International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 4, Jul-Aug 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

ANN-Based Control of Photovoltaic-Battery Integrated UPQC for Power Quality Enhancement in Grid-Tied Microgrids

Kisan Kumar Jaisawal[1], Pramod Kumar Rathore[2]

[1]M Tech Scholar, RKDF College of Engineering, Bhopal, Madhya Pradesh, India
[2]Assistant Professor, RKDF College of Engineering, Bhopal, Madhya Pradesh, India

ABSTRACT

A grid-tied microgrid equipped with a UPQC generates clean, efficient power. ANN-controlled voltage source converters UPQCs may be more economical and less complex. This controller replaces costly DSPs, FPGAs, and a-b-c-d-q-0 conversion. A photovoltaic-battery-unified power quality conditioner system with harmonic supply voltage and nonlinear unbalanced loads is analyzed using an artificial neural network controller. Consider sag and swell voltage. The Levenberg-Marquardt algorithm is used for backpropagation in artificial neural network control. This control method sustains the target voltage of the dc-link capacitor using dependable reference signals. MATLAB/Simulink simulates photovoltaic-battery-unified power quality conditioner systems using synchronous reference frame and artificial neural networks. The testing indicated that the proposed technique was the most effective. The impacts of supply currents and dc-link capacitor voltage in relation to synchronous reference frame (SRF) and artificial neural network (ANN) controller-based universal power quality conditioner (UPQC) are also analyzed. The proposed controller surpasses the total harmonic distortion of load voltage and supply current. In contrast to SRF-based and ANN control.

KEYWORDS: *Maximum Power Point Tracking; Artificial Neural Network (ANN); UPQC; Synchronous Reference Frame; Total Harmonic Distortion (THD).*

How to cite this paper: Kisan Kumar Jaisawal | Pramod Kumar Rathore "ANN-Based Control of Photovoltaic-Battery Integrated UPQC for Power Quality Enhancement in Grid-Tied Microgrids" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-4, August 2025, pp.700-713, URL: www.ijtsrd.com/papers/ijtsrd97325.pdf

IJTSRD97325

1. INTRODUCTION

Regulating power quality using electronic controllers, switches, computer power supply, and adjustable speed drives presents challenges [1,2]. These devices induce sinusoidal fluctuations in voltage and current under load, diminishing the efficiency of power networks and equipment [3]. Power is augmented via the use of active, passive, and FACTS controllers. They resolved this issue by using passive power filters. The recent findings augment system dimensions and oscillation, necessitating an alternative resolution. Consequently, active power filters addressed issues without inducing resonance or necessitating system growth. Inexpensive passive power filters Power quality concerning voltage sag/swell, non-linearity, and harmonics is enhanced by the use of APC, AVC, DVR, and DSTAT-COM FACTS controllers [4,5]. A unified power quality conditioner (UPQC) has recently been shown to be a cost-effective common connection device for power distribution (CPD). Safeguards power supply apparatus and clientele against fluctuations in power quality. [6]. UPQCs mitigate harmonics, non-linearity, and voltage sag/swell. DC connections use both series and shunt active power filtering. Active Power Filters (APF) mitigate load-side current harmonics. The APF series mitigates voltage sags, swells, and flickers in the source voltage. Source [7] examines UPQC. UPQC regulates voltage and current reference signals. Signal-regulated inverters govern essential operations [5]. IAR power theory, SRF theory, UVT generation, FFT, DWT, and ECA provide UPQC reference signals. [5]. The efficiency and accuracy of reference signal generation influence UPQC performance [3]. Refer to [8] for the current and voltage reference signals of the IAR power theory inverter. Proposed zeroing of the cut-off frequency DC offset. Generate reference signals with synchronous reference frame theory [9]. Low-Pass or

High-Pass Filter Filters eliminate direct current. Reduces cut-off frequencies and controller dynamics. Unit vector templates produced reference signals [10]. Complex frequency sequencer phase-locked loops energize UVT. Investigated reduced load current and source voltage occurrences with FFT [11]. This method is effective just in stable systems. Least squares discrete wavelet transform (DWT) decreases frequency, phase angle, and fundamental component amplitude. The exponential composition algorithm (ECA) is assessed digitally [13]. Total Harmonic Distortion (THD) is minimized to comply with IEEE standards by basic mathematical calculations.

Improvements in control techniques may modify the dimensions of traditional systems. Advanced control systems addressed intricate manufacturing and industrial control challenges. Each controller feature is distinct. Acquire knowledge, commit to memory, deduce. The ANNMPC-based UPQC lowers harmonics in the distribution network and enhances power quality [14]. MATLAB/SIMULINK simulates and visualizes system data. Intelligent artificial neural fuzzy-based UPQC controllers enhanced power quality [15]. Artificial intelligence, specifically neural networks, influences power electronics. ANN-ADES predicts that admission increases enhance UPQC dynamic performance [16]. Unbalanced loads, harmonic mitigations, and voltage sag/swell were simulated using MATLAB and FPGA. This technique may be used for irregular load durations. The performance of DCC ANN-based UPQC under distorted supply voltage and unbalanced non-linear loads was analyzed [17,18]. This research eschews complex controls and mathematical models. Artificial Neural Network (ANN) controllers have supplanted proportional-integral (PI) controllers for the regulation of voltage-related current in shunt active power filters (APFs) [3].

Multi-objective systems are also under investigation. There is a need for off-grid renewable energy options that enhance electricity quality. Solar photovoltaic technology is essential for renewable energy generation due to its cost-effectiveness and ecological sustainability. The three-phase PV-UPQC system was assessed under different irradiance and voltage sag/swell conditions [1]. The transition between grid-connected and independent modes of a solar PV-battery integrated UPQC was assessed [19]. Residential photovoltaic systems use real-time fuzzy maximum power point tracking and an advanced step-up converter [20]. Design is challenging. The P&O Technique for tracking optimizes photovoltaic array power efficiently and precisely [21].

Under various operational conditions, the neural network controller ensures the speed and stability of the converter system. Development tool for new power quality control circuits. Recent advancements have been made in the investigation of UPQC control circuit design. These investigations aim for resilient control methods and rapid signal switching [3]. Universal power quality conditioners in photovoltaic systems are based on artificial neural networks [22]. The electrical quality improves and operations persist throughout Low Voltage Ride Through (LVRT) events. Time-frequency analysis using SWT-ANN [5]. This approach identifies and resolves power quality issues in microgrid-connected distribution systems. The incorporation of UPQC devices into a grid-connected micro-grid using ANFIS reduces power quality distortion [6]. The ANFIS-based PV-integrated UPQC accommodates both symmetrical and asymmetrical loads and sources [15]. PQ and SRF control use a-b-c to a-b-0, d-q-0, and reverse transformations. Digital Signal Processors (DSPs) and Field-Programmable Gate Arrays (FPGAs) are proficient at handling memory-intensive advanced controllers. However, these controllers operate with more speed. Their complexity increases system costs and complexities.

