# Design and Implementation of a Hybrid Energy Storage Based Unified Power Quality Conditioner for Smart Grid Reliability Enhancement

**GUDISE HARITHA[1], M. Sirisha[2], S. Anusha[3]**
[1]Post Graduate Student, JNTUA College of Engineering, Anantapuram
[2]Assistant Professor (Adhoc), JNTUA College of Engineering, Anantapuram
[3]Assistant Professor (Adhoc), JNTUA College of Engineering, Anantapuram
[1]harithalucky13@gmail.com, [2]shirishamesa1031@gmail.com, [3]sankranthi.anusha2425@gmail.com

## Abstract:

This article focuses on SPV-UPQC circuit examination for various changed and lopsided weight conditions during power quality issues, such as voltage dips, voltage amplification, sporadic voltage attributes, and so on. This survey looks into the use of a Unified Power Quality Conditioner (UPQC) to alleviate power quality issues that arise when the BESS starts and delivers power, particularly during longer-term voltage interruptions. An autonomous PV-UPQC structure is less robust than a hybrid PV-BESS system due to its fragility and reliance on the environment. As a result, BESS will continuously increase voltage support capacity over time, simplify the computation of the DC-interface voltage rule, and continue to deliver clean energy. The UPQC controller's stage synchronization action is organized by a self-tuning channel (STF) based on the unit vector generator (UVG) methodology. Due to the execution of STF, the UPQC will have to work successfully under inconsistent and worn cross-section voltage conditions. As a result, the PLL is unnecessary, and the STF-UVG is used to create synchronization stages for the UPQC controller's series and shunt dynamic power channel (APF) compensators. Finally, to emphasize the significance of the proposed system, the proposed STF-UVG procedure is distinguished from the standard synchronous reference frame-phase-locked loop (SRF-PLL) technique-based UPQC. Different context-based examinations are also under consideration. The ANFIS (Adaptive Neuro-Fuzzy Inference System) control method may be superior to the PI (Proportional-Integral) cushioned reasoning-based control technique, and the simulation is executed using reenactment in MATLAB/Simulink.

**Keywords:** Battery energy storage system (BESS), power quality, self-tuning filter (STF), solar photovoltaic (PV), unified power quality conditioner (UPQC), ANFIS

## I. INTRODUCTION:

Solar photovoltaic (PV) frameworks have outperformed record establishments as of late [1], demonstrating that environmentally friendly power age is quickly advancing. Strategies for most extreme force point following (MPPT), which were as of late evaluated for instance in [2, 3], framework reenactments [4], and power electronic circuit geographies for dc-dc converters and inverters are altogether instances of PV-related writing. Sustainable power sources are innately unpredictable, and energy stockpiling may hypothetically be utilized to moderate related issues. PV incline rate control, in which the BESS charges or releases when the PV yield power slope rate surpasses preset restrictions assessed from irradiance information projections, is investigated in the writing. In ongoing many years, the expression "power quality" has gotten energetic reactions from researchers, especially in the electrical designing field. Energy proficiency is kept up with by amending for issues in power quality , guaranteeing smooth electrical energy age and empowering network decarburization. The idea of force quality can have an assortment of implications and translations depending on the climate and conditions. Because of force quality issues, power misfortunes, undesirable and abnormal attributes of gear can cause impedance in adjoining correspondence lines, just as disturbance to various purchasers. Force quality worries in framework associated miniature lattice frameworks can be separated into two classifications: utility-related PQ issues and client related PQ issues. Voltage list/expand, flash, indents, lopsided source, interference are utility-related PQ issues, while absolute symphonious mutilation (THD), unequal burden, receptive force interest, and slacking power factor are client related PQ issues [3-5]. Voltage drop is a significant PQ mutilation on the utility side, though consonant twisting is a genuine PQ contortion on the client side. These PQ mishapenings debase the effectiveness of the force framework organize and abbreviate the existence of the related gear. As indicated by new exploration, the UPQC is a practical custom force gadget that may be used

at the (PCC) to protect both the utility and the consumer against Power Quality distortion With a common DC connect capacitor, the UPQC gadget consolidates a series and shunt dynamic force channel (APF). The appropriate guideline of DC connect voltage decides the UPQC gadget's compensatory capacities. Long interferences and substantial voltage hang, on the other hand, weren't really taken into account in their investigation. The dynamic voltage rectifier (DVR) was also coupled to a superconductivity attractive energy stockpiling framework (SMES) to supply the heap throughout an extended timeframe, resolving the issue of extended interference [22]. In any case, the current issue with related sounds was not considered. In this example, an energy stockpiling framework, for example, BESS can be associated with the Photovoltaic-Unified Power Quality Conditioner and offer fantastic help for giving genuine capacity to the heap on a nonstop premise. BESS is most. The PV is associated with the DC-interface through a Direct Current -Direct Current support converter, while the BESS is connected by a DC-DC buck-help converter [23]. Battery energy storage system has a wide scope of uses, including energy stockpiling, exchange, voltage guideline, and recurrence guideline. By and large, the photovoltaic framework supplies dynamic power to the heap; however, when the PV framework can't do as such, the BESS initiates and gives power, especially during longer-term voltage interferences, to further develop the dispersion power framework's strength. PV-BESS is a predominant choice since it can support the DC connect capacitor of an UPQC remotely, decreasing the heap on the DC-interface capacitor. The guideline of DC connect voltage in average UPQC gadgets is cultivated utilizing a typical PI regulator. Under high voltage misfortune and dynamic working circumstances, the conventional PI regulator block requires a straight numerical recipe, which neglects to manage DC interface voltage [9-11]. Also, for every single working condition, a steady reference esteem is utilized to deal with the real DC connect voltage. Consistent reference DC lick voltage brought about an enormous force drop across the heap terminal during voltage drop conditions [12]. A versatile neuro fluffy deduction framework (ANFIS) is a useful asset that incorporates both fluffy framework and neural organization learning. Not at all like traditional regulator [13],. In the proposed work, ANFIS is prepared to work as reference DC interface voltage assessor and DC connect voltage regulator. The UPQC should be ready to play out the synchronization activity viably by infusing the voltage and current in stage with the framework. The vast majority of UPQC regulators are built with an ordinary SRF-PLL for the synchronization stage calculation, which is unsuitable for handling unequal and twisted voltage lattice conditions. Furthermore, a typical PLL regulator includes a low pass channel, which introduces stage delay in the synchronization activity, resulting in undesirable waves in the reference current and voltage. Furthermore, a PLL's PI regulator complicates control and necessitates time-consuming calibration [29]. The use of STFs with improved stage following and critical part extraction capabilities could be a potential solution for stage location synchronization. In this work, to deliver and concoct a basic regulator structure by its operating guideline, it includes the age of unit vectors comprising sine and cosine work for the most common way of removing consonant current calculation and voltage calculation errors. Furthermore, the synchronization stages in terms of unit vectors are applied to the reference current age in the shunt compensator that plans on coordinating along with strength STF with the working idea of the immediate quadrature-zero (STF-$dq_0$) that does not rely on any parts of the PLL. In the series compensator, the reference voltage generation will also utilize the dq0 working principle, incorporating synchronization stages for in-stage compensation. The relationship between the presentation of a Unified Power Quality Conditioner with only a direct current-connected capacitor and a Unified Power Quality Conditioner coordinated with a photovoltaic and battery energy storage system is also demonstrated. Furthermore, to address the shortcomings of traditional PLLs, the STF combined with the UVG approach (STF-UVG) is used to generate synchronization phases for the UPQC controller.

## 1.2 OBJECTIVES:

1. To address the complicated issues of power quality, especially the long voltage interruption utilizing PV-BESS-UPQC system.
2. To use the STF-UVG technique to generate the synchronization cycles for such UPQC controller.

