www.ijbar.org
ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

DESIGN AND ANALYSIS OF ANN BASED CENTRALIZED CONTROLLER FOR ON GRID HYBRID RENEWABLE ENERGY SYSTEM.

N.Harsha Vardhan[1], N.Ganesh[2], P.Ramya[3], P.Deepika[4], Dr.Ch.Ranga Rao[5]
1,2,3,4 UG Students, Department of Electrical and Electronics Engineering
5, Associate Professor, Department of Electrical and Electronics Engineering
R.V.R& J.C College of Engineering, Chowdavaram, Guntur (Dt), AP, India.
harshavardhannirujogi@gmail.com, ganeshnaradasu@gmail.com, ramyapujala2003@gmail.com, deepikapanthagani89@gmail.com, chegudi.rangarao@gmail.com

ABSTRACT: Microgrid sources such as solar photovoltaic (PV) and wind power play a vital role in modern electricity generation. However, their dependency on weather conditions results in intermittent energy production, leading to fluctuations in power output. These variations place significant demands on energy transmission and distribution systems to maintain stability and ensure reliable operation. This paper presents a novel smart grid application that enhances power system performance by integrating a Static Compensator (STATCOM) to improve power quality, optimize power flow, mitigate harmonic distortions, and provide reactive power compensation.

The proposed solution incorporates a quasi-Z-Source Inverter (qZSI)-based STATCOM within a Three-Phase Four-Wire (3P4W) distribution system. This compensator circuit integrates a qZSI with a PV system to enhance switching capabilities. To regulate the compensator, an Adaptive Frequency Fixed (AFF) Second Order Generalized Integrator (SOGI) is employed. While Fuzzy Logic Control (FLC) has traditionally been used to optimize the Proportional-Integral (PI) controller gains, this paper introduces a Hybrid Artificial Neural Network (ANN)-based Fractional Order Controller optimization approach. Experimental findings indicate that the Hybrid ANN-based Fractional Order Controller significantly improves dynamic performance and accuracy compared to FLC. The proposed system successfully reduces the Total Harmonic Distortion (THD) of the source current to 0.68%, outperforming the 3.01% achieved with FLC. Furthermore, it efficiently supplies active power to the load, demonstrating the Hybrid ANN-based Fractional Order Controller's enhanced control precision and adaptability in modern smart grid applications.

Key Words: PV, STATCOM, Quasi Z Source Inverter, SOGI, FLC and ANN

I. Introduction

In the present day, Renewable Energy Sources (RES) are extensively employed to meet the increased power requirements of contemporary society. The utilisation of non-renewable energy sources is steadily diminishing as a result of the consequences of global warming and the adoption of RES. Renewable Energy Sources (RES) are regarded as crucial energy resources for meeting the electricity needs in distant and secluded regions. In the current state of economic progress, RES offer a clean, cost-effective, and reliable energy supply to the intended system. The benefits of RES include being environmentally benign and having unlimited potential. The various categories of RES include tidal power, solar energy, wind power, biomass energy, hydroelectric power, and geothermal energy. Additionally, photovoltaic (PV) systems offer other advantages such as noiselessness, absence of fuel expenses, strong reliability, and ease of installation.

In addition to this, a cost-efficient solution has been implemented in rural areas where the construction has been integrated with an extensive gearbox system. The primary limitation of the Renewable Energy System (RES) is mostly contingent on the topological state of specific locations, resulting in erratic outputs. Furthermore, a solitary RES is insufficient to meet the total energy requirements of the load. Therefore, a consistent power supply can be achieved by combining two or more RES into a single unit. Thus, a dependable, adaptable, and economical Energy Management System (EMS) has been developed by combining the modular power-generating and storage devices known as hybrid systems. The primary obstacles encountered in the RES-based EMS are the ubiquitous presence and environmentally favourable nature of wind and solar energy. Nevertheless, the aforementioned solutions proved inadequate in delivering uninterrupted power to the system due to their erratic characteristics. The equilibrium between the photovoltaic (PV) source and the load is maintained by the battery storage in the EMS. However, the PV/Wind/battery-based system fails to meet the long-term energy demands due to its limited battery capacity. The EMS procedure is challenging because it involves the creation of constant variations in RES and varying loads.

The extensive integration of RES presents substantial obstacles to grid frequency regulation (FR) in upholding the stability and dependability of the power system. Energy storage systems (ESSs) are seen as a potential technology for providing FR services. They help maintain stability by balancing power supply and load demand. There has been extensive research on integrating energy storage devices with RES in order to mitigate grid frequency fluctuations. Researchers have explored different types of ESS technology for FR, including battery ESSs (BESSs), supercapacitors (SCs), superconducting magnetic energy storage (SMES), and flywheels. Nevertheless, a battery is defined by its low power and high energy density, which means that it has a negative effect with a rapid response at a momentary moment. Consequently, extensive research has been carried out on FR hybrid energy storage systems (HESSs), which involve combining batteries with high-power density devices including SCs, SMES, and flywheels.

To further enhance the efficiency and stability of the EMS, Artificial Neural Network (ANN)-based fractional order controllers have been introduced. ANN-based Fractional order controllers offer an intelligent and adaptive approach to managing RES by predicting energy generation patterns, optimizing energy storage utilization, and regulating grid frequency fluctuations. The ANN-based fractional order controller with EMS leverages historical and real-time data to improve power dispatch decisions, mitigate uncertainties, and enhance system responsiveness. By incorporating an ANN-based controller, the system can dynamically adjust to fluctuations in RES output and varying load demands, thus ensuring optimal energy distribution and reducing dependency on conventional grid stabilization techniques. ANN-based controllers significantly enhance the overall efficiency, resilience, and reliability of hybrid RES-based energy management systems, making them a promising solution for the future of sustainable energy integration.

a) Literature review

The authors, L. de Oliveira-Assis, P. García-Triviño, E. P. P. Soares-Ramos, R. Sarrias-Mena, C. A. García-Vázquez, C. E. Ugalde-Loo, and L. M. Fernández-Ramírez, discuss the need for research and development to enhance the technology [1] of charging stations for electric vehicles (EVs) in order to promote their widespread adoption. This research introduces a novel energy management system (EMS) for a hybrid electric vehicle (EV) charging station. The system is based on a Biogeography-Based Optimisation (BBO) algorithm and incorporates Z-source converters (ZSC) into medium voltage direct current (MVDC) grids. The EMS utilises the evolutionary Biogeography-Based Optimisation (BBO) algorithm to optimise a fitness function that defines the equivalent hydrogen consumption/generation. The charging station comprises a photovoltaic (PV) system, a local grid connection, two rapid charging units, and two energy storage systems (ESS): a battery energy storage (BES) and a complete hydrogen system with a fuel cell (FC), an electrolyser (LZ), and a hydrogen tank. By employing the BBO algorithm, the EMS effectively regulates the energy distribution between components to maintain power equilibrium in the system. This results in decreased hydrogen consumption and enhanced hydrogen generation efficiency [2]. The paper's primary contributions are the Energy Management System (EMS) and the charging station layout utilising ZSCs. The EMS's behaviour is showcased by connecting three electric vehicles to the charging station under varying levels of sun irradiation. Furthermore, the suggested EMS is contrasted with a less complex EMS to determine the most efficient approach for managing ESS in hybrid settings. The simulation results demonstrate that the suggested EMS provides a significant enhancement in the equivalent hydrogen consumption/generation compared to the less complex EMS. By implementing the suggested arrangement, the output voltage of the components can be increased to MVDC, while simultaneously minimising the number of power converters in comparison to other setups that lack ZSC.