Photovoltaic-powered Unified Power Quality Conditioners use Artificial Neural Networks for rapid and intelligent control. Microgrids regulate voltage fluctuations, including sags, swells, and harmonics. Artificial neural network (ANN) controllers save expenses. Eliminating the mathematical technique enables a basic microcontroller to do the task, hence decreasing system cost and complexity. Stabilizes voltage and current in the power supply. The system was developed using MATLAB Simulink. The system has three stages. An MPPT P&O algorithm begins with a DC-DC boost converter. Series and second-stage shunt active power filters use the Synchronous Reference Frame (SRF) technique, whereas third-stage shunt and series active power filters utilize Artificial Neural Networks (ANN).

2. POWER QUALITY PROBLEMS

IEEE Std 1100 delineates power quality as the provision of electricity and grounding for sensitive electronic devices. Power quality comprises a collection of electrical characteristics that allow a device to function optimally without compromising performance or longevity [10]. Power quality in transmission and distribution depends on a voltage variation of +/- 5% [11]. Voltage violations must be rectified within 2 seconds [12]. Substandard power quality diminishes the longevity and efficacy of electrical devices. The voltage, current, and frequency of electrical devices interact. An effective distribution system restricts voltage amplitude and guarantees the purity of sinusoidal voltage and current waveforms at the fundamental frequency. Distribution networks using overhead cables instead of underground connections may have power quality problems. In windy situations, birds, tree branches, and power lines may cause disturbances. Line disruptions may occur due to falls, trees, and lightning strikes. All these factors influence network power quality. Industrial motors and power electronics engage and disengage capacitors, inductor banks, transformers, and other components to regulate substantial amounts of energy [10, 13].The thesis examines power quality phenomena:

Short-term voltage variations last for less than a minute, but long-term alterations survive for an extended period [10, 13]. Voltage fluctuations and power quality problems may harm electronic devices.

• Electrical Factor and Reactive Power: The IEEE Recommended Practice for Photovoltaic (PV) System Utility Interface mandates that all PV systems must inject energy at a power factor of one. The integration of photovoltaic systems elevates connection point voltage and introduces nonlinearity. Reactive electricity from photovoltaic systems (PVs) may influence connection voltage. To equilibrate demand, generate reactive power in proximity to demand, enhancing the capacity of network conductors and transformers [10]. Power electronics loads are used to enhance power quality, nevertheless their disadvantages [10]. This study will address and resolve the following challenges. All mitigating devices will use VSC. Small-scale distributed generation (DG) units mostly consist of photovoltaic (PV) systems. This thesis use DER, DG, and PV interchangeably.

2.1. UNIFIED POWER QUALITY CONDITIONER (UPQC)

The idea of the Unified Power Flow Controller is shown in Figure 1.7. The hybrid system comprises a DSTATCOM and a DVR interconnected by a DC bus. UPQC is a multifunctional device capable of injecting current in parallel and voltage in series under a dual control mode. It can adjust due to its regulation of voltage and workload. The UPQC, similar to the DSTATCOM and DVR, may generate distorted voltages and currents.

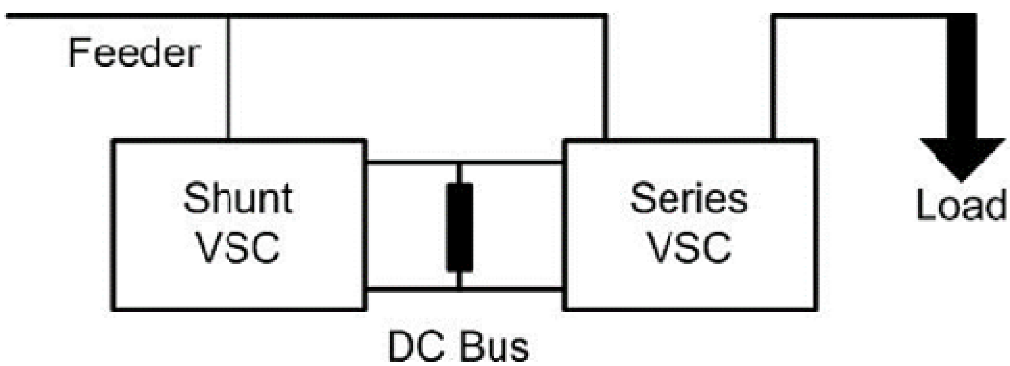


Fig. 1: Schematic diagram of UPQC

3. CONFIGURATION OF SYSTEM INTEGRATED WITH UPQC

Figure 3.1 illustrates the circuit design of the proposed grid-tied PV-battery-UPQC system. An MPPT Perturb and Observe (P&O) algorithm is used to get optimum power extraction from a photovoltaic (PV) system. This is achieved by using a boost converter with three-phase voltage source inverters (VSI) at the point of common coupling (PCC). The Voltage Source Inverter (VSI) employs six Insulated Gate Bipolar Transistors (IGBTs) as switching elements to regulate the power transfer between the utility and the DC-link. An AINN-based control strategy is used to optimize system performance. Figure 3.2 presents the flowchart that delineates the functioning of the grid-tied PV-battery UPQC system.

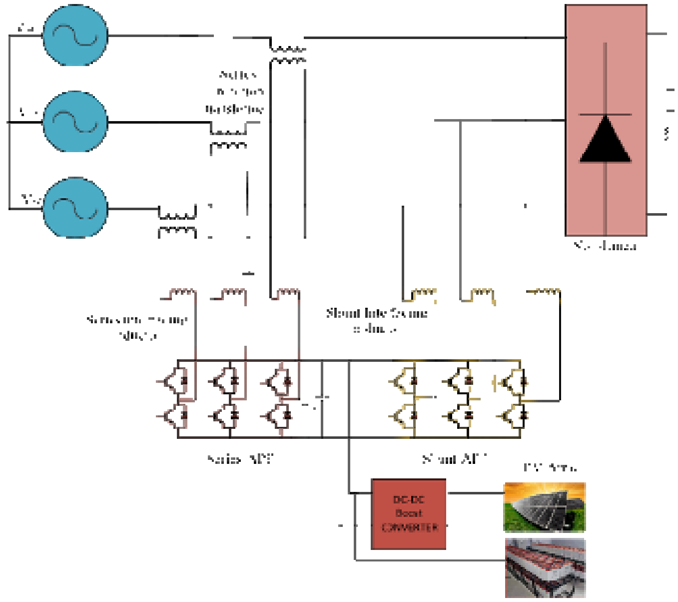


Figure 3.1. Block diagram of a system.