# II. METHODOLOGY:

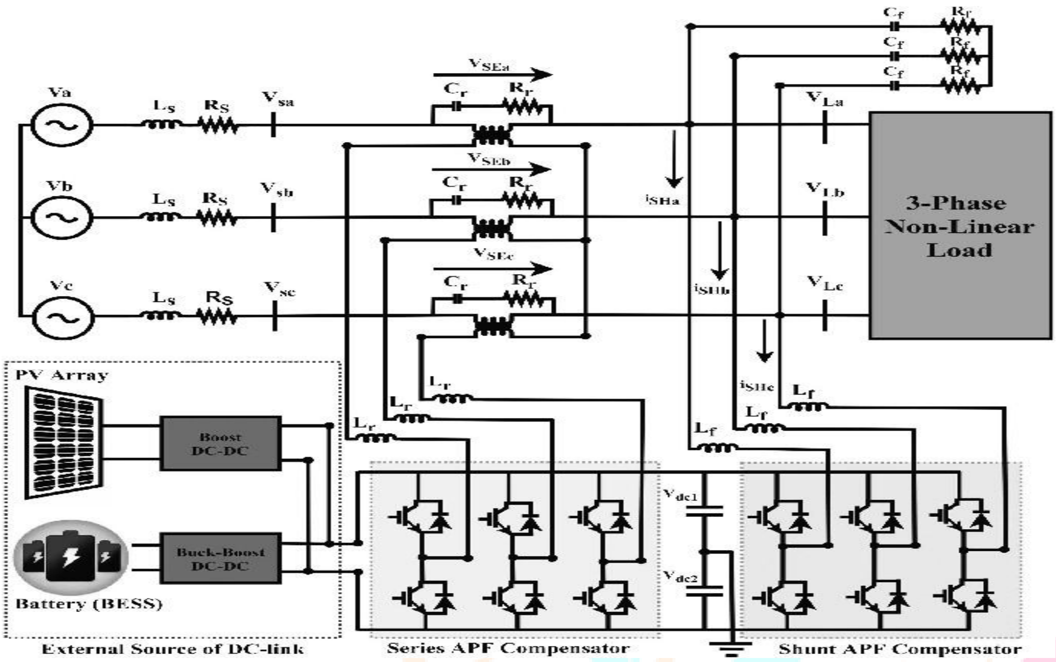



FIGURE **1.** UPQC system configuration.

Figure 1 depicts the PV-BESS construction. UPQC's PV-BESS-UPQC model requires a three-phase system. The PV-BESS-UPQC consists of a series and shunt APF compensator connected to a DC-link split capacitor. The battery and PV array are connected to the DC link in parallel. The lift converter links the PV to the DC interface. As a result, the BESS is linked to the DC interface using a buck-boost converter. The series compensator functions similarly to a regulated voltage source by reducing stock voltage hangs, enlargements, interference, and voltage symphony. However, the shunt compensator reduces the current music for the heap. Both the series and shunt APF compensators are connected by interfacing inductors. Music is produced as a result of the converter exchanging activity, and the Swell Filter is used to sift through the sounds. The series compensator embeds voltage into the network using a series infusion transformer. In this study, a three-stage non-straight burden is employed. The PV cluster is designed so that the maximum power point tracking (MPP) voltage is equal to the reference DC interface voltage, as the photovoltaic exhibit is directly related to the Unified Power Quality Conditioner DC connection. Under normal operating conditions, the photovoltaic exhibit rating ensures that the dynamic power load is supplied by the photovoltaic cluster, which also provides energy to the grid and charges the battery storage system. Additionally, the BESS is designed to supply power when the PV cluster generates less energy than the demand from the DC interface load, providing an amount of energy that corresponds to the decrease in DC-connected voltage. Furthermore, if the photovoltaic display does not generate any power, the battery storage system will bear the entire load. BESSs have been proposed as a strategy for addressing various issues identified with irregular age, as well as voltage problems, reduction, or cost savings through photovoltaic (PV) power demand switching.

The main functions of the UPQC-PV with BESS are:

1) To defend sensitive essential loads from source voltage interruptions by transferring active power to the load and network in standalone mode.

2) To defend the sensitive nonlinear load from swell/sag distortions by regulating the load voltage.
3) To correct for nonlinear load current's reactive power and harmonic component.

## 2.1 BESS (BATTERY ENERGY STORAGE SYSTEM):

At the point of common coupling (PCC) (VSCs), BESS is connected to the rest of the system via power-electronic interfaces, such as voltage source converters and bidirectional DC-DC converters. While the VSC transforms DC to AC power, the DC-DC converter increases the voltage from the battery to the DC link. The Li-ion battery was selected for this project due to its low maintenance expenses, slow self-discharge, and high power density and energy compared to other batteries.

+++--6

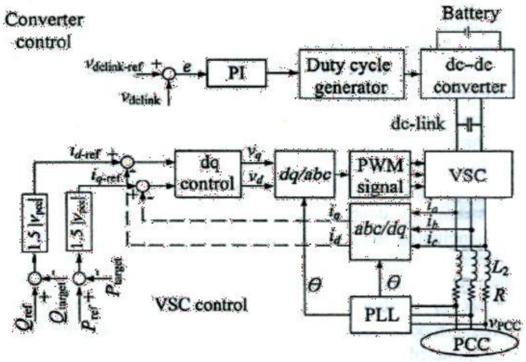



Fig 3 BESS control structure

The filter output current is regulated by the current control loop for quick dynamic response, and the inner control loop is built with a voltage control loop to stabilize the system voltage. The active power of the Battery Energy Storage System may be calculated as

$$P_{BESS} \square P_{DCLINK} \square P_{PV} \text{-----(1)}$$

Here, $P_{DCLINK}$ is the DC-link active power, $Ppv$ isthe total active power supplied by the PV

**2.2. SELF-TUNING FILTERTECHNIQUE:**

The suggested STF-UVG technology uses a non-iterative algorithm to separate the synchronizing cycles again from source voltage.