S. Parthiban and V. Madhaiyan discuss the current issue of power quality and the challenges associated with the deployment of power electronic devices [3]. The voltage stabilisation of power distribution networks coupled with Photo Voltaic (PV) is crucial for ensuring the efficient functioning of all interconnected devices in the distribution system. Ensuring the stability of voltage levels is a significant obstacle when integrating photovoltaic (PV) systems into the power grid. Traditional devices like passive filters, series and shunt filters, synchronous condensers, etc. are not enough to solve the many issues related to power quality. The series compensator is employed to enhance voltage quality, while the shunt compensator is utilised to improve current quality. Furthermore, when both of these power quality issues are addressed at the same time, the device is employed in the distribution system referred to as Unified Active Power Filter (UAPF). The UAPF is fitted with a Z-source inverter (ZSI) in both the shunt and series compensator. This study focusses on the voltage and current issues related to power quality, namely voltage sag, voltage swell, and voltage and current distortion. It also involves simulating the UAPF device to mitigate these problems.

L. Ashok Kumar and V. Indragandhi present the Renewable energy sources, which are anticipated to be a viable substitute for traditional energy sources, might present novel issues when integrated into the power system [4]. Nevertheless, the power provided by renewable energy sources is inherently variable as a result of environmental conditions. The injection of wind power into an electric grid impacts electricity quality due to the fluctuating nature of the wind and the use of relatively new types of wind generators. The performance of the wind turbine and power quality are determined based on measurements and norms described in the IEC-61400 standard set by the International Electro-technical Commission. The power generated by a wind turbine when it is connected to the grid system is measured in terms of power quality. This includes active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and the electrical behaviour of switching operations. These measurements are conducted in accordance with national and international guidelines. The study unequivocally demonstrates the presence of a power quality issue resulting from the installation of a wind turbine connected to the grid. The suggested scheme involves the connection of a STATIC COMPENSATOR (STATCOM) FACTS device to a battery energy storage system (BESS) at a point of common coupling. This connection aims to mitigate power quality issues. The battery energy storage technology is incorporated to bolster the actual power source during unpredictable wind power variations. The control strategy of the FACTS Device (STATCOM) is simulated using MATLAB/SIMULINK in the power system block set to enhance the power quality of the grid-connected wind energy generation system [5]. The suggested technique aims to alleviate the main supply source from the reactive power requirements of both the load and the induction generator. Based on the findings we obtained, we have confirmed that the approach is both feasible and practical for the applications we investigated.

In their study, F. S. Ahmed, A. N. Hussain, and A. J. Ali examined the impact of using multiple sources of photovoltaic (PV) cells and batteries on the input dc link channel of a voltage source converter (VSC) for distribution STATCOM (DSTATCOM) [6]. They implemented a highly coordinated design on the input of a three-leg VSC for DSTATCOM to ensure a consistent voltage output over time, without any delays or interruptions in power. This was achieved through the control circuit and the DC to DC circuit, which boosted the output of the photovoltaic cells and performed a buck-boost operation on the battery. During periods of high solar radiation, the photovoltaic (PV) system generates electricity which is then provided to the three-leg voltage source converter (VSC) of the distribution static synchronous compensator (DSTATCOM) to compensate for power demand. Any excess power is stored in the battery for later use. The battery is discharged during nighttime or overcast days to ensure the long-term operation of the VSC DSTATCOM. Furthermore, the design incorporates a Star / Delta transformer to separate the three-leg VSC for DSTATCOM. This allows for the creation of a closed loop for zero sequence fundamental and the subsequent reduction of harmonics in the neutral current. The primary objective of employing DSTATCOM is to mitigate current source harmonics, rectify reactive currents, and neutralise ground currents at the point of common coupling (PCC). The technique employed to synchronise and manage the compensation process of DSTATCOM is known as the synchronous reference frame (SRF) algorithm.

The authors, K. Muthuvel and M. Vijayakumar, offer a description of a Quasi Z-source inverter (QZSI)-based unified power quality conditioner (UPQC) supported by solar photovoltaic (SPV) technology [7]. The purpose of this system is to improve power quality. The Unified Power Quality Conditioner (UPQC) is comprised of converters that are interconnected both in parallel and series. Parallel and series connections of active power filters (APFs) are a versatile method of specialised power circuitry used to mitigate current and voltage instabilities. The primary purposes of QZSI are to amplify the variable direct current (DC) voltage to a desired alternating current (AC) output voltage, minimise the required components, and mitigate harmonic distortion. The compensating function of the UPQC mostly depends on the control system utilised for generating the reference current and voltage. The suggested system utilises the enhanced second order generalised integrator (ESOGI) to extract the reference current of QZSI-UPQC. The proposed Unified Power Quality Conditioner (UPQC) incorporates a Solar Photovoltaic (SPV) system, which includes an energy storage unit. This unit is utilised to counterbalance prolonged disturbances in current and voltage, while also meeting the active power requirements of the electrical grid. The experimental findings validate that the SPV-supported QZSI-UPQC effectively produces grid currents with a total harmonic distortion (THD) of around 1.2%, hence enhancing the power efficiency of the interconnected SPV power distribution network

II. Proposed System Design

Power generators, such as solar systems and wind turbines, are widely utilized to effectively meet power demands, outperforming other energy sources due to their affordability and adaptability. This ensures that wind turbines can reliably supply both linear and non-linear energy needs. To enhance power quality within the distribution network, compensation circuits are implemented. Along with the distribution network, a STATCOM compensator incorporating a quasi-Z-Source Inverter (qZSI) is designed to address power quality issues at their source. The proposed compensator integrates the qZSI with the photovoltaic (PV) system into a single unit, utilizing STATCOM during switching. Figure 1 illustrates the STATCOM model based on qZSI.

The compensator is tasked with maintaining the voltage and frequency of the wind energy system within acceptable limits using the Adaptive Frequency Filtering Second-Order Generalized Integrator (AFF-SOGI) management approach. Additionally, this method mitigates the impact of inherent harmonics in the three-phase four-wire (3P4W) distribution system. The settings of the frequency controller are optimized using a fuzzy-tuned proportional-integral (PI) controller. This approach regulates power flow through the load by compensating for reactive power in the power sources and eliminating harmonics. Figure 2 presents the flow diagram outlining the setup of the PV-qZSI-STATCOM in different operational modes.

The PV-assisted qZSI-STATCOM operates in four distinct modes, utilizing coordinated control to provide quadrature zero-sequence injection static synchronous compensation. The first mode represents photovoltaic power generation, the second mode signifies battery backup, the third mode ensures continuous supply, and the fourth mode involves energy storage using flywheels. The status of power electronic switches (S1-S7) in each mode determines the operational state of the system.

A mode shift occurs in the control system under different conditions:

1. When the power demand of the load exceeds the power output of the photovoltaic (PV) system, the system transitions to this mode. The switch configurations are as follows: If the battery's State of Charge (SOC) is at or below 50%, S4 is activated; otherwise, S5 remains deactivated, while S6 and S7 are activated.

2. If the power output of the PV system drops below 10% of its peak power (PPV), the control mechanism switches to mode 2.

3. At a voltage value of zero (Vsabc = 0), mode 3 is activated with the following switch configurations: S1, S2, and S3 are turned on. If PPV is below 10%, S4 is turned on. S5 remains off, while S6 and S7 are turned on.

4. Mode 4 is triggered when the power generated by the wind energy system (Pwind) exceeds the power required by the load (PLoad). The system parameters are detailed in Table 1.