3.1. Maximum Power Point Tracking MPPT

Figure 3.3 depicts the non-linear voltage-current characteristics of a photovoltaic array, which are affected by solar radiation and temperature conditions. Therefore, it is essential to observe it at full capacity. Consequently, the Maximum Power Point Tracking (MPPT) method is used with a DC-DC converter to enhance the power extraction efficiency from the photovoltaic (PV) array. DC-DC converter topologies use many converters, including boost, buck, and buck-boost configurations. The boost converter has crucial importance since it efficiently inhibits reverse current flow into the PV Array [8]. The characteristics of a photovoltaic array, including Voc (open circuit voltage) and Isc (short circuit current), are affected by external factors like as irradiance and temperature. The output of the photovoltaic array is quantified by the duty cycle, which indicates the highest power point used to operate the boost converter. The PWM module produces a signal that controls the duty cycle of the IGBT switch. The system's inputs include the open-circuit voltage and the photovoltaic short-circuit current. The system's output is the duty cycle, which aligns with the reference voltage derived from the photovoltaic source.

Figure 3.2. Maximum Power Point tracking algorithm.

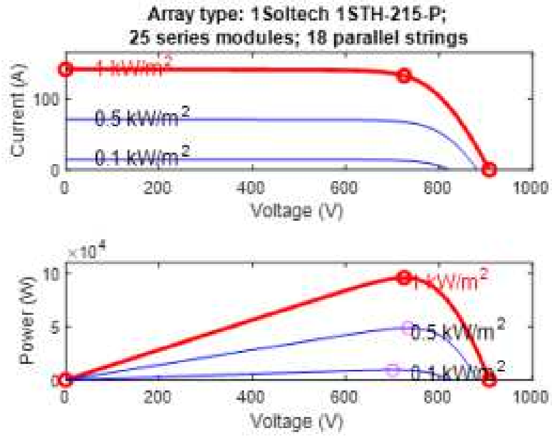


Figure 3.3. PV array current and voltage with different conditions of irradiation.

The graph above depicts the correlation among many parameters. It illustrates that the current is exactly proportional to the irradiation level, although the voltage is marginally affected by temperature conditions. A 100-kW photovoltaic (PV) system is used for the model simulations.

4. CONTROL ALGORITHM OF UPQC

4.1. Control Algorithm of UPQC Based on SRF

Multiple control approaches are used to create reference signals for current and voltage. The SRF approach is used to provide a rapid and temporary reaction [9].

A. Control Technique of Shunt Compensator

The shunt compensator is used to extract the active basic component of load current for load current compensation. The shunt compensator is operated using the SRF technique to achieve this. The synchronous basic d-q-0 frame is a time-domain method derived from the space vector transformations of three-phase systems. This method is appropriate for active filtering since it catches the fundamental of non-sinusoidal current, which can be used to calculate the compensatory current [1,2]. Figure 4.1 depicts the control methodology of the shunt compensator, whereby the load currents are transformed into the d-q-0 domain using frequency and phase information obtained from a phase-locked loop (PLL). The PCC voltage serves as the input to the PLL. The d-component is subjected to filtering to get a filtered DC component, regarded as a fundamental element inside the synchronous reference frame. A low pass filter is used to separate the fundamental component of the load current, Ifl.

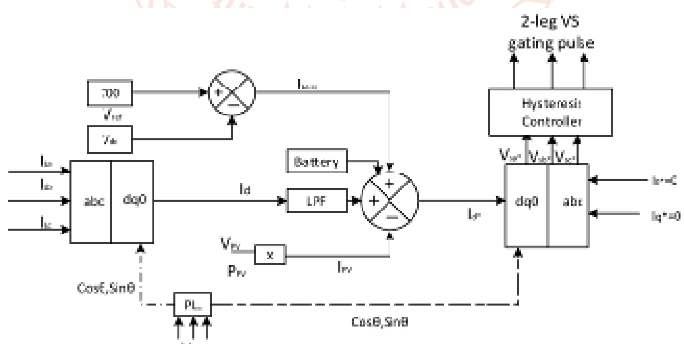


Figure 4.1. Conventional control strategy of PV-battery-shunt active power filter.

Figure 4.1 illustrates the control method of the shunt active power filter, which is based on the SRF synchronous reference frame. The shunt compensator optimizes the solar PV array's performance by operating it at its highest power point, so extracting the maximum power from it. The DC-link reference voltage for the PV-UPQC is established by the use of the maximum power point tracking (MPPT) technique. A PI controller is then utilized to maintain a constant voltage.

B. Control Technique of Series Compensator

The compensator injects phase voltages to minimize voltage harmonics, sag, and swell. Figure 4.2 illustrates the extraction of the PCC fundamental component and reference load voltages from the PLL via the use of phase and frequency data. The PCC and load voltage are transformed into the d-q-0 reference frame domain. Both are compared, with the peak load reference voltages being compared to the d-axis, while the q-axis component is set to zero. The discrepancy between the load voltage and PCC voltages determines the benchmark voltages for producing pulses via the PWM controller to activate and deactivate the IGBTs of the series compensator.

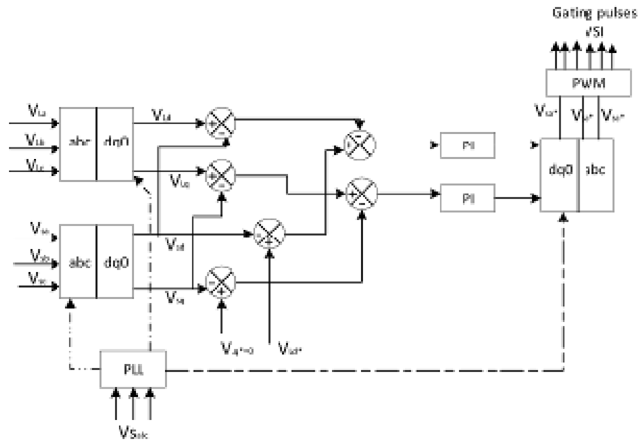


Figure 4.2. Conventional control strategy of series active power filter.

Figure 4.2 depicts the control method of the series active power filter, which is based on a synchronous reference frame (SRF). This text describes the control mechanism used in a series active power filter with SRF. The primary goal of the APF series is to alleviate the adverse effects of voltage harmonics, voltage imbalance, sag, and swell resulting from abrupt high loads and tripping.