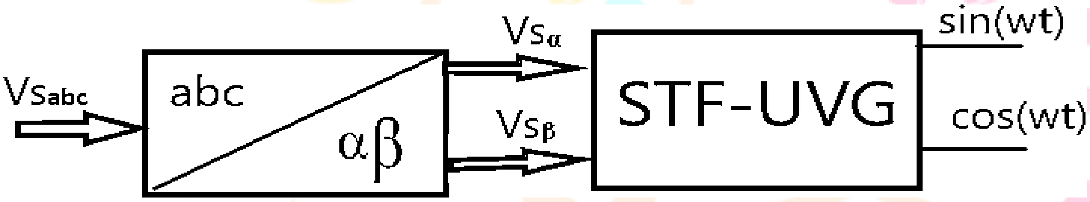



Fig a

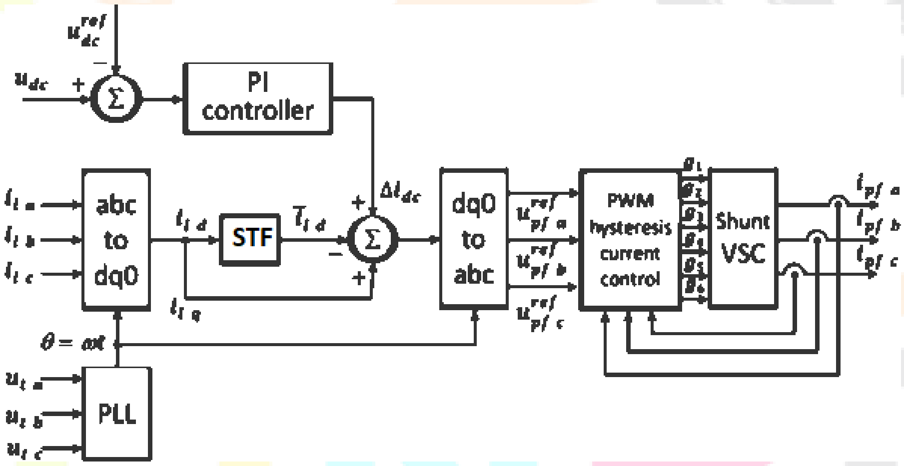



Fig b

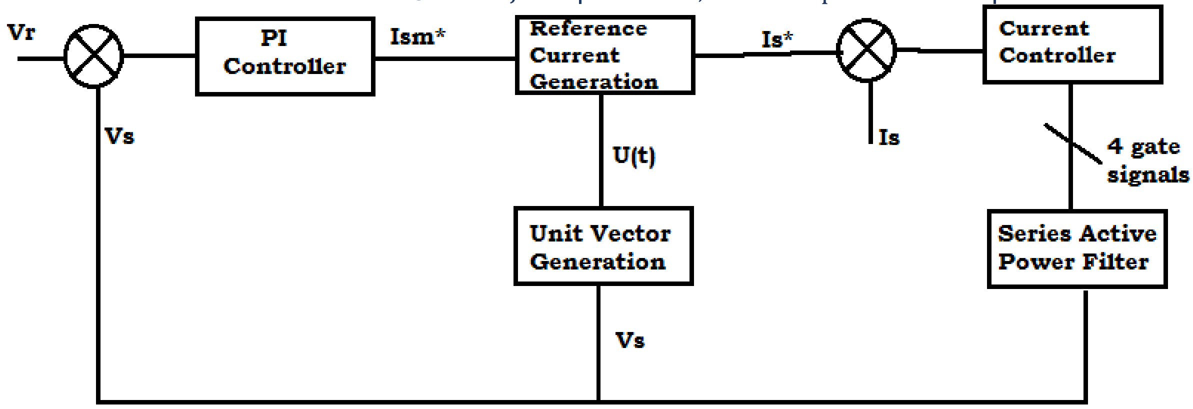
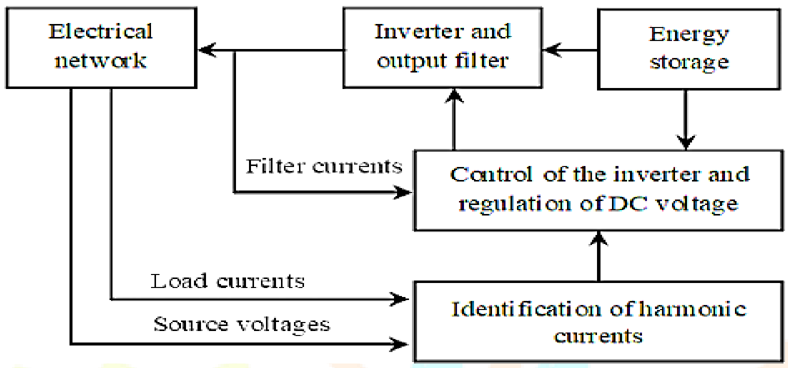



Fig c




(d)

Fig 4 In the UPQC controller design, a control block diagram for the self-tuning filter (STF) approach is shown. (a)STF-UVG (b) Shunt APF control scheme (c) Shunt APF control scheme (d) Series APF control scheme STF for Active Filter.

The source voltage is converted from abc-domain to αβ0 -domain using a Clarke transformation matrix. Only two phases in the domain are considered for separating the distorted supply voltage into fundamental and harmonic components. $i_{errordc}$ is measured by reducing the error obtained between total instantaneous dc-link voltage and reference dc link voltage *Vdcref* with a PI controller.

In domain, Vs (fund) denotes the fundamental (fund) component and Vs (har) denotes the harmonic (har) component. To establish synchronization phases, both of the essential components in the -domain are necessary Self-tuning filtering (STF) is used to remove the essential components. To suppress the existing harmonic components in the distorted supply voltage, the STF approach is used. As a result, the synchronizing phases are extracted more precisely, and the extraction quality is increased.

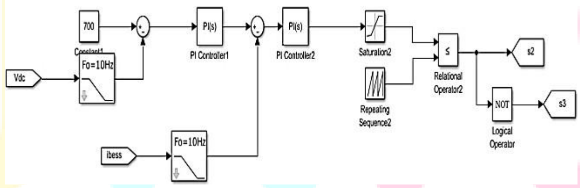



Fig 5: PI Controller

Where kp and ki are the proportional and integral gains of the controller PI, respectively. The values are 0.3 and 2. The ANFIS controller is used to regulate the dc link voltage, and it produces better results than the PI controller.

## III. ANFIS controller:

The adaptive network based fuzzy inference system(ANFIS) is a data driven procedure representing a

The adaptive network based fuzzy inference system (ANFIS) is a data-driven process for solving function approximation issues that uses a neural network approach. The clustering of a training set of numerical samples of the unknown function to be approximated is often used in data-driven processes for the synthesis of ANFIS networks. ANFIS networks have been used to solve categorization difficulties, rule-based process management, pattern recognition, and other challenges since their debut. The fuzzy model [34, 35] introduced by Takagi, Sugeno, and Kang to define a systematic way to construct fuzzy rules from input output data set is used in this fuzzy inference system.