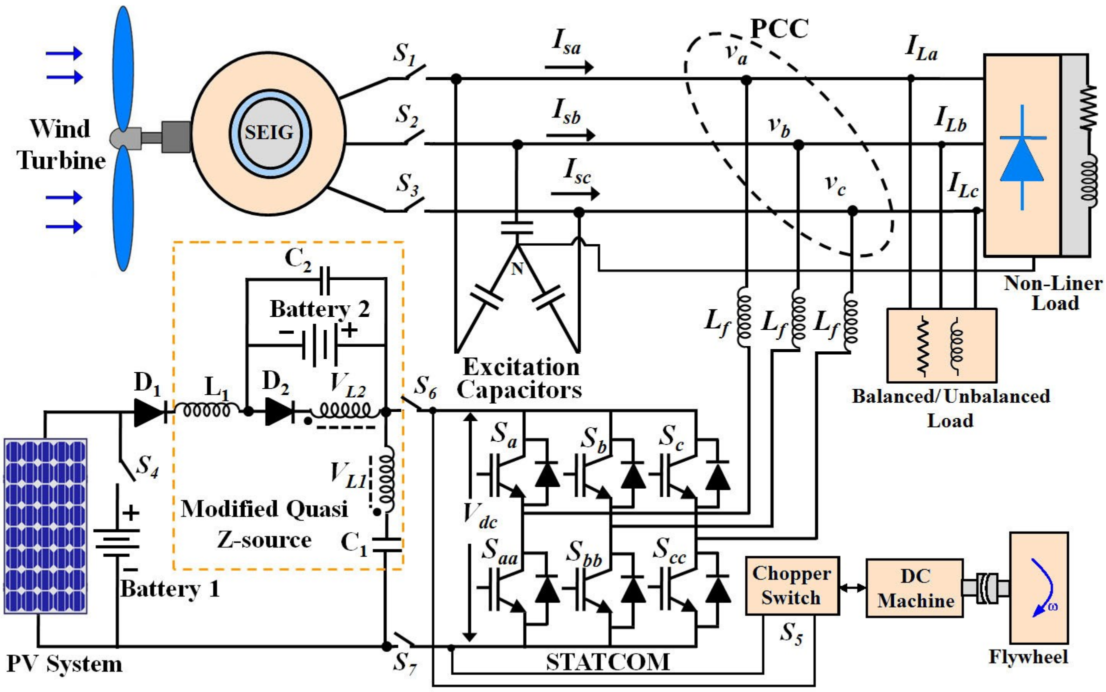

Figure 1 Integration of a qZSI-STATCOM with a wind energy conversion system.

Table-1 System parameters used

www.ijbar.org
ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

Symbol	Value	Description
V_{ph}	230V	System Voltage (Phase)
f	50Hz	System Frequency
L	26 mH	Filter Inductance
R	1.5Ω	Resistance
Ah	500Ah	battery capacity
PV_w	600 W	Power output of PV array
V_{PV}	72V	PV Nominal voltage
V_L / V_{Ph}	400 V/ 230 V	SEIG Voltage
P	4 kW	SEIG Power rating
N	1410 rpm	SEIG speed
kW	10 kW	Flywheel rated power
N_f	1500 rpm	Flywheel speed
D_f	500 mm	Diameter of Flywheel

When it comes to reactive power consumption from connected loads and harmonics, this qZSI-STATCOM control has you covered. The power grid's general dependability is greatly enhanced by this control mechanism. Also, even with distorted load currents or unbalanced voltages, the goal is to make certain the resulting grid currents have pure sinusoidal waveforms. In spite of uneven grid voltages and distorted load currents, the AFF-SOGI may be used to estimate sinusoidal reference grid currents. Figure 3 shows the qZSI-STATCOM control system, which is based upon the AFF-SOGI protocol. AFF-SOGI just takes into account the currents at the fundamental frequencies. The acronyms "ZCD," "S/H," and "Absolute" denote various circuit components.

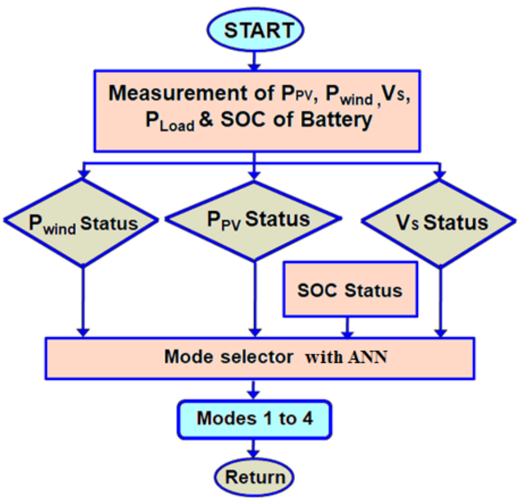

Figure 2 Flowchart for operating mode for the PV-qZSI-STATCOM.

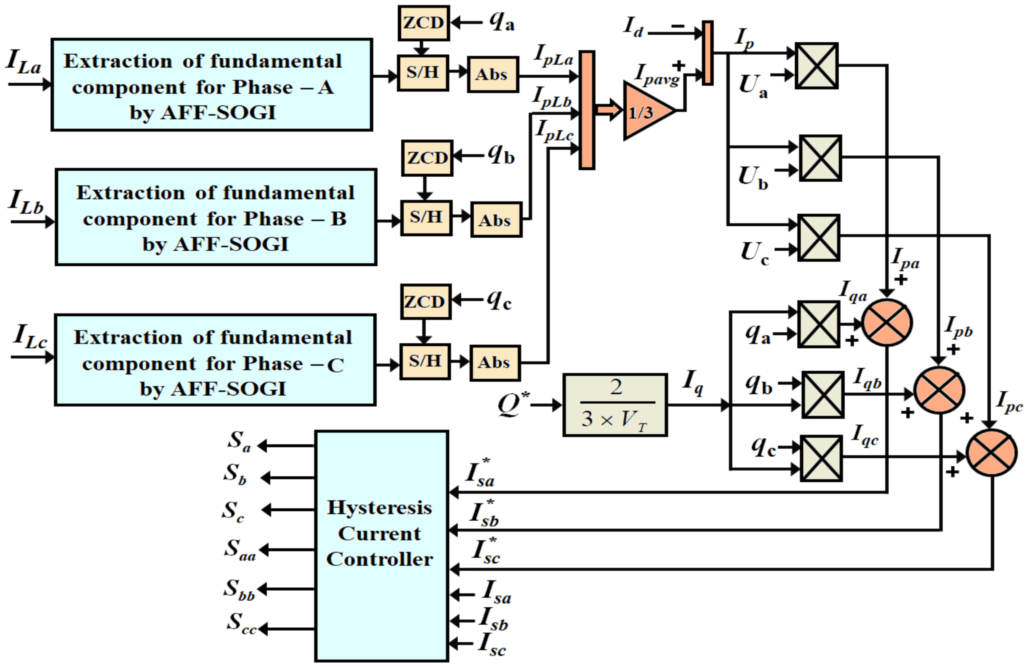

Figure 3 Control system representation

Fig 3 illustrates the AFF-SOGI control system used for the qZSI-STATCOM. The second frequency component can't generate those currents, thus they can't enter the circuit. That's how it works. All that's permitted instead is currents produced by the different frequency component. As a result, the source is only actively supplied with power by the system. In addition, the controller makes use of unit voltage vectors computed from the grid's positive sequence voltages. That way, the reference currents will be unaffected by voltage aberrations or imbalances on the grid.

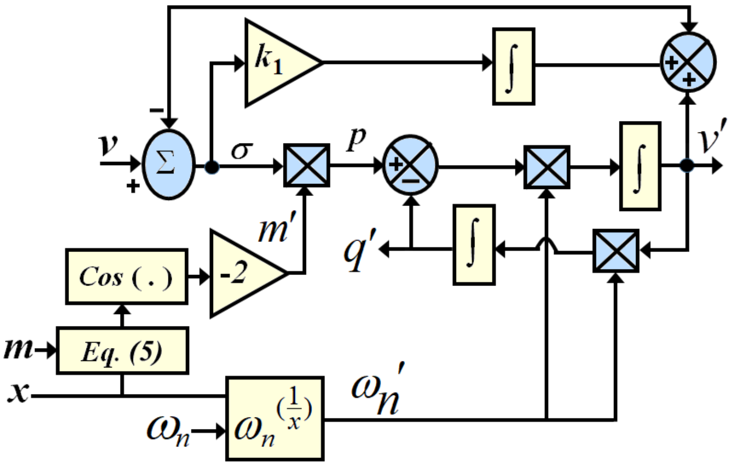

Figure 4 Internal composition of AFF-SOGI.

This approach, which is based on a SOGI algorithm that uses a fixed frequency, allows the main electric current to be effectively isolated by replacing the damping factor the resonant frequency by their fractional order equivalents. The AFF-SOGI's efficiency has been substantially improved by including a DC offset rejection loop. After completing this loop, any direct current offsets within the load current will no longer impact the basic current calculation. You can see the internal organization of the AFF-SOGI in Figure 4, which is a schematic showing the device.