4.2. Control Algorithm of UPQC Based on ANN

An advantageous aspect of the suggested approach is its lack of need for mathematical modeling, as well as the presence of a self-computing tool for training the ANN controller. The model may be trained using the input-output data of the system. The fundamental architecture of the Artificial Neural Network (ANN) is shown in Figure 4.3. The key advantage of the ANN controller is its capacity to acquire knowledge, adjust, compute the mean square error, and forecast the uncertainty necessary to minimize the discrepancy between the input and output. In addition, the ANN controller use the same technique to train both the shunt and series compensator. In order to compensate for UPQC, it is necessary for the controller's reaction to be both fast and precise. The ANN controller exhibits rapid and precise detection of a perturbed signal, as well as efficient processing of the reference signal. The SRF controller exhibits complexity and is less effective in handling non-linear load disturbances, while the ANN based controller demonstrates a rapid and dynamic reaction over a wide variety of operating conditions [17,18].

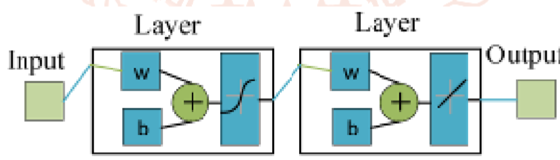


Figure 4.3. ANN structure.

The input layer of an Artificial Neural Network (ANN) receives all the inputs, which are then stored and processed in the hidden layer. In the hidden layer, the weights of the inputs are multiplied by the bias before being processed further. Once certain computations have been carried out, the outcomes are then processed and sent to the output layer. The data in an Artificial Neural Network (ANN) is processed concurrently, resulting in faster processing speeds compared to conventional systems [17]. ANN incorporates various learning principles and architectures to generate reference currents and voltages. The selected method for power electronic applications in this study is feed forward error back propagation. In this design, if the required output is not obtained, it diagnoses the mean square error and adjusts the weights both backward and forward until the desired output is attained and the error is erased.

- For creating and training the ANN model, the built-in command in MATLAB environment (nftool) is used, and its working is explained in Figure 4.4. Moreover the performance analyzed by looking at its mean square error and regression curve analysis.
- The network automatically sets by default based on the number of samples, 70% of samples for training, 15% for validation and 15% for testing.
- The size of the system can be selected according to the hidden layer selected for training the network. The number of neurons can be changed if the system does not perform well after training.

- The training will be continued until the generalization stops improving and the number of iterations has completed its desired epochs. It can be stopped by evaluating the mean square error; if it is small enough, then the user can stop it.
- After successful training the Simulink model can be created.

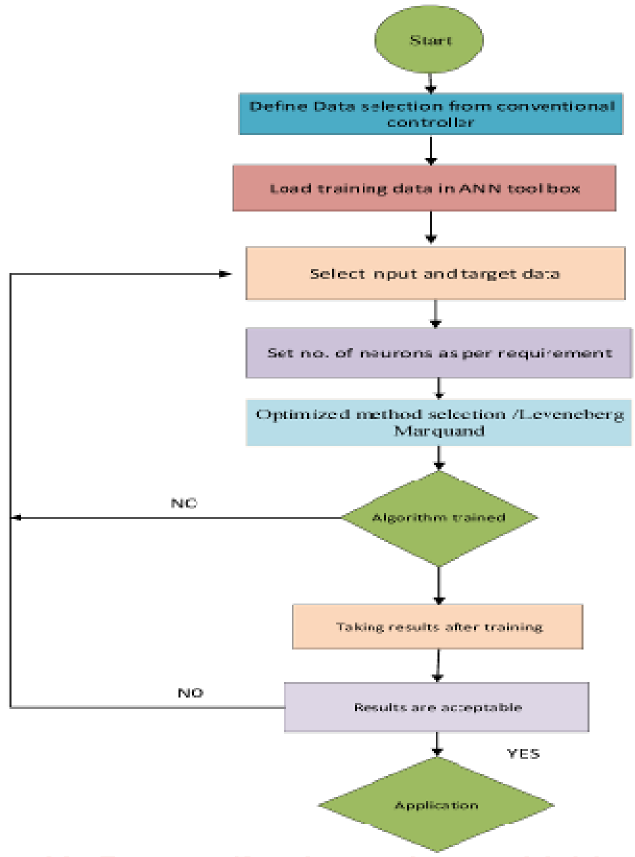


Figure 4.4. ANN training Algorithm.

5. SIMULATION RESULTS AND DISCUSSION

Figure 5.1 illustrates the configuration of the PV-Battery-UPQC system. The system is structured as a tripartite system. The PV-Battery-UPQC is comprised of a shunt active power filter and a series active power filter that are interconnected in a back-to-back configuration using a shared DC-bus. The system is configured so that the shunt Active Power Filter (APF) is linked to the load side, while the series APF is attached to the source side. Additionally, the Photovoltaic (PV) system and battery are directly connected to the Unified Power Quality Conditioner (UPQC) by a DC-link. The APF series operates in voltage control mode to mitigate voltage-related issues, such as sag/swell and shunt. The Active Power Filter (APF) is used in current control mode to address current-related issues, such as harmonics and unbalancing, and mitigate their effects. The shunt and series components are linked to the grid by the use of connecting inductors. The series injected transformer is used to inject the necessary compensating voltage to mitigate voltage issues in the grid. A bridge rectifier is used as a non-linear load.

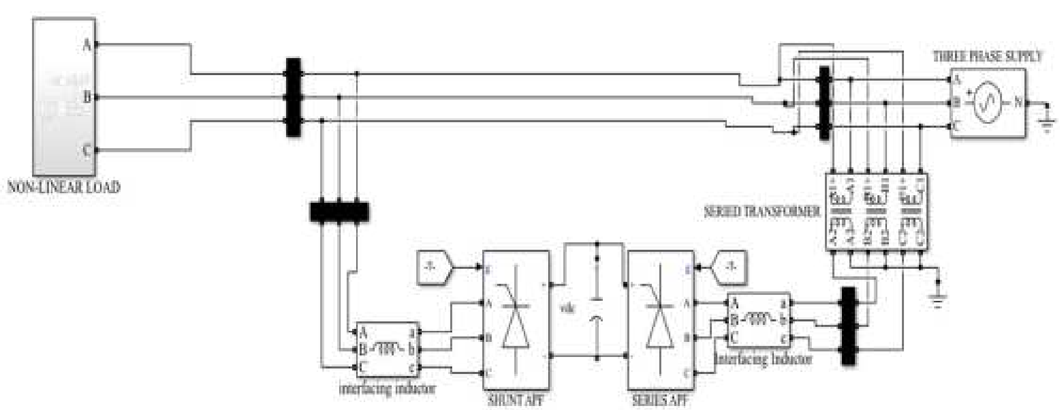


Figure 5.1 MATLAB Simulink Model.