## 3.1ANFIS structure

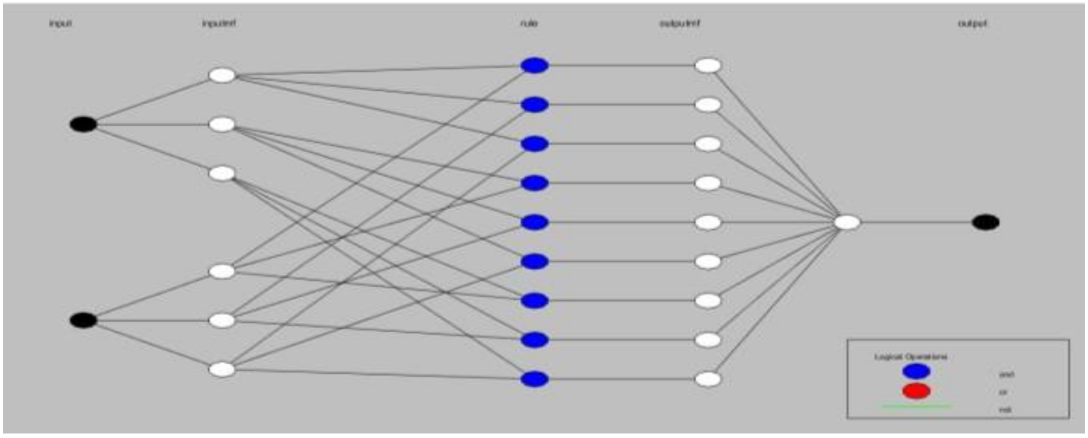



Fig 6: ANFIS model structure

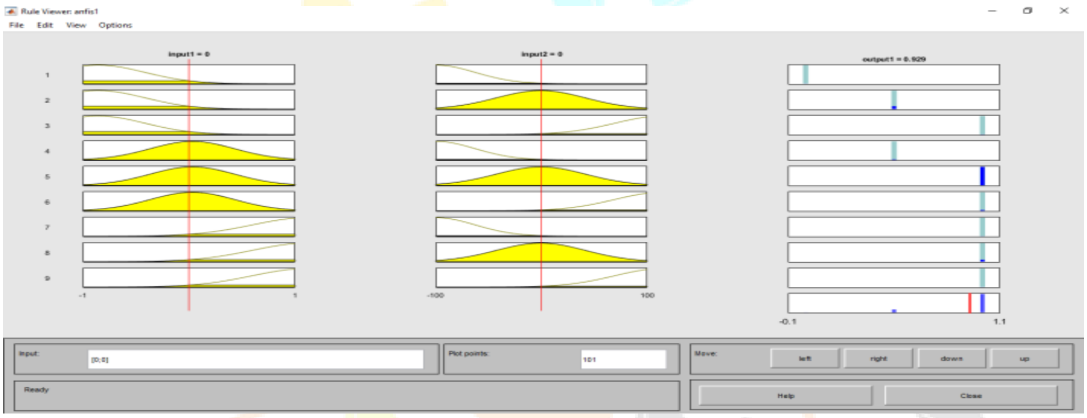


Fig 7 rules view

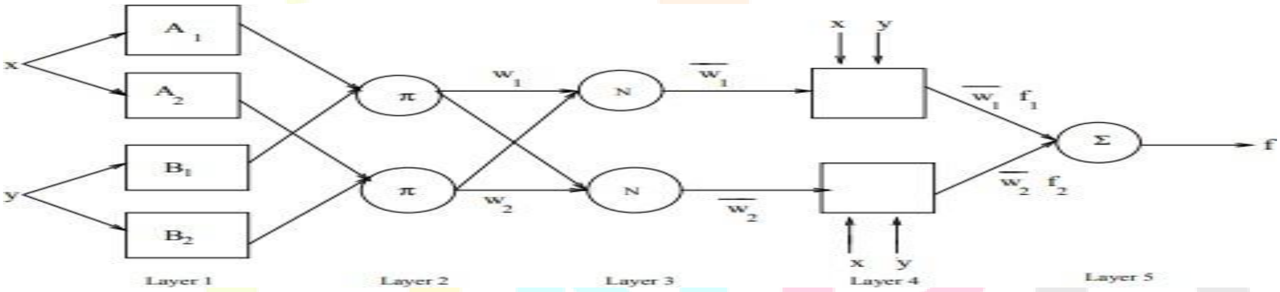



Figure 8: Type-3 ANFIS model

The corresponding equivalent ANFIS structure is shown in Fig.8

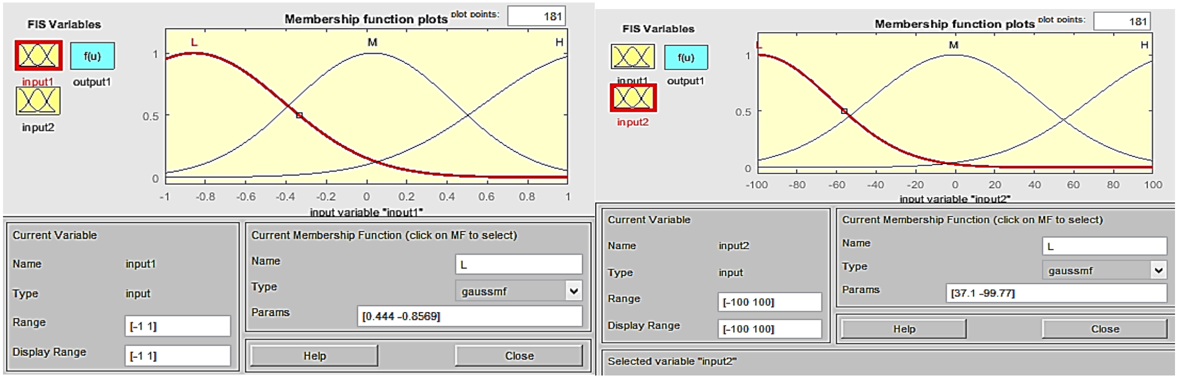



Fig 9 : Membershipfunction

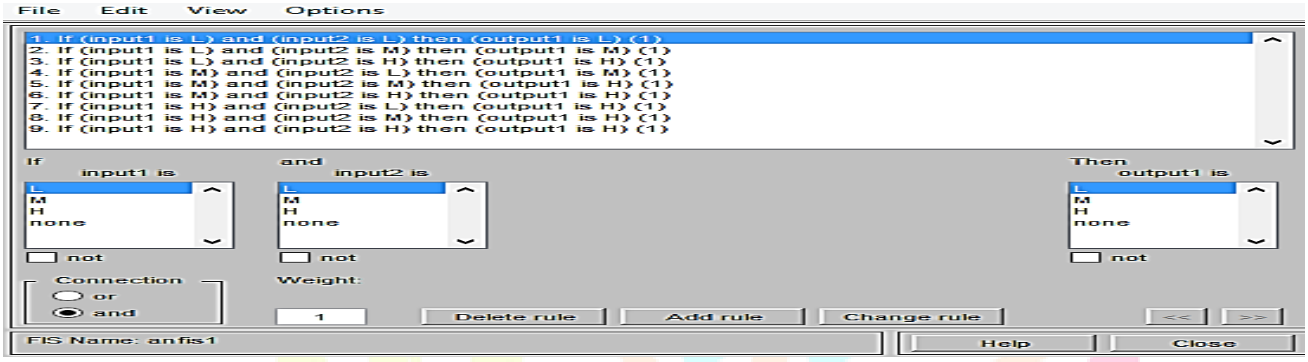



Fig 10 Rules for ANFIS

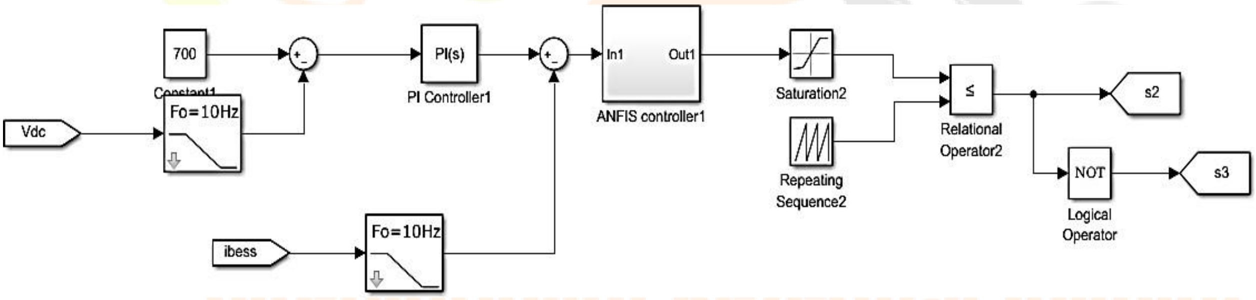



Fig 11 Simulink diagram of ANFIS controller

## IV.SIMULATION RESULTS:

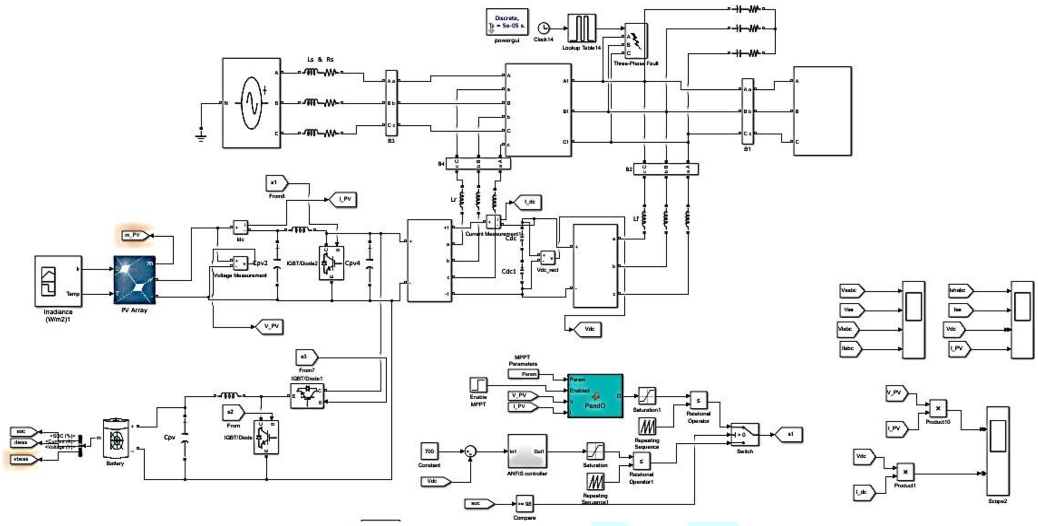


FIG 12: Simulation diagram

Case 1:

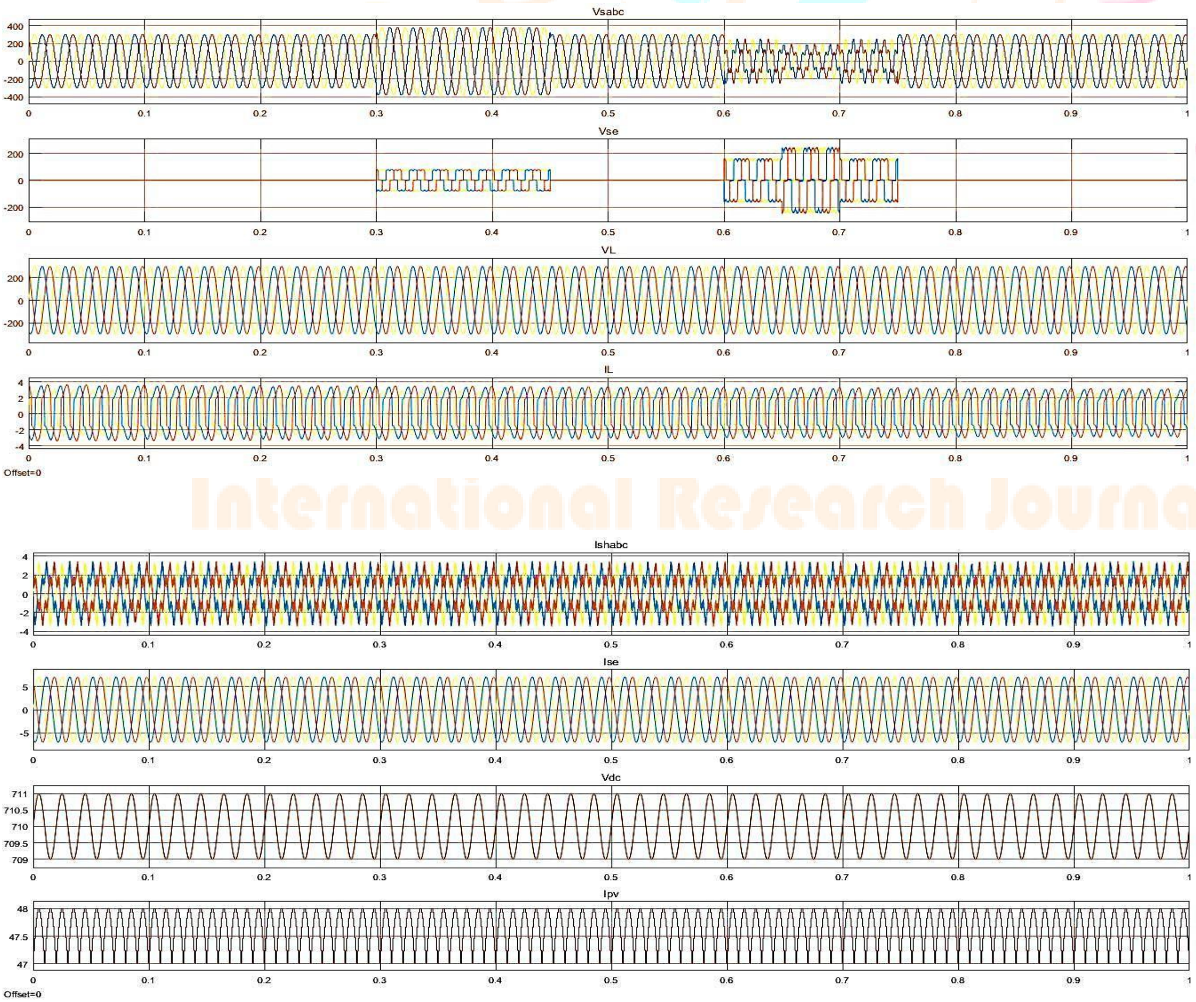
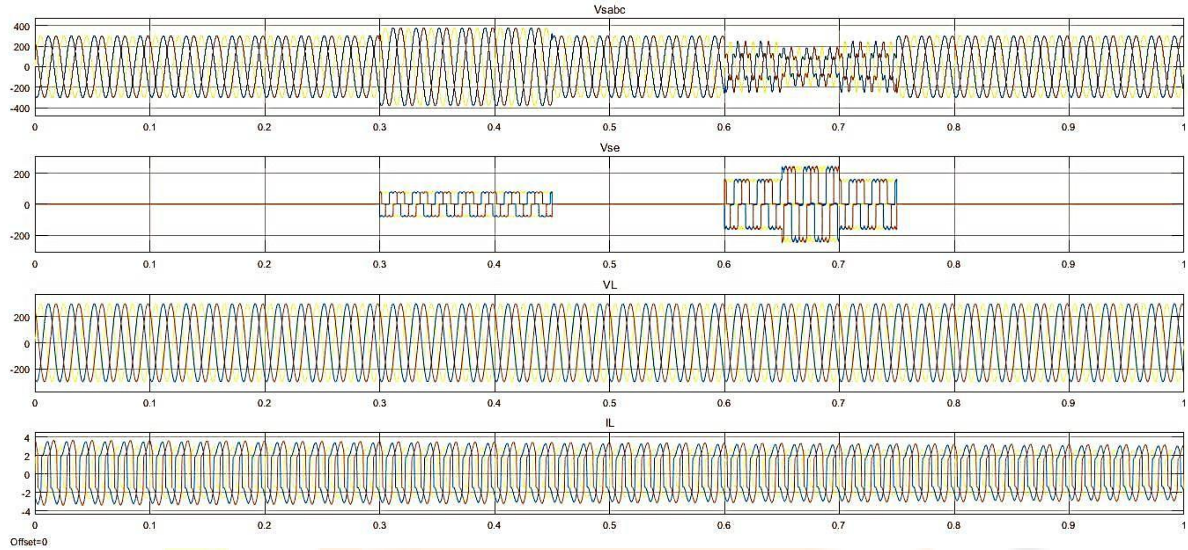



Fig13 simulation results of three-phase source voltage (B) Injection voltage of Series APF (C) Load Voltage (D) Load Current (E) Injection Current of Shunt APF (F) Source Current. G) DC-Link Voltage H) Photovoltaic current

Voltage harmonics can be seen from 0.3s to 0.45s, and a composition of harmonic and sag of 0.7 pu can be seen from 0.6s to 0.65s, and a combination of voltage harmonic and voltage sag of 0.4 pu can be seen from 0.65s to 0.7s. The series compensator injects an appropriate voltage VSE to attenuate the source voltage, VS in certain scenarios during sag, as shown in Fig. 12(B), in order to keep the demand voltage, VL equivalent to the rated value. The voltage at load is sinusoidal and equal to the rated voltage, as shown in Fig. 12(C) above. The unbalanced non-linear load creates a distorted load current, iL, as seen in

## Case2:

Fig. 13. This study takes into account a three-phase imbalance load. Because a non-linear load is used, the shunt compensator compensates for the source current, iS, by injecting a current, iSH, into the gridcurrent to make it sinusoidal. Figure 13 depicts the sinusoidal grid current. The DClink voltage is steady at 700V during the voltage harmonic and the combination of voltage harmonic and voltage sag, as shown in Fig. 13. PV current is estimated to be roughly 46.2 A. Furthermore, the DC's power is increased from 0.6 to 0.75 seconds, reducing harmonics and allowing the load to be supported while voltage at source is insufficient.



