rate	0.04
Activation function	5tansig/purelin

4. SIMULATION RESULTS AND DISCUSSION

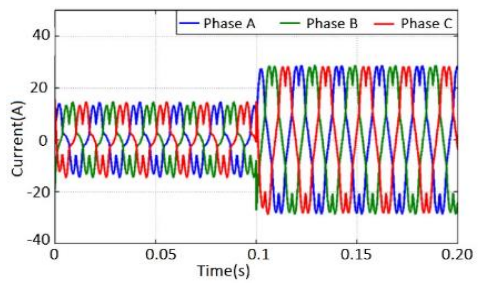
Using MATLAB/Simulink, we evaluate the SOGI based ANN controller applied to a Photovoltaic integrated shunt APF under different load current condition. The simulation results are presented for with and without a PV linked shunt APF. The Photovoltaic interfaced SAPF system settings are detailed in *table 2*. Increasing the load current (Case 1) and decreasing the load current (Case 2) are considered to test the proposed control scheme.

Table 2: Simulation System Parameters

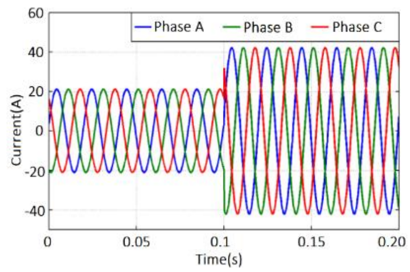
Parameters	Value
Input voltage (source)	220 V
Frequency	50 Hz
SAPF Filter (L, C)	22mH,1.2Ω
DC link capacitor and voltage	200μF and 600V
Feeder Impedance	1+j2.325 Ω
Nonlinear Load Diode rectifier with RL load	25Ω, 15mH
Battery bank rating	12V, 450Ah
PV Array rating	12V, Max Power- 210W (36.6 V x 5.75 A)



(a) Load current before installation of SAPF

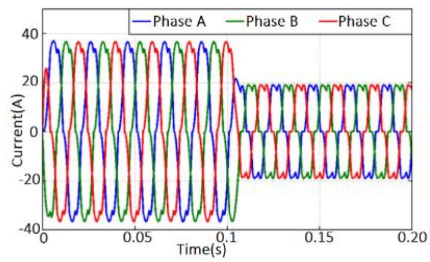


(b) Injected Current

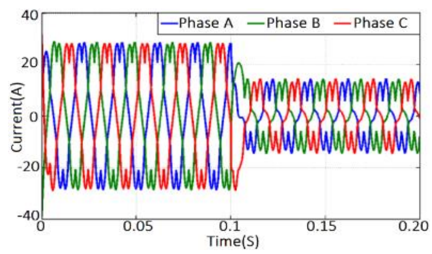


(c) Waveforms of Source current after installing SAPF

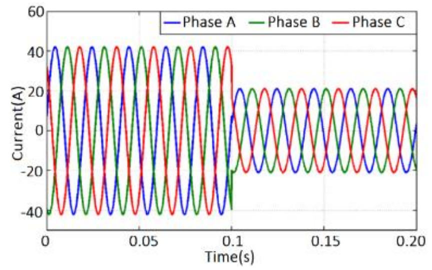
Figure 3: Increasing of load current (Case 1)



(a) Load current before installation of SAPF



(b) Injected Current



(c) Waveforms of Source voltage after installing SAPF

Figure 4: Decreasing of load current (Case 2)

Figure 3 displays the results of a simulation run that examined the effects of a rising load current on the load current, the injected current, the three-phase source voltage and current before and after installation of SAPF is presented. The load switch is used to turn on nonlinear load to confirm the exactness of the current compensation achieved by the Photovoltaic cell-based shunt APF using the ANN-SOGI algorithm. In the event that the load switch is closed, a greater load current is produced. Three-phase source currents, and voltages, load currents, compensation currents, before and after the installation of a Photovoltaic cell-based Shunt APF for decreasing load current are depicted in *figure 4*. As soon as the load switch is opened, the current through the load is lowered.

Before the PV-shunt APF was installed, the source currents had harmonic distortion levels of 25.63%, 24.55%, and 26.21%, respectively; these levels dropped to 1.87%, 1.81%, and 1.87%, respectively, after the APF was installed. The simulation findings validated the ANN- SOGI control algorithm's capacity to lessen the total harmonic distortion (THD) shown in *table 3*.