The performance of both compared techniques is discussed and the parameters of PV are taken as standard condition of temperature and irradiation (1000 Wm^2/,25° C).

The system is evaluated based on both balanced and unbalanced non-linear circumstances. The findings are shown below, along with the Total Harmonic Distortion (THD).

A. AT LOAD UNBALANCED CONDITIONS

Non-linear loads alter the parameters of a system. These non-linear loads generate sudden and short bursts of current, as seen in Figure 5.2a, occurring at certain time intervals such as t = 0.45 to 0.5, 0.7 to 0.75, and so on. These sudden bursts of energy disturb the patterns of electrical currents, causing additional frequencies that might potentially impact the functioning of the equipment in the load and distribution system. Figure 5.2a illustrates a phase imbalance resulting from a discrepancy in the supply voltage, which has the potential to damage costly equipment. Furthermore, Figure 5.2b illustrates the occurrence of supply voltage sag and swell. A voltage sag is defined as a decrease in RMS voltage of 10% or more below the acceptable use level. Voltage swell refers to a situation when the root mean square (RMS) voltage exceeds the permitted limit by 10%. The UPQC device is required to rectify voltage sag and swell of up to 30% as seen in Figure 5.2b. Figure 5.2b depicts instances of voltage swell and sag in the power supply.

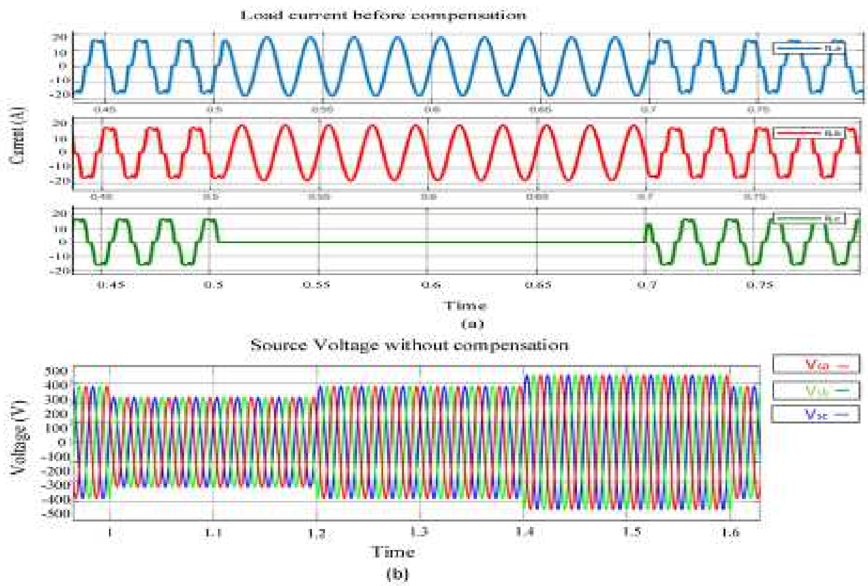


Fig. 5.2: (a) Load current before compensation, (b) source voltage without compensation.

B. AT UNBALANCED MITIGATION

Figure 5.2a clearly demonstrates that phase C experiences a complete loss of voltage from t = 0.5 s to t = 0.7 s as a result of a discrepancy in the supplied voltage. This results in a deviation from regular functioning of the whole system. To address the issue of phase unbalancing and provide smoother operation, the UPQC compensation has been built using SRF and ANN control approaches. Figure 5.3 illustrates the outcome achieved via the use of both strategies, demonstrating the transformation of phase C into a sinusoidal waveform. Both the SRF and ANN approaches effectively address phase unbalancing, although the SRF controller exhibits slower response compared to ANN. Figure 5.3 illustrates the mitigation achieved using UPQC compensation.

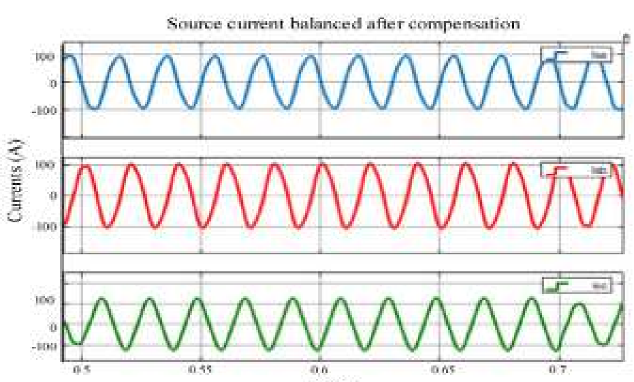


Fig. 5.3: Load unbalanced mitigation after UPQC compensation.

C. AT SAG CONDITION

The PV-battery based UPQC's performance is evaluated using the suggested ANN control approach under a distorted voltage supply with a voltage sag of 30%. Figure 5.4a illustrates the duration of the sag, which occurs between t = 1 s and t = 1.2 s. The supply voltages fall from 415 V to 280 V. Figure 5.4b demonstrates the effective reduction of the ANN converter for the desired voltage sag, while still maintaining the necessary sinusoidal voltage waveform for a consistent and uninterrupted power supply. The UPQC based ANN device facilitates all of these processes. Figure 5.4d clearly demonstrates that the suggested UPQC approach successfully reduces the presence of harmonics. The findings indicate a more consistent and sinusoidal pattern for both the source current and load voltage.