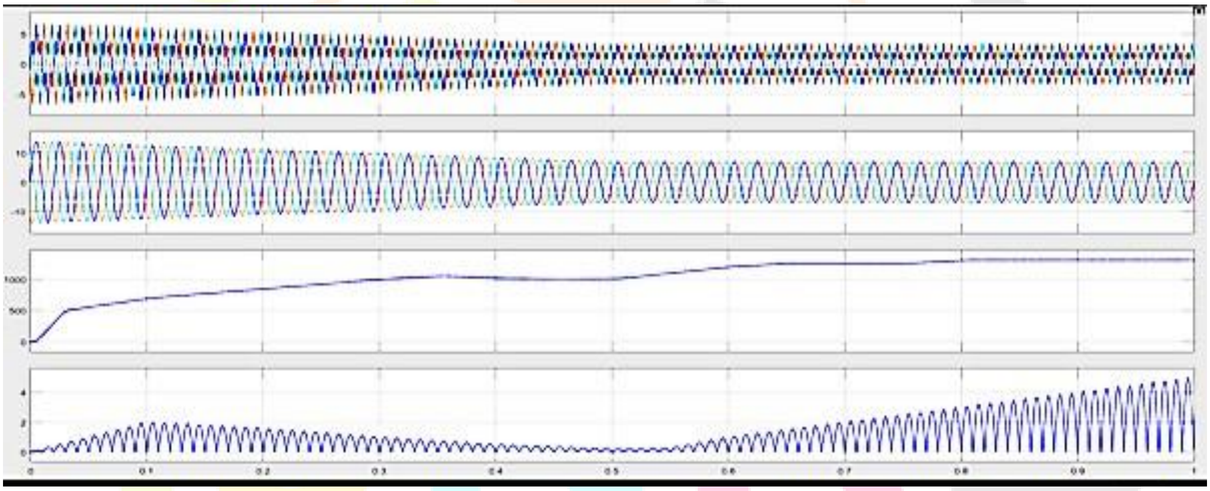
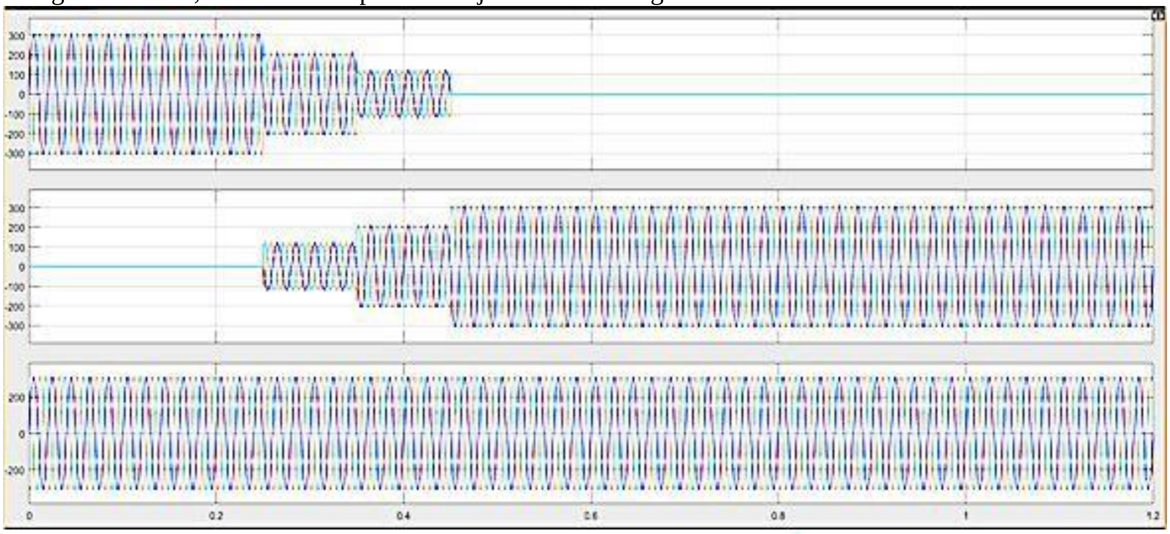



Fig 14 simulation results of three-phase source voltage (B) Injection voltage of Series APF (C) Load Voltage (D) Load Current (E) Injection Current of Shunt APF (F) Source Current. G) DC-Link Voltage H) Current ofPV

(I) Simulation findings acquired the detected voltage magnitude under Case study 2: Scenario B for unbalancevoltage sag and swell condition

Case 2 investigates the PV-BESS-UPQC under sinusoidal-balanced source voltage sag and swell conditions at PCC. PV-BESS-UPQC performance simulations in the context of sinusoidal-balanced source voltage sags and swells at the Point of Common Coupling are presented as simulation waveforms. Observed waveforms include supply voltages, series compensated voltages, load voltages, load currents, shunt compensated currents, and source currents. The figure shows that the source voltage, VS, at the Point of Common Coupling has a 0.7 pu voltage sag from 0.3 s to 0.35 s and 0.4 s to 0.45 s, as well as a 0.4 pu voltage sag from 0.35 s to 0.4 s. Furthermore, there is a 1.3 pu voltage swell from 0.6s to 0.65s and 0.7s to 0.75s, as well as 1.6 pu voltage swell from 0.65s to 0.7s. In these Case 3 situations, the series APF compensator injects the appropriate voltage, VSE, to compensate for the source voltage at the PCC. To maintain the load voltage, VL is equivalent to the rated voltage; during voltage dips, the injected voltage is in phase with the grid voltage, while during voltage swells, it is in phase with the source voltage. Because this study employs a non-linear load, the shunt APF compensator compensates for the source current, iS, by injecting a suitable current, iSH, to maintain a sinusoidal current. Figure (I) shows that the correction is carried out appropriately during the imbalanced voltage sag and swell. In the figure, the series compensator compensates for swells (0.25s to 0.5s) and sags (0.65s to 0.85s). Depending on the need, the series compensator injects various magnitudes.



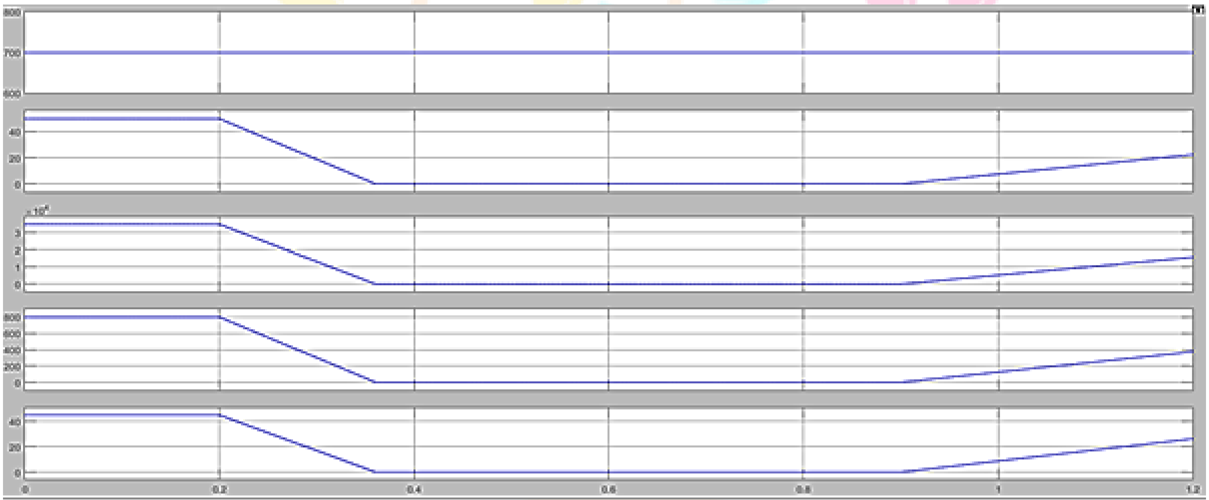


Fig 15 simulation results of three-phase source voltage (B) Injection voltage of Series APF (C) Load Voltage (D) Load Current (E) Injection Current of Shunt APF (F) Source Current. G) DC-Link Voltage H) Current ofPV