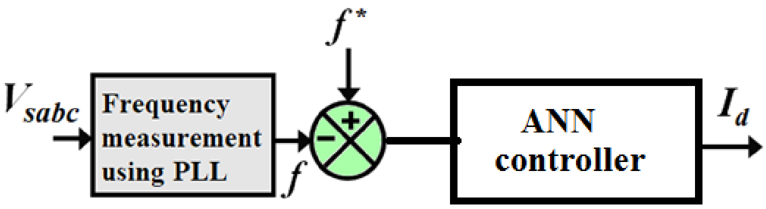

Figure 5 displays a frequency controller withANN

The Zero-Crossing Detector (ZCD) is used to find out whether a signal has gone negative or positive. In order to achieve synchronization, unit vectors are employed to express the grid voltage's phase & frequency. For vectors to remain undistorted, the distortion and imbalanced voltages must be unit-amplitude pure sinusoids.

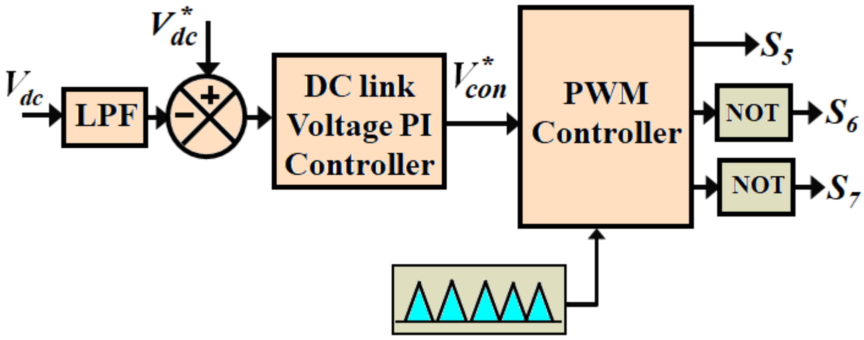

Figure 6 illustrates a controller for the DC link voltage.

This is accomplished by deriving the unit vectors using positive sequence voltages. A Phase Locked Loop (PLL) which accepts three-phase terminal voltages for input is used to calculate the system's frequency. This predicted frequency is compared to the standard frequency using an ANN-based controller, which then regulates the frequency error. By drawing active current, the compensating circuitry produces the frequency PI controller's output. Kpd stands for the proportional gain while Kid for the integral gain within the context that the frequency PI controller, respectively. It is possible to modify the PI controller's gain parameters using the ANN-based controller. A controller built around ANN is shown in Fig 5. A three-phase system's load needs are spread out evenly since the average active currents are high. In the event of voltage fluctuations or unequal load demands, the grid currents will maintain their balance. The qZSISTATCOM DC-link voltage controller appears in Fig 6.

III. Simulation Results

Scenario 1: Equally distributed non-linear loads under a consistent wind speed

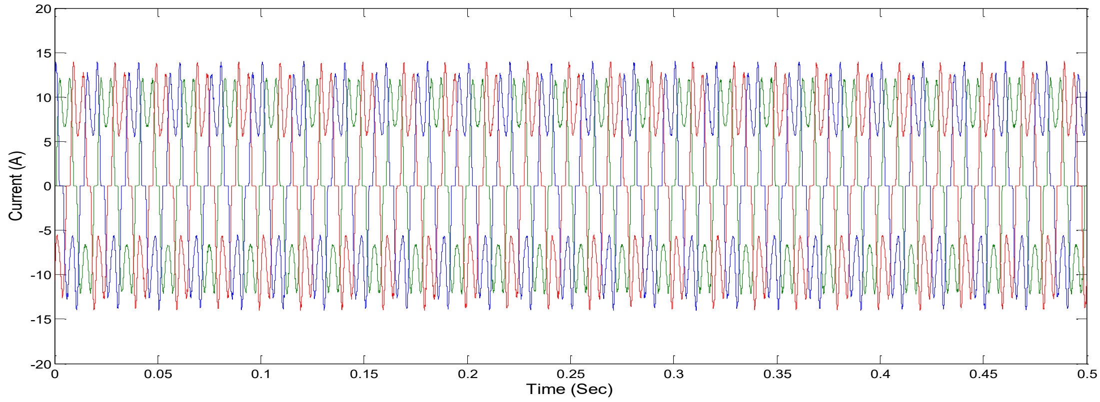

Figure 7 Currents of nonlinear loads in the proposed system.

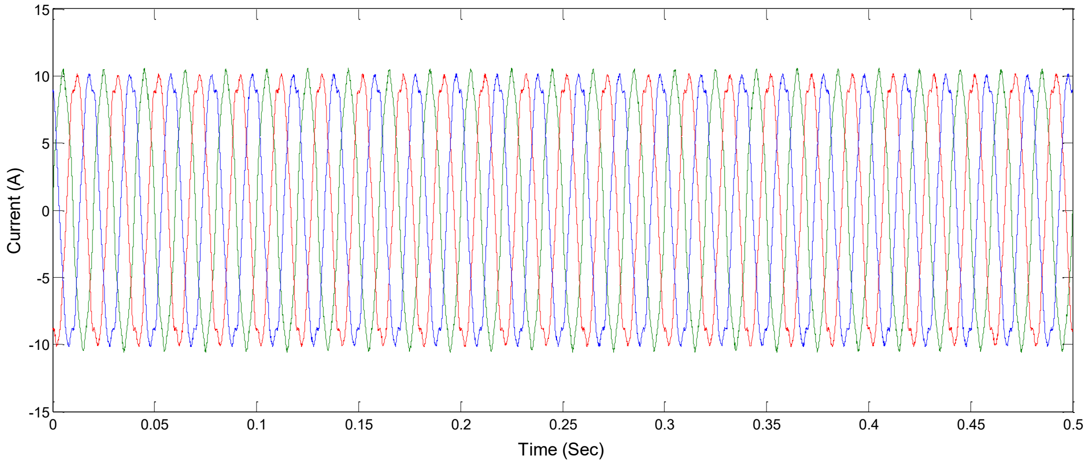

Figure 8 Currents of a balanced load in the proposed system.

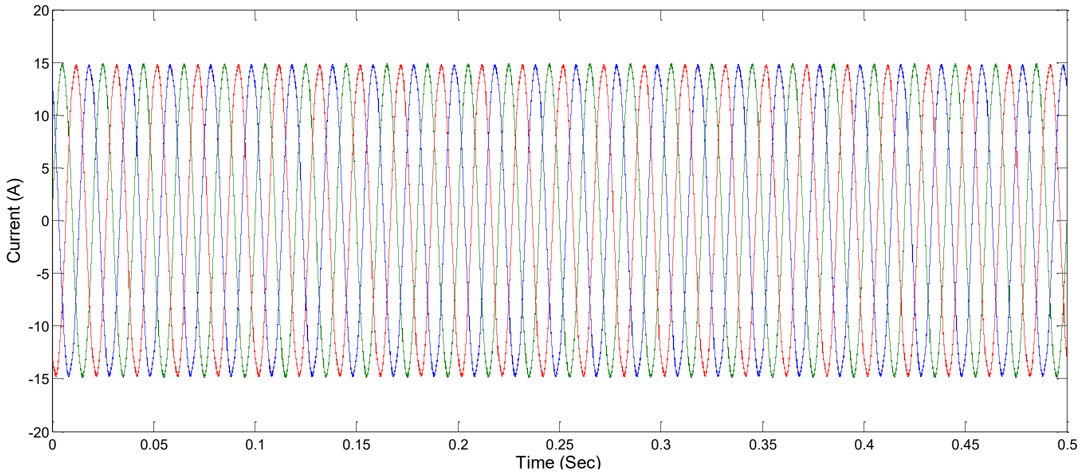

Figure 9 Source currents originating from the proposed system.