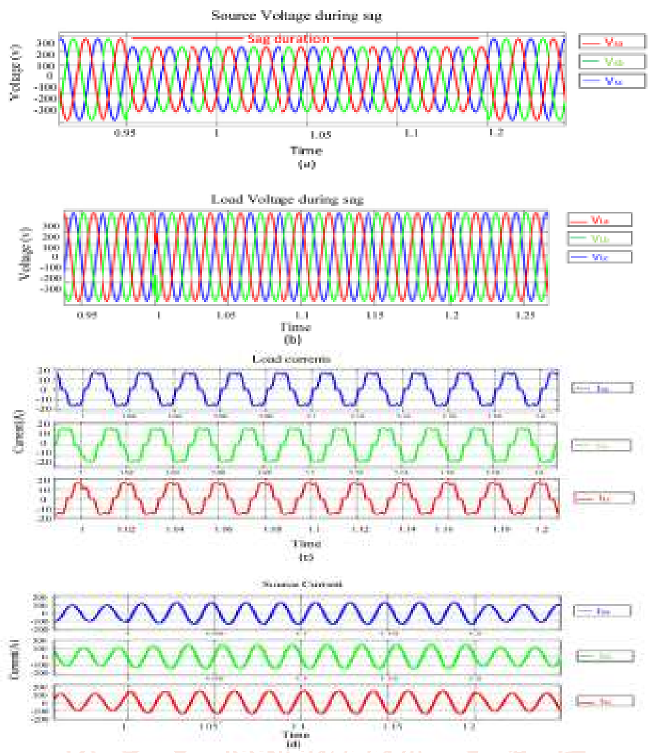
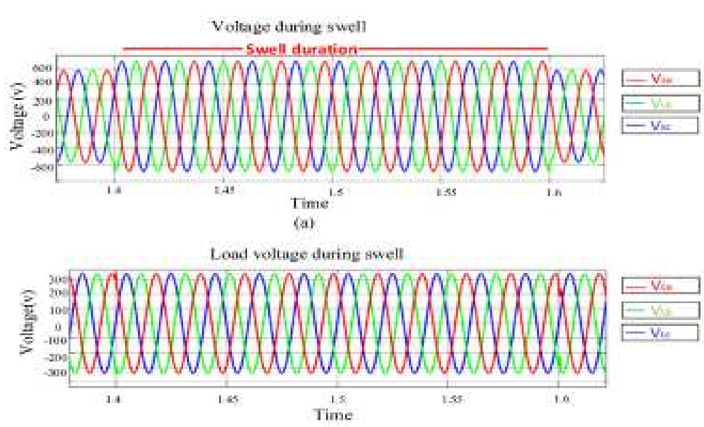


Fig. 5.4: (a) supply voltages, (b) load voltages, (c) load currents, (d) source currents after UPQC compensation.

D. AT SWELL CONDITION

The performance of the PV-battery-UPQC with the suggested ANN control approach is evaluated in the presence of a distorted voltage supply and a 30% voltage swell. Figure 5.5a illustrates the duration of the swell, which ranges from t = 1.4 s to t = 1.6 s. The supply voltage has increased from 415 V to 615 V. In this scenario, the series converter utilizes the dc-link capacitor to occupy and prevent the increase in voltage. Figure 5.5b demonstrates that the ANN-based UPQC effectively mitigates the increased voltage swell needed for correction and maintains the sinusoidal voltage waveform. This situation leads to a reduction in the current pulled from the power line by the shunt converter, which is utilized for compensating reactive power in the power supply. Figure 5.5d contains this information.



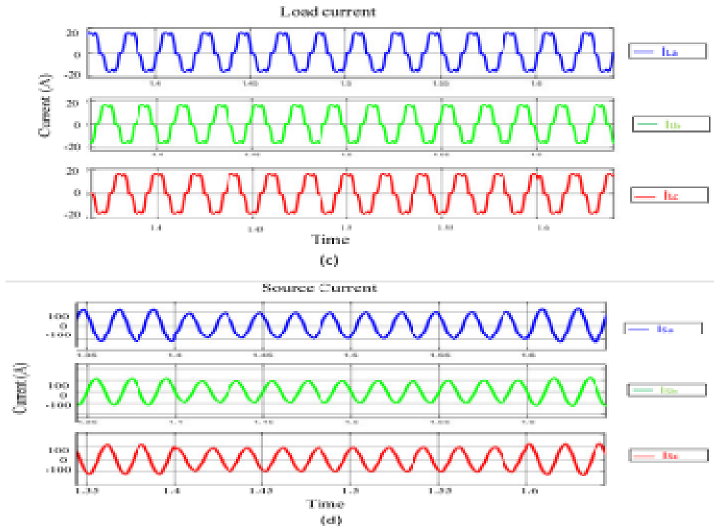


Fig. 5.5: (a) Supply voltages (b) load voltages (c) load currents, before UPQC compensation (d) source currents, after UPQC compensation.

E. INJECTED VOLTAGE OF SERIES CONVERTER

The ANN based series converter is capable of adjusting the voltage from the line in response to voltage fluctuations (sag and swell) in the supply voltage. This adjustment ensures that the load voltage remains sinusoidal and also helps reduce harmonics on the load side. Figure 5.6a shows that the magnitude supplied by the series converter is influenced by the magnitude of the distorted voltage from its fundamental component. Figure 5.6a illustrates the voltage supplied by the series converter during the sag.

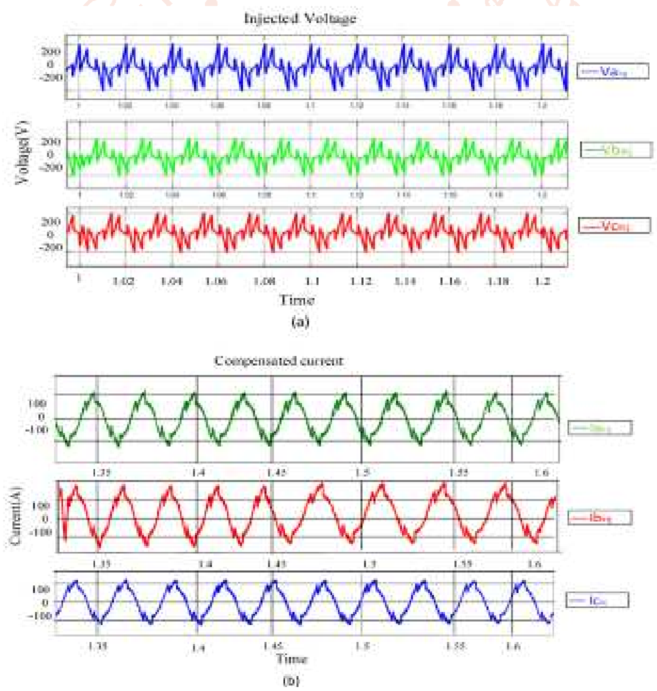


Fig. 5.6: (a) Injected voltage (b) Compensated current.

F. INJECTED CURRENT OF SHUNT CONVERTER

The ANN-based shunt converter provides current in a phase that counteracts the harmonics generated by unbalanced and non-linear loads in the load currents. As a result, compensation of the supply currents is necessary. The quantity of current supplied by the shunt converter is directly influenced by the size of the distorted current originating from its basic component. Figure 5.6b demonstrates the use of a shunt converter to provide reactive currents for compensating the supply current.

G. VOLTAGE BALANCING OF CAPACITOR

Ensuring a consistent direct current (dc) connectivity is the primary focus of UPQC. This study investigates and compares the control strategies of ANN (Artificial Neural Network) and SRF (Sliding-Mode Repetitive Control) for the purpose of balancing the dc-link voltage, as well as generating reference current and voltage signals.