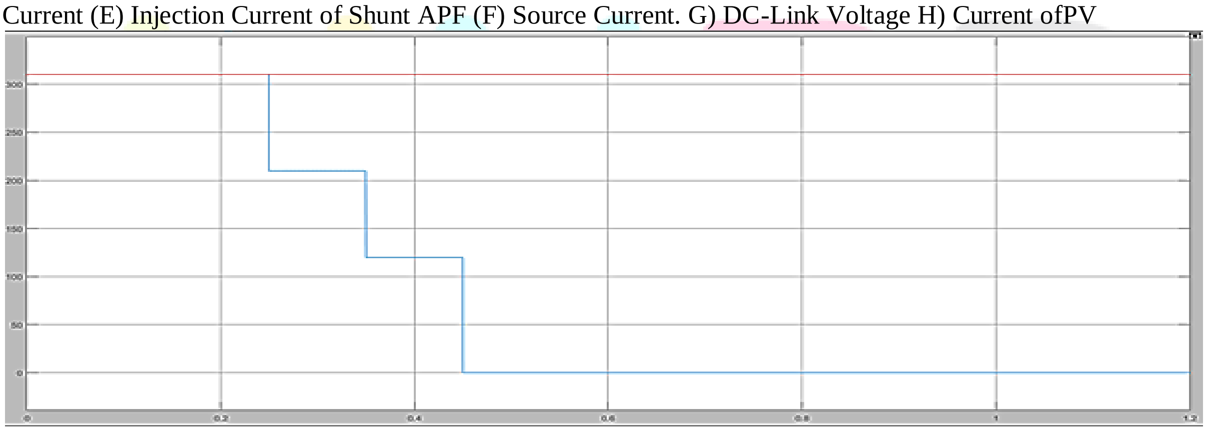


Fig 15 (I) Simulation findings acquired the detected voltage magnitude under Case study 3: for voltage interruption condition.

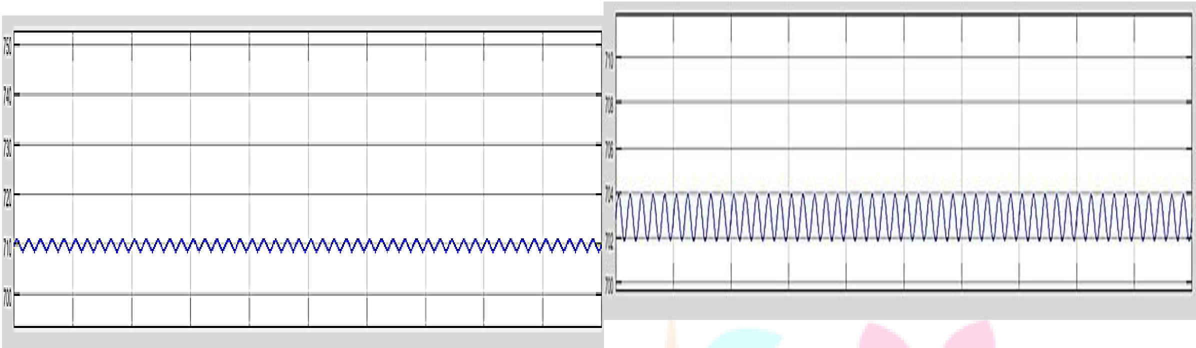
Supply voltages, series compensated voltages, load voltages, load currents, and shunt compensated currents, as well as source currents, are among the waveforms measured. There is a 0.6 pu sag from 0.25 to 0.35s and a 0.3 pu sag from 0.35 to 0.45s, as seen in Fig. Furthermore, from 0.45s through the completion of the simulation, the voltage supply is disconnected. In these instances, the series compensator injects an appropriate voltage Vse to compensate for the voltage at the source and fully maintain the demand during grid voltage disruptions. The magnitudes of the source and load voltages are shown in Figure 15 (I). The source voltages are shown as dotted lines, whereas the

.

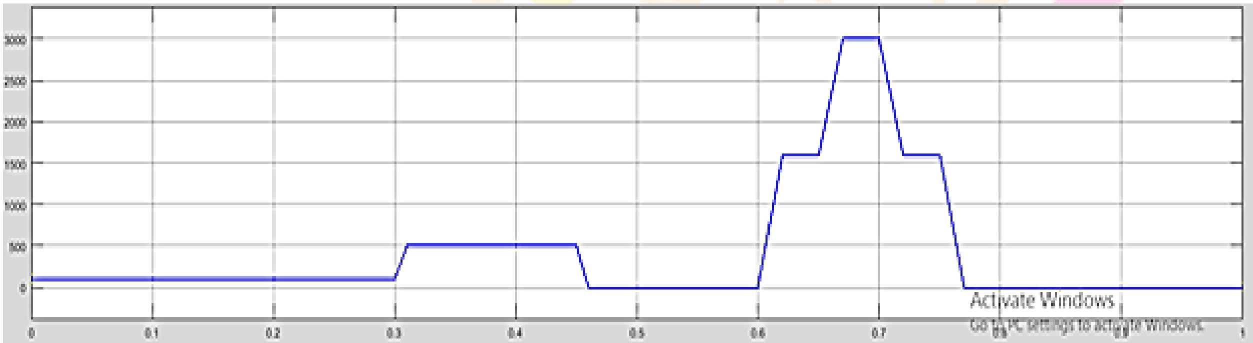
## WITH PI CONTROLLER

load voltages are shown as straight lines. The compensation is appropriately achieved, as can be seen in Fig 15 (I). The correction by the series compensator during the voltage sag from 0.25s to 0.45s is depicted in Fig 15 (I), and from 0.45s onwards, the series compensator supplies the entire load voltage using the Photovoltaic and Battery Energy Storage System. The series compensator injects an appropriatevoltage in phase with the grid voltage to compensate for the source voltage in both scenarios. As a result, during both the voltage sag and the voltage interruption, the load voltage reached the rated level