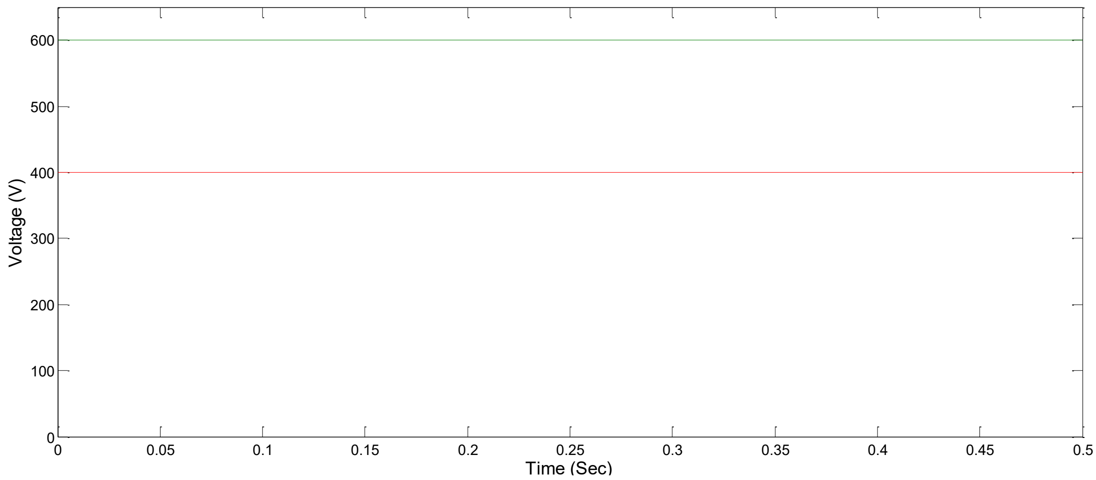

Figure 10 DC link (Vdc) and the voltage of the PV array (VPV) in the proposed system.

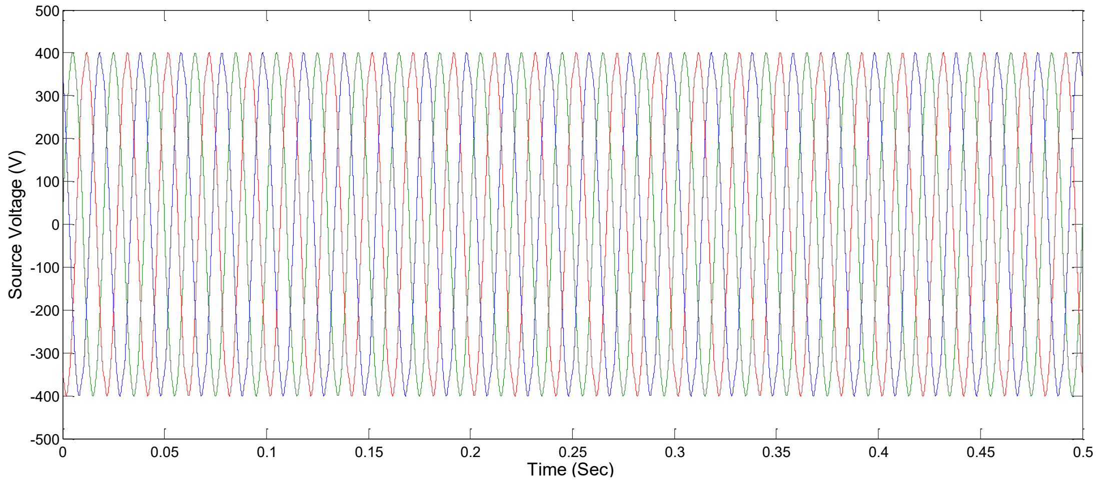

Figure 11 displays the source voltages of the proposed .

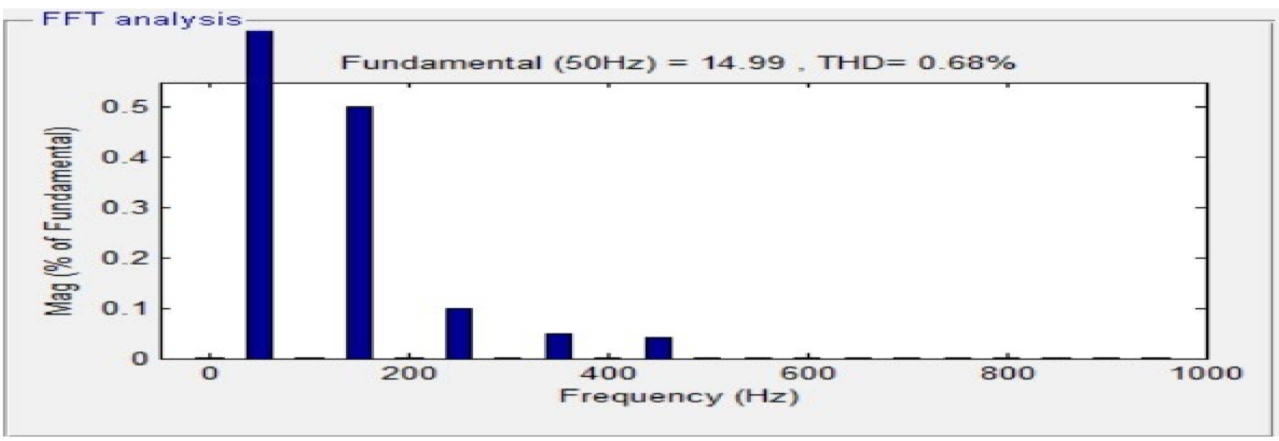

Figure 12 FFT analysis of Source current with ANN Controller

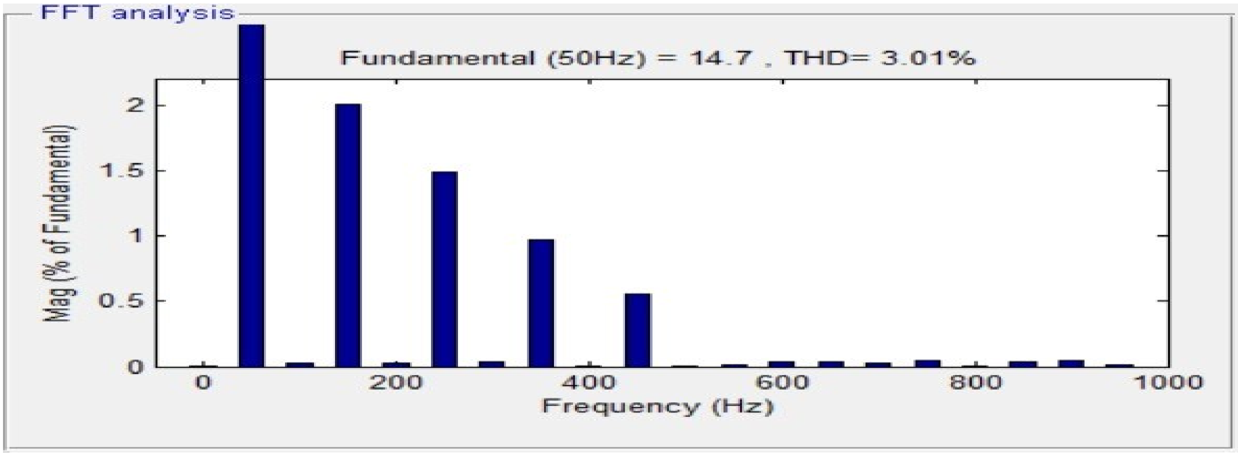

Figure 13 FFT analysis of Source current with fuzzy Controller

PV-STATCOM is assessed when the wind speed is constant and the non-linear loads are equalised. The compensatory experimental findings for Case 1 are displayed in Fig. 2, 3, and 4. The compensator circuit can be used to maintain a constant voltage and current, notwithstanding the impact of the non-linear balanced load. The experimental findings for the DC link voltage, PV array voltage, and source voltage and current are depicted in Figs 5 and 6.