Table 3: Comparison of THD

	Phase	Before installation of PV-SAPF	After SOGI installed for PV-SAPF	After SOGI with ANN installed for PV-SAPF
Case 1 THD %	A	26.68%	2.72%	2.18%
	B	26.63%	2.79%	2.21%
	C	26.43%	2.74%	2.19%
Case 2 THD%	A	25.63%	2.45%	1.87%
	B	24.55%	2.47%	1.81%
	C	26.21%	2.48%	1.87%

5. CONCLUSION

To reduce the current harmonic distortions and compensate the reactive power, a shunt active power filter (APF) with an SOGI-ANN control algorithm is used. The SOGI with ANN, is used to make an approximation of the reference signal without relying on any information related to voltage. As a result, the voltage sensor and PI regulator are superfluous, and the system can function without them. Actively engaging the solar system interfaced SAPF reduces current harmonics in the distribution system and ensures a steady, clean power supply. To ensure a steady flow of energy to consumers, photovoltaic systems can be set up in a variety of operating modes with the use of a straightforward coordination logic control. This straightforward control technique allowed us to successfully correct for current harmonics, reactive power, and voltage interruption across a wide range of load and voltage situations. In nonlinear load with variable current conditions, the source current has a THD of around 1.81%, which is within the tolerable limit of 5% established by IEEE Std.519- 1992.

Authors Contribution

Conceptualization provided by Sujith M and Vijayakumar G.; methodology, Pardeshi D.B.; software and validation, Madhubalan S.; formal analysis, X.X.; investigation, resources, data curation, Arulnantham D.; writing—original draft preparation, Sujith M.; writing—review and editing, Vijayakumar G.; visualization, Pardeshi D.B.; supervision, Madhubalan S.; project administration, Arulnantham D. All authors have read and agreed to the published version of the manuscript".

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Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

[1] Zhang L.; S. Shenglong Yu.; Fernando T.; Ho-Ching Iu H.; Po Wong K. An online maximum power point capturing technique for high-efficiency power generation of solar photovoltaic systems. J Mod Power Syst Clean Energy, Vol.7, pp. 357–368, 2019.

[2] Schaefer J. C. Review of photovoltaic power plant performance and economics. IEEE Trans Energy Convers, Vol.5, pp.232– 238, 1990.

[3] Ahmed Elmelegi.; Mokhtar Aly.; Emad M. Ahmed.; Abdullah G. Alharbi. A simplified phase-shift PWM-based feedforward distributed MPPT method for grid-connected cascaded PV inverters. Solar Energy, Vol. 187, pp.1-12, 2019.

[4] López-Erauskin R.; González A.; Petrone G.; Spagnuolo G.; Gyselinck J. Multi-Variable Perturb and Observe Algorithm for Grid-Tied PV Systems with Joint Central and Distributed MPPT Configuration. IEEE Trans Sustain Energy, Vol. 12, pp.360 – 367, 2021.

[5] Alsumiri M. Residual Incremental Conductance Based Nonparametric MPPT Control for Solar Photovoltaic Energy Conversion System. IEEE Access, Vol. 7, pp. 87901–87906, 2019.

[6] Sen T.; Pragallapati. N.; Agarwal V.; Kumar R. Global maximum power point tracking of PV arrays under partial shading conditions using a modified particle velocity-based PSO technique. IET Renew Power Gener, Vol. 12, pp. 555–564, 2018.

[7] Chebabhi M. K. Fellah.; M. F. Benkhoris. Control of the three phase four-wire four-leg SAPF using 3D-SVM based on the two methods of reference signals generating CV and SRF in the dq0-axes. J. Electr. Eng., Vol. 1, no. 1, pp. 32–39, March 2015.

[8] Kalla U K.; Kaushik H.; Singh B.; Kumar S. Adaptive Control of Voltage Source Converter Based Scheme for Power Quality Improved Grid-Interactive Solar PV–Battery System. IEEE Transactions on Industry Applications, Vol. 56, No. 1, pp. 787-799, Jan 2020.