- VDC=710 V

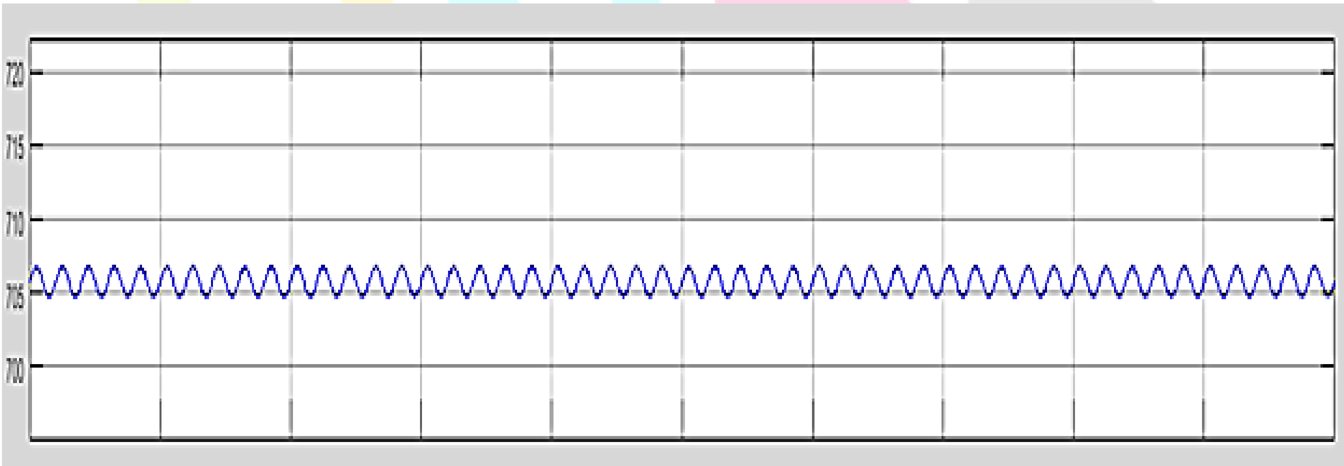


- POWER DC=3000W

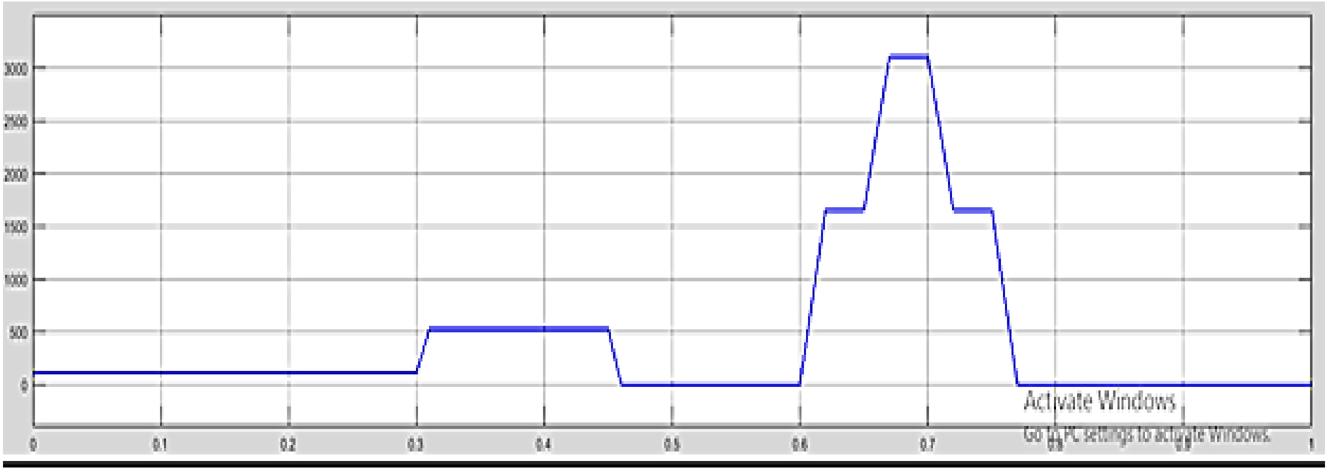



## WITH FUZZZY CONTROLLER:

- VDC=706 V



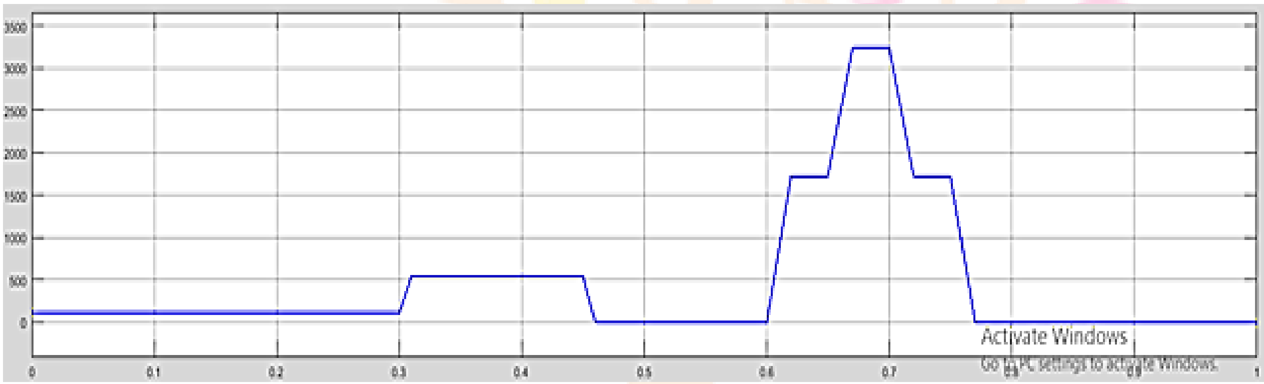
➢ POWER DC=3100W

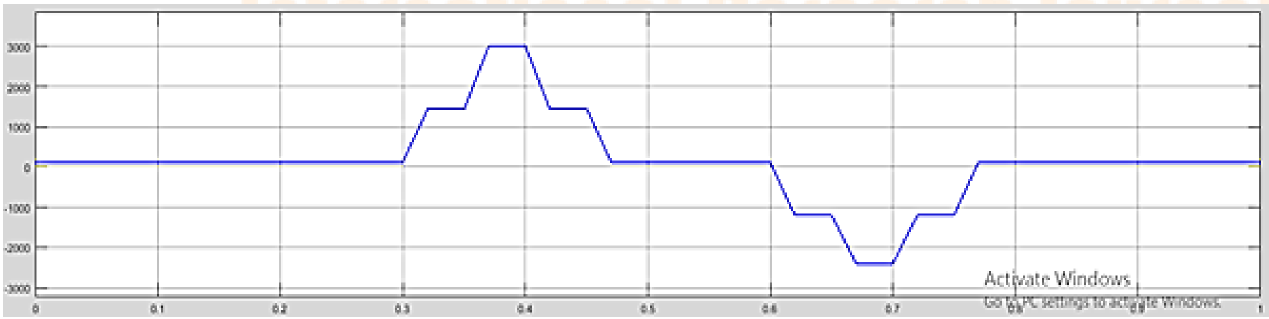



# WITH ANFIS CONTROLLER

➢ VDC=704V

POWER DC=3200W

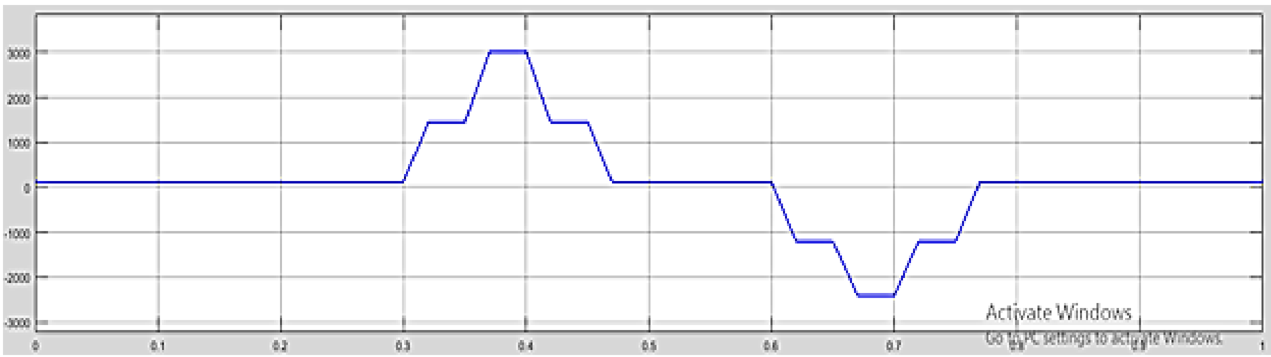


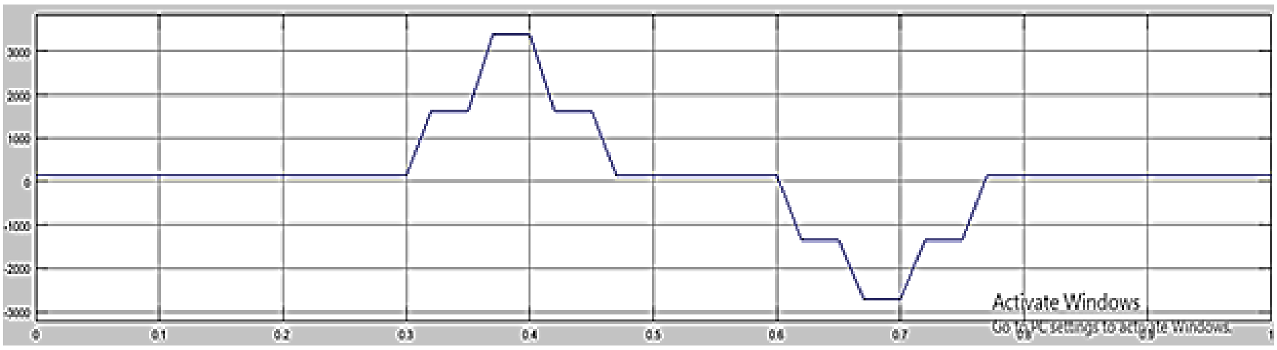

➢ DC-Link output power with pi



➢ DC-Link output power with fuzzy



➢ DC-Link output power with anfis