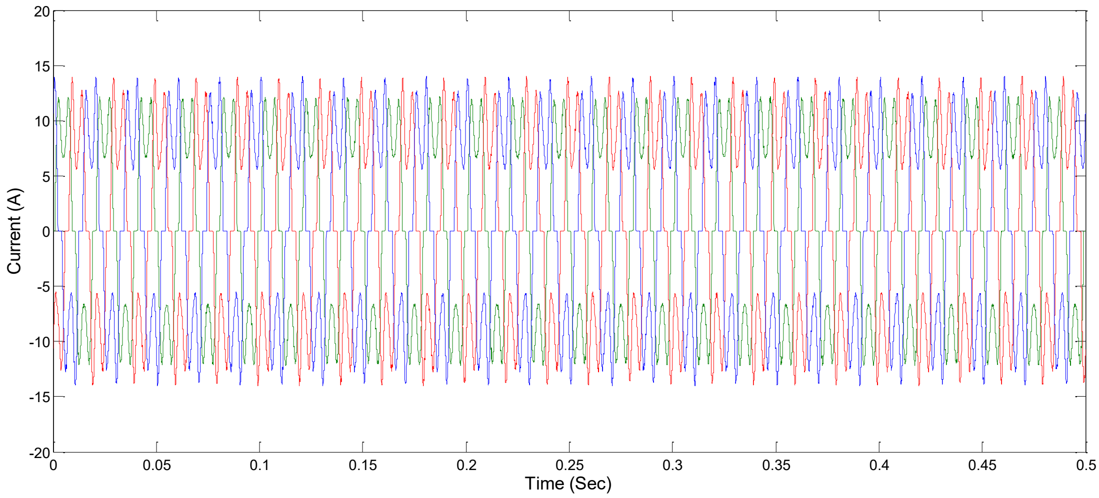

Figure 14 Currents of nonlinear loads in the extension system.

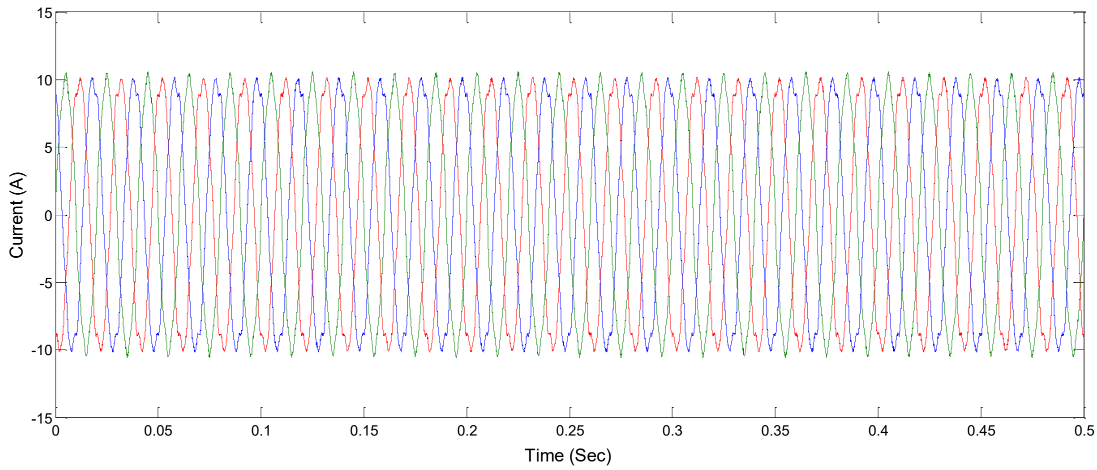

Figure 15 Currents of a balanced load in the extension system.

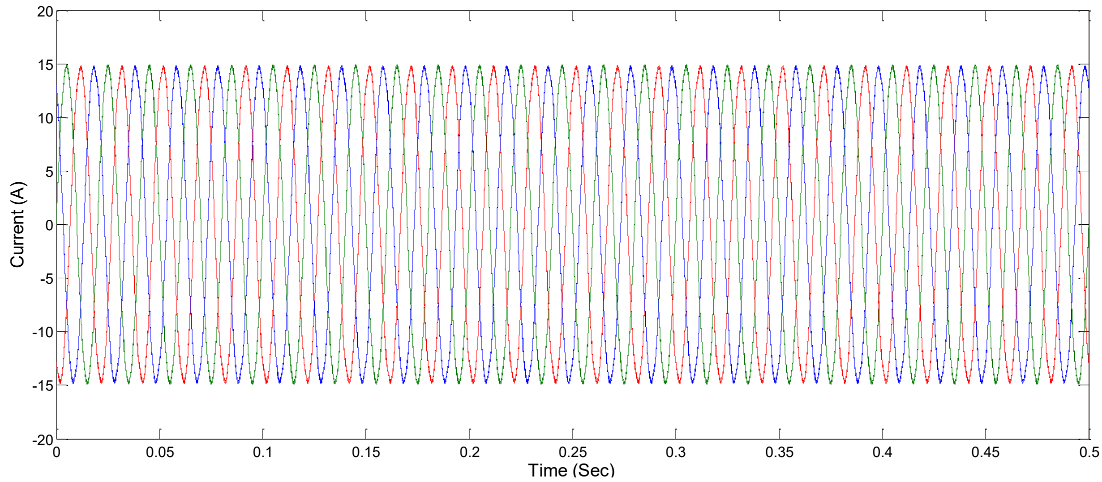

Figure 16 Source currents originating from the source in the Extension system.

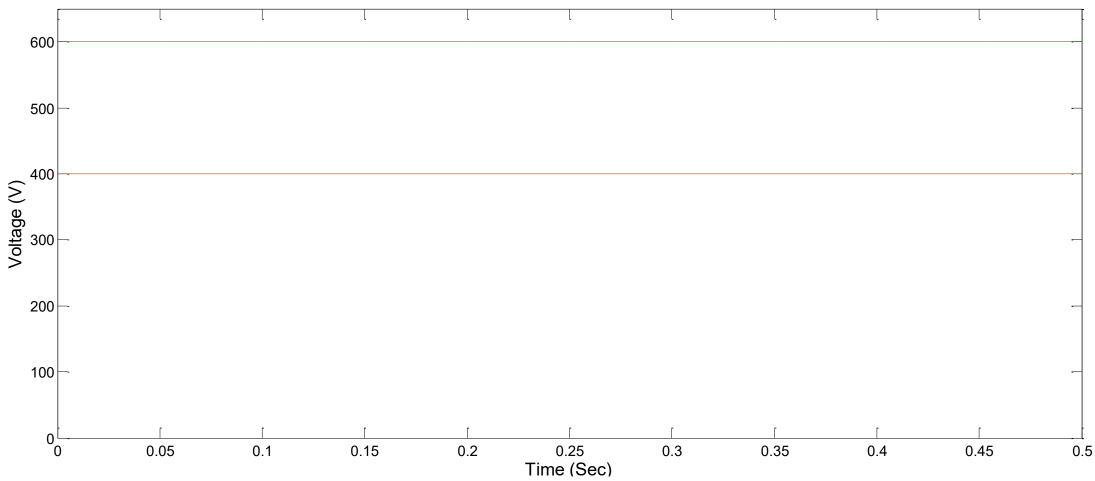

Figure 17 DC link (Vdc) and the voltage of the PV array (VPV) in the extension system.

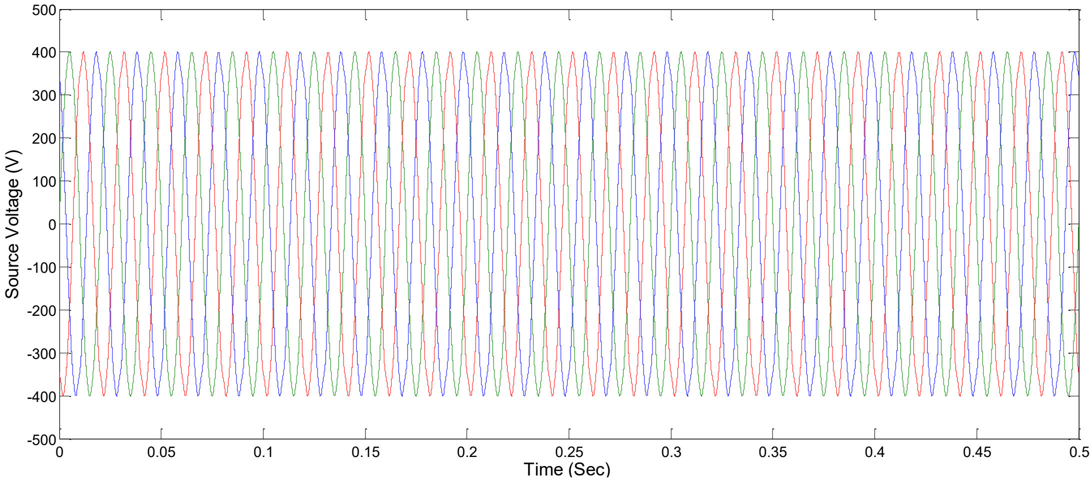

Figure 18 Voltages of the source in the Extension system.