[9] Yingying L.; Yonghai X.; Xiangning X.; Yongqiang Z.; Chunlin G. A stages compensation and control strategy for series power-quality regulator. IEEE Trans. Power Del., vol. 25, no. 4, pp. 2807-2813, Oct. 2010.

[10] Shukl P.; Singh B. Delta-Bar-Delta Neural-Network-Based Control Approach for Power Quality Improvement of Solar-PV-Interfaced Distribution System. IEEE Transactions on Industrial Informatics, Vol. 16, No. 2, pp. 790-801, 2020.

[11] S. K. Dash.; P. K. Ray. Power quality improvement utilizing PV fed unified power quality conditioner based on UV-PI and PR-R controller. CPSS Transactions on Power Electronics and Applications, Vol. 3, No. 3, pp. 243-253, 2018.

[12] Ashish Patel, Mathur H.D.; Surekha Bhanot. An improved control method for unified power quality conditioner with unbalanced load. International Journal of Electrical Power & Energy Systems, Vol. 100, pp.129-138, 2018.

[13] Kumar Ravinder.; Hari Om Bansal. Investigations on shunt active power filter in a PV-wind-FC based hybrid renewable energy system to improve power quality using hardware-in-the-loop testing platform. Electric Power Systems Research, Vol. 177, 2019, 105957.

[14] Chishti F.; Murshid S.; B. Singh. Development of Wind and Solar Based AC Microgrid With Power Quality Improvement for Local Nonlinear Load Using MLMS. IEEE Transactions on Industry Applications, Vol. 55, No. 6, pp. 7134-7145, 2019.

[15] Bajaj M.; Singh A. K.; Alowaidi M.; Sharma N. K.; Sharma S. K.; Mishra S. Power Quality Assessment of Distorted Distribution Networks Incorporating Renewable Distributed Generation Systems Based on the Analytic Hierarchy Process. IEEE Access, Vol. 8, pp. 145713-145737, 2020.

[16] Chen C.I.; OrcID C.K. L.; Chen Y.C.; Chen C.H. Adaptive frequency-based reference compensation current control strategy of shunt active power filter for unbalanced non-linear loads. Energies, Vol. 12, No. 6, pp. 3080–3093, 2019

[17] Han Y.; Xu L.; Khan M. M.; Yao G.; Zhou L.D.; Chen C. Study on a novel approach to active power filter control using neural network-based harmonic identification scheme. Elect. Eng., Vol. 91, No. 6, pp. 313-325, 2010.

[18] Dubey K.; Mishra J. P.; and Kumar A.; Modified CCF based shunt active power filter operation with dead-band elimination for effective harmonic

and unbalance compensation in 3-phase 3-wire system. IEEE Trans. Power Del., vol. 37, no. 3, pp. 2131-2142, Aug. 2021.

[19] Bajaj A.; Flah M.; Alowaidi M.; Sharma N. K.; Mishra S.; Sharma S. K.A Lyapunov-function based controller for 3-phase shunt active power filter and performance assessment considering different system scenarios", IEEE Access, Vol. 9, pp. 66079-66102, 2021.

[20] Wang X.; Blaabjerg F.; Harmonic stability in power electronic-based power systems: concept, modeling, and analysis, IEEE Transactions on Smart Grid, Vol. 10, No. 3, pp. 2858–2870, 2019.

[21] Ouchen S.; Benbouzid M.; Blaabjerg F.; Betka A.; Steinhart H. Direct Power Control of Shunt Active Power Filter Using Space Vector Modulation Based on Super twisting Sliding Mode Control. IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 9, No. 3, pp. 3243-3253, June 2021.

[22] Jiang W.; Ding X.; Ni Y.; Wang J.; Wang L.; Ma W.; "An improved deadbeat control for a three-phase three-line active power filter with current-tracking error compensation", IEEE Trans. Power Electron., Vol. 33, No. 3, pp. 2061-2072, Mar 2018.

[23] Karbasforooshan M.S.; Monfared M. An improved reference current generation and digital deadbeat controller for single-phase shunt active power filters. IEEE Trans. Power Del., Vol. 35, No. 6, pp.2663-2671, Dec. 2020.

[24] Asif R. M.; Rehman A. U.; Rehman S. U. Design and analysis of robust fuzzy logic maximum power point tracking based isolated photovoltaic energy system. Engineering Reports, vol. 9, no. 16, 2020.