Figure 5.7 vividly displays the comparison between the ANN and SRF dc-link voltage. The SRF controller, which is based on the dc-link voltage, is shown in Figure 5.7a.

There is a significant overshoot of around 1.15 volts before the system reaches its steady-state. Additionally, the response of the SRF based controller shows a high level of volatility and variance. However, an Artificial Neural Network (ANN) controller exhibits a quicker rising time. The ultimate output is achieved in a mere 0.09 seconds, exhibiting a minimal delay time, absence of overshoot, and no discernible variation. In artificial neural networks (ANN), the voltage across a capacitor achieves its steady-state more quickly compared to the self-resonant frequency (SRF). During the sag and swell correction in the SRF approach, it is seen that the magnitude of the dc-link voltage undergoes several fluctuations. It is evident that the suggested ANN controller operates well.

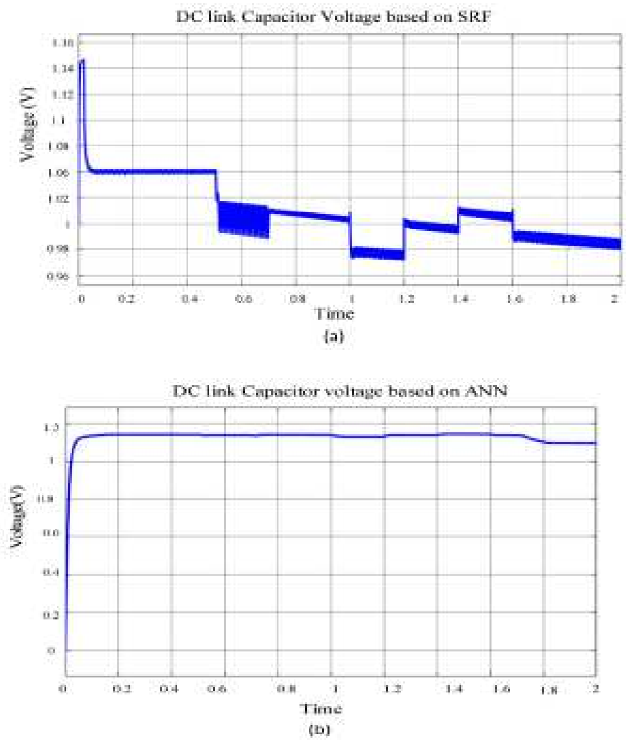


Fig. 5.7: (a) SRF based DC link capacitor voltage, (b) ANN based DC link Capacitor voltage.

H. TOTAL HARMONIC DISTORTION

Table 1 displays the representation of THD using SRF and ANN controller approaches. It has been observed that in both ways, the amount of Total Harmonic Distortion (THD) has fallen and reduced. The ANN controller has effectively minimized the excessive Total Harmonic Distortion (THD) in both current and voltage parameters, surpassing the performance of the SRF controller. Furthermore, Table 2 presents a dynamic comparison of both control approaches.

Table 1. Comparison between conventional UPQC using SRF based control and ANN controller.

[illegible]		Fundamental Component		% THD	
		Before	After	Before	After
SRF Source voltage	B	342.1	342	14.27	5.56
	R	342.6	340	15.5	5.56
	G	341.7	[illegible]	15.4	5.6
SRF Supply currents	B	16.59	106.6	24.2	8.84
	R	17.22	107.5	24.1	8.84
	G	15.43	105.4	24.1	8.1
ANN source voltage	B	[illegible]	[illegible]	14.77	0.72
	R	342.3	338	15.5	0.71
	G	341.7	[illegible]	15.4	0.71
ANN supply currents	B	16.68	94.73	23.76	2.67
	R	17.22	101.2	23.4	2.86
	G	15.43	102.2	22.8	2.67

Table 2. Comparison between SRF based controller and ANN based controller.

Features	UPQC (Based on SRF Controller)	UPQC (Based on ANN Controller)
%THD	[illegible]	[illegible]
Complexity	High	Low
Process of Controlling	slower	Fast
Dynamic response	Low level	High Level
Accuracy	Low Level	High Level

6. CONCLUSION

The ANN controller based on PV-battery-UPQC is evaluated in conditions of distorted supply voltage, non-linear and unbalanced loads, and a renewable energy system. ANN-based PV-battery UPQCs effectively rectify load voltage and source current harmonics while mitigating voltage sag and swell. The ANN approach enhances the capacitor's reaction, expediting compensation for current unbalance and more precisely diminishing harmonics. In comparison to synchronous reference frame (SRF) management, the proposed technique significantly reduced total harmonic distortion (THD). The artificial neural network (ANN) approach obviates mathematical computations. Consequently, DSPs and FPGAs are nonessential for the implementation of control schemes, thereby reducing system cost and complexity. Microcontrollers need compact memory to implement the prescribed control mechanism. The integration of photovoltaic batteries with UPQC enhances power quality and provides essential energy to the grid and linked loads. Artificial Neural Networks (ANN) surpass Simple Random Forest (SRF) in research efficacy. The system's operation is modeled using MATLAB/Simulink. The ANN control approach achieves enhanced control, elimination of current harmonics, reduction of voltage fluctuations, compliance with IEEE standards for %THD reduction, and enhancement of power quality. ANN surpassed SRF in all these areas. Under dynamic situations, the suggested controller exhibits strong performance in both steady-state and transient scenarios. This novel approach has also circumvented the substantial expenses associated with the prior technique. This system may undergo testing and be evolved into a real-time prototype.

REFERENCES

[1] J. Rodriguez-Herrejon, E. Reyes-Archundia, J. A. Gutierrez-Gnecchi, J. Olivares-Rojas, and A. Méndez-Patiño, "Analysis by traveling waves for a protection scheme of transmission lines with a UPFC," IEEE Lat. Am. Trans., vol. 22, no. 1, pp. 46–54, 2024.

[2] N. Mazibuko, K. T. Akindeji, and K. Moloi, "Perfomance comparison of Machine Learning (ML) based fault detection scheme for a compensated transmission line," in 2024 IEEE PES/IAS PowerAfrica, 2024, pp. 1–5.

[3] D. P. Chinta, V. S. Sasapu, D. V. R. Poduri, S. Somarouthu, N. Kishor, and M. Biswal, "Cyber resilient differential protection scheme for transmission lines," in 2023 IEEE 3rd International Conference on Smart Technologies for Power, Energy and Control (STPEC), 2023, pp. 1–4.

[4] A. Saini, K. Yatendra, and A. Verma, "Comparative analysis of FACTS device in the transmission line network on the zonal protection," in 2023 3rd International Conference on Intelligent Technologies (CONIT), 2023, pp. 1–5.