Scenario 2: Imbalanced load currents affected by changing wind speed.

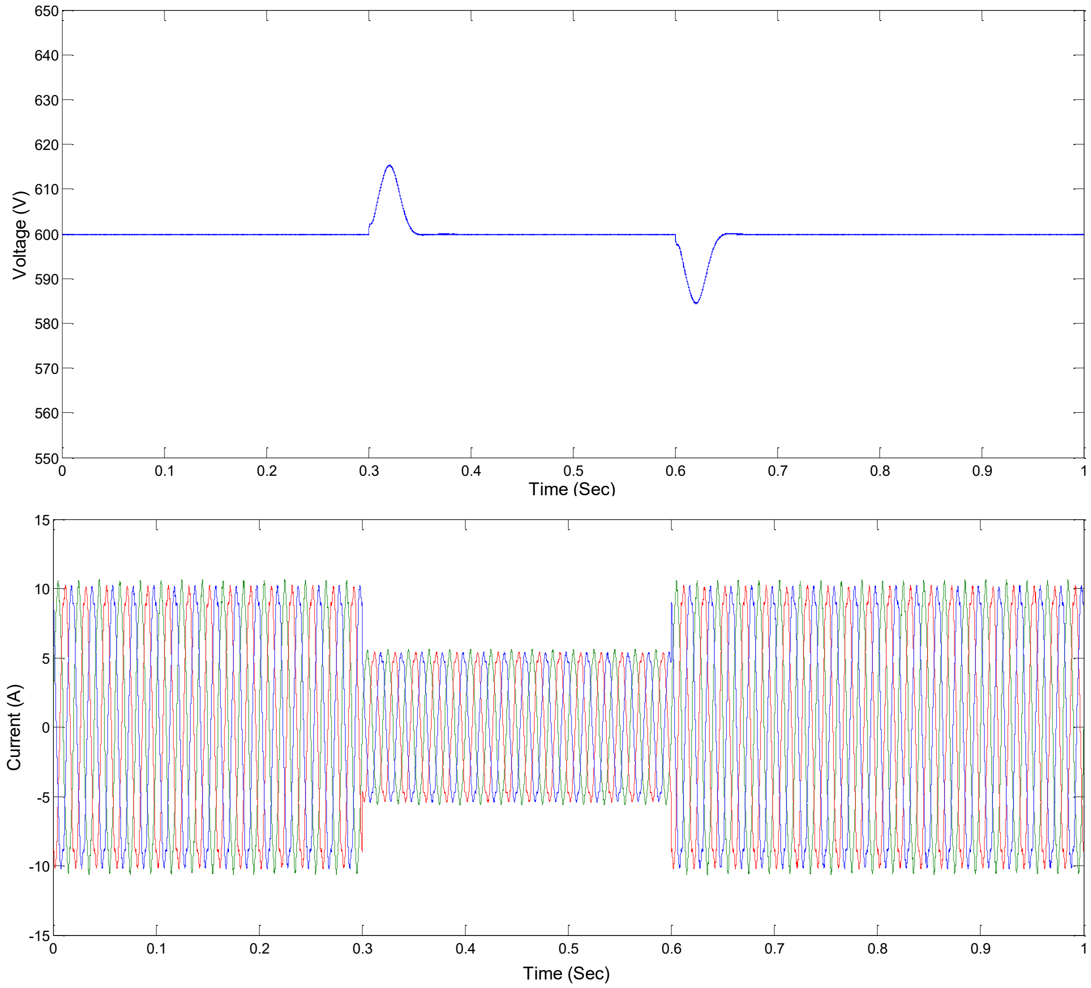

Figure 19 DC link voltage when there are sudden fluctuations in the load. (Suggested system)

The application of step loads yields the results depicted in Fig 12. When a nonlinear load is deactivated, the power that was previously supplied is transferred to the DC link until a new reference for the supply current is calculated based on the new load current.

www.ijbar.org
ISSN 2249-3352 (P) 2278-0505 (E)
Cosmos Impact Factor-5.86

Consequently, the voltage of the DC link surpasses the designated value. Upon switching the nonlinear load, the DC link voltage experiences a decrease of around 50 volts. The DC link voltage is regulated after a few power cycles in both situations.

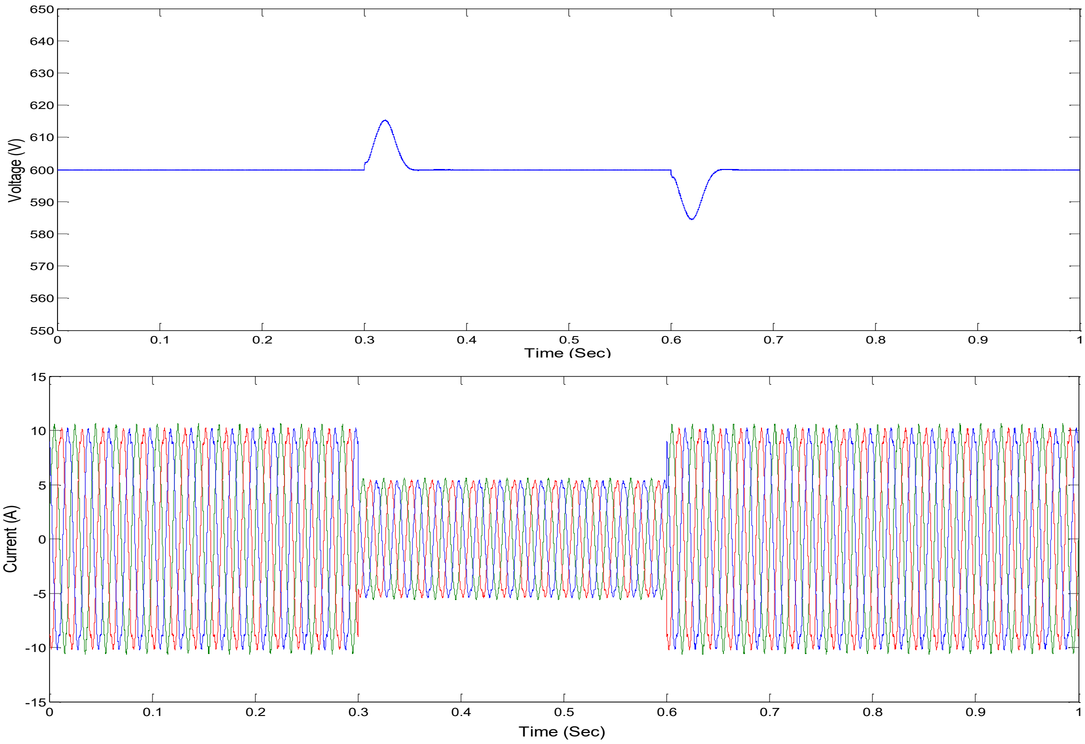

Fig 5.13 displays the direct current (DC) link voltage when there are sudden fluctuations in the load. The extension system

IV. Conclusion

Incorporating a Three-Phase Four-Wire (3P4W) distribution system with a STATCOM based on quasi-Z-Source Inverters (qZSIs) is a novel approach to enhancing grid power system operation. Solar photovoltaic (PV) and other renewable energy sources enable the system to effectively counteract variations in power output caused by weather conditions. The compensator is efficiently controlled using the proposed control strategy, which employs an Adaptive Frequency Fixed (AFF) Second Order Generalised Integrator (SOGI).