[5] M. O. Donovan, N. Barry, and J. Connell, "Distance protection of transmission lines connected to inverter-based resources," in 2023 58th International Universities Power Engineering Conference (UPEC), 2023, pp. 1–6.

[6] Hongchuan Li; Bin Li; Zhongge Luo; Hang Li; Yu Zhao "Power Supply Reliability Enhancement for Low-Voltage Distribution Area With Power Quality Improvement Function" 2022 IEEE Access (Volume: 10).

[7] Sisir Kumar Yadav; Ashish Patel; Hitesh Datt Mathur "Study on Comparison of Power Losses Between UPQC and UPQC-DG" IEEE Transactions on Industry Applications (Volume: 58, Issue: 6, Nov.-Dec. 2022).

[8] Ch. Rami Reddy; A. Giri Prasad; D. Chandra Sekhar; B. Srikanth Goud; K. Kumari; M. Dilip Kumar "Voltage Sag and Swell Compensation in Integrated System using Advanced UPQC" 2021 International Conference on Decision Aid Sciences and Application (DASA).

[9] Dinesh Mahendra Matlani; Mehul D Solanki "UPQC: An Exhaustive Solution to Improve Power Quality" 2020 4th International Conference on Electronics, Communication and Aerospace Technology (ICECA).

[10] Maheswar Prasad Behera; Omkar Tripathy; Pravat Kumar Ray "UPQC based Grid-Connected Photovoltaic System with Fuzzy Logic Controller" IEEE 3rd International Conference on Energy, Power and Environment: Towards Clean Energy Technologies 2020.

[11] Nirav Karelia; Amit Vilas Sant; Vivek Pandya "Comparison of UPQC Topologies for Power Quality Enhancement in Grid Integrated Renewable Energy Sources" IEEE 16th India Council International Conference (INDICON) 2019.

[12] Mahmood T. Alkhayyat; Sinan M. Bash "Reduce the Impact of Voltage Sag with Phase Jumping in AC Line Using Unified Power Quality Conditioners UPQC and Open UPQC" 2nd International Conference on Electrical, Communication, Computer, Power and Control Engineering (ICECCPCE) 2019.

[13] Ashish Patel; Hitesh Datt Mathur; Surekha Bhanot "Improving Performance of UPQC-DG for Compensation of Unbalanced Loads" 8th IEEE India International Conference on Power Electronics (IICPE) 2018.

[14] Santanu Kumar Dash; Pravat Kumar Ray "Investigation on the performance of PV-UPQC under distorted current and voltage conditions" 5th International Conference on Renewable Energy: Generation and Applications (ICREGA) 2018.

[15] Shilpa M Devaraddi; P. Sandhya "Harmonie mitigation in multi feeders by using MC-UPQC system with the predictive ANN & SVM" International Conference On Smart Technologies For Smart Nation (SmartTechCon) 2017.

[16] Nikhil S. Borse; Suhas M. Shembekar "Power quality improvement using dual topology of UPQC" International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC) 2016.

[17] Anup Kumar Panda; Nishant Patnaik; Ranjeeta Patel "Power quality enhancement with PAC-SRF based single phase UPQC under non-ideal source voltage" Annual IEEE India Conference (INDICON) 2015.

[18] Arpit Agrawal; Pramod Agarwal; Premalata Jena " Compensation of voltage flicker using Unified Power Quality Conditioner (UPQC)" IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) 2014.

[19] Chao-Shun Chen; Chia-Hung Lin; Wei-Lin Hsieh; Cheng-Ting Hsu and Te-Tien Ku, "Enhancement of PV Penetration With DSTATCOM in Taipower Distribution System," *IEEE Transactions on Power Systems,* vol.28, no.2, pp.1560-1567, 2013.

[20] P Jahangiri and D.C Aliprantis, "Distributed Volt/VAr Control by PV Inverters," *IEEE Transactions on Power Systems*, vol.28, no.3, pp.3429- 3439, 2013.

[21] A. Navarro; L.F Ochoa; D. Randles, "Monte Carlo-based assessment of PV impacts on real UK low voltage networks," *IEEE Power and Energy Society General Meeting (PES)*, 2013, pp.1-5.

[22] M.J.E Alam, K.M Muttaqi. and D Sutanto, "Effectiveness of traditional mitigation strategies for neutral current and voltage problems under high penetration of rooftop PV," *IEEE Power and Energy Society General Meeting (PES),* 2013, vol., no., pp.1,5, 21-25 July 2013

[23] Liu Xiaohu; A. Aichhorn,; Liu Liming and Li Hui, "Coordinated Control of Distributed Energy Storage System With Tap Changer Transformers for Voltage Rise Mitigation Under High Photovoltaic Penetration," *IEEE Transactions on Smart Grid, vol.3, no.2, pp.897-906*, June 2012.

[24] Yan Ruifeng and T.K.Saha, "Voltage Variation Sensitivity Analysis for Unbalanced Distribution Networks Due to Photovoltaic Power Fluctuations," *IEEE Transactions on Power Systems*, vol.27, no.2, pp.1078-1089, 2012.

[25] M. J E Alam; K.M Muttaqi and D Sutanto, "A comprehensive assessment tool for solar PV impacts on low voltage three phase distribution networks," 2nd International Conference on the Developments in Renewable Energy Technology (ICDRET), 2012, pp.1-5.

[26] Lin Chia-Hung; Hsieh Wei-Lin; Chen Chao-Shun; Hsu Cheng-Ting; Ku Te-Tien,

"Optimization of Photovoltaic Penetration in Distribution Systems Considering Annual Duration Curve of Solar Irradiation," *IEEE Transactions on Power Systems*, vol.27, no.2, pp.1090-1097, 2012.

[27] S.A Pourmousavi; A. S Cifala and M.H Nehrir, "Impact of high penetration of PV generation on frequency and voltage in a distribution feeder," *North American Power Symposium (NAPS)*, 2012, pp.1-8.

[28] M.H Hairi; Qi Shaofan; Li Haiyu and D.Randles, "Impact of PV generation on low voltage networks," *47th International Universities Power Engineering Conference (UPEC)*, 2012., pp.1-5.

[29] R Tonkoski; D Turcotte and T. H M EL-Fouly, "Impact of High PV Penetration on Voltage Profiles in Residential Neighborhoods," *IEEE Transactions on Sustainable Energy*, vol.3, no.3, pp.518-527, July 2012.

[30] R. Tonkoski; L. A C Lopes; T. H M and EL-Fouly,, "Coordinated Active Power Curtailment of Grid Connected PV Inverters for Overvoltage Prevention," *IEEE Transactions on Sustainable Energy,* vol.2, no.2, pp.139-147, 2011