The traditional Fuzzy Logic Controller (FLC) is outperformed by a Hybrid Artificial Neural Network (ANN) based Fractional Order Controller when it comes to optimizing the parameters of the Proportional Integral (PI) controller. Experimental results demonstrated a significant reduction in Total Harmonic Distortion (THD) to 0.68% with the Hybrid ANN-based Fractional Order Controller, compared to 3.01% using FLC, emphasizing its superior performance. This hybrid approach enhances dynamic response, control precision, and adaptability in the system. These findings highlight the potential of Hybrid ANN-based Fractional Order Controllers for smart grid applications, leading to improved energy management in future power systems by enhancing power quality, stability, and active power delivery.

References

[1] L. de Oliveira-Assis, P. García-Triviño, E. P. P. Soares-Ramos, R. Sarrias-Mena, C. A. García-Vázquez, C. E. Ugalde-Loo, and L. M. Fernández-Ramírez, ''Optimal energy management system using biogeography based optimization for grid-connected MVDC microgrid with photovoltaic, hydrogen system, electric vehicles and Z-source converters,'' *Energy Convers. Manage.*, vol. 248, Nov. 2021, Art. no. 114808.

[2] S. Ouchen, A. Betka, S. Abdeddaim, and A. Menadi, ''Fuzzy-predictive direct power control implementation of a grid connected photovoltaic system, associated with an active power filter,'' *Energy Convers. Manage.*, vol. 122, pp. 515–525, Aug. 2016.

[3] P. Aree, ''Dynamic performance of self-excited induction generator with electronic load controller under starting of induction motor load,'' in *Proc.5th Int. Conf. Electr., Electron. Inf. Eng. (ICEEIE)*, Malang, Indonesia, Oct. 2017, pp. 21–24.

[4] A. B. Shitole, H. M. Suryawanshi, G. G. Talapur, S. Sathyan, M. S. Ballal, V. B. Borghate, M. R. Ramteke, and M. A. Chaudhari, ''Grid interfaced distributed generation system with modified current control loop using adaptive synchronization technique,'' *IEEE Trans. Ind. Informat.*, vol. 13, no. 5, pp. 2634–2644, Oct. 2017.

[5] H. Abu-Rub, A. Iqbal, S. M. Ahmed, F. Z. Peng, Y. Li, and G. Baoming, ''Quasi-Z-source inverter-based photovoltaic generation system with maximum power tracking control using ANFIS,'' *IEEE Trans. Sustain. Energy*, vol. 4, no. 1, pp. 11–20, Jan. 2013.

[6] J. Zhang, ''Unified control of Z-source grid-connected photovoltaic system with reactive power compensation and harmonics restraint: Design and application,'' *IET Renew. Power Gener.*, vol. 12, no. 4, pp. 422–429, Mar. 2018.

[7] J. G. Cintron-Rivera, Y. Li, S. Jiang, and F. Z. Peng, ''Quasi-Zsource inverter with energy storage for photovoltaic power generation systems,'' in *Proc. 26th Annu. IEEE Appl. Power Electron. Conf.Expo. (APEC)*, Fort Worth, TX, USA, Mar. 2011, pp. 401–406.

[8] N. Cheraghi Shirazi, A. Jannesari, and P. Torkzadeh, ''Self-start-up fully integrated DC–DC step-up converter using body biasing technique for energy harvesting applications,'' *AEU-Int. J. Electron. Commun.*, vol. 95, pp. 24–35, Oct. 2018..

[9] S. Parthiban and V. Madhaiyan, ''Experimental validation of solar PV sustained ZSI based unified active power filter for enrichment of power quality,'' *Automatika*, vol. 62, no. 1, pp. 137–153, Jan. 2021.

[10] M. Vijayakumar and S. Vijayan, ''PV based three-level NPC shunt active power filter with extended reference current generation method,'' *Int. J. Electr. Energy*, vol. 2, no. 4, pp. 258–267, 2014.

[11] M. Vijayakumar and S. Vijayan, ''A novel reference current generation method of PV based three level NPC shunt active power filter,'' *UPB Sci.Bull. C*, vol. 77, no. 3, pp. 235–250, 2015.

[12] A. K. K. Giri, S. R. Arya, R. Maurya, and B. C. Babu, ''Power quality improvement in stand-alone SEIG-based distributed generation system using Lorentzian norm adaptive filter,'' *IEEE Trans. Ind. Appl.*, vol. 54, no. 5, pp. 5256–5266, Sep. 2018.

[13] M. Ahmed, M. Orabi, S. Ghoneim, M. Alharthi, F. Salem, B. Alamri, and S. Mekhilef, ''Selective harmonic elimination method for unequal DC sources of multilevel inverters,'' *Automatika*, vol. 60, no. 4, pp. 378–384, Oct. 2019.

[14] K. Patil and H. H. Patel, ''Modified SOGI based shunt active power filter to tackle various grid voltage abnormalities,'' *Eng. Sci.Technol., Int. J.*, vol. 20, no. 5, pp. 1466–1474, Oct. 2017.

[15] B. Singh, S. Kumar, and C. Jain, ''Damped-SOGI-based control algorithm for solar PV power generating system,'' *IEEE Trans. Ind. Appl.*, vol. 53, no. 3, pp. 1780–1788, May/Jun. 2017.
[16] J. A. Barrado, R. Grino, and H. Valderrama-Blavi, ''Power-quality improvement of a stand-alone induction generator using a STATCOM with battery energy storage system,'' *IEEE Trans. Power Del.*, vol. 25, no. 4, pp. 2734–2741, Oct. 2010.
[17] F. U. Nazir, N. Kumar, B. C. Pal, B. Singh, and B. K. Panigrahi, ''Enhanced SOGI controller for weak grid integrated solar PV system,'' *IEEE Trans. Energy Convers.*, vol. 35, no. 3, pp. 1208–1217, Sep. 2020.
[18] S. Senguttuvan and M. Vijayakumar, ''Solar photovoltaic system interfaced shunt active power filter for enhancement of power quality in three-phase distribution system,'' *J. Circuits, Syst. Comput.*, vol. 27, no. 11, Oct. 2018, Art. no. 1850166.
[19] T. Jayakumar and A. A. Stonier, ''Implementation of solar PV system unified ZSI-based dynamic voltage restorer with U-SOGI control scheme for power quality improvement,'' *Automatika*, vol. 61, no. 3, pp. 371–387, Jul. 2020.
[20] M. Ghanaatian and S. Lotfifard, ''Control of flywheel energy storage systems in the presence of uncertainties,'' *IEEE Trans. Sustain. Energy*, vol. 10, no. 1, pp. 36–45, Jan. 2019.
[21] K. Muthuvel and M. Vijayakumar, ''Solar PV sustained quasi Z-source network-based unified power quality conditioner for enhancement of power quality,'' *Energies*, vol. 13, no. 10, p. 2657, May 2020.
[22] M. Hanif, M. Basu, and K. Gaughan, ''Understanding the operation of a Z-source inverter for photovoltaic application with a design example,'' *IET Power Electron.*, vol. 4, no. 3, pp. 278–287, 2011.
[23] *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*, IEEE Standard 519-2014 (Revision of IEEE Std519-1992), 2014, pp. 1–29.
[24] F. S. Ahmed, A. N. Hussain, and A. J. Ali, ''Power quality improvement by using multiple sources of PV and battery for DSTATCOM based on coordinated design,'' *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 745, no. 1, Feb. 2020, Art. no. 012025.
[25] L. Popavath and P. Kaliannan, ''Photovoltaic-STATCOM with low voltage ride through strategy and power quality enhancement in a grid integrated wind-PV system,'' *Electronics*, vol. 7, no. 4, p. 51, Apr. 2018.
[26] L. Ashok Kumar and V. Indragandhi, ''Power quality improvement of grid-connected wind energy system using facts devices,'' *Int.J. Ambient Energy*, vol. 41, no. 6, pp. 631–640, May 2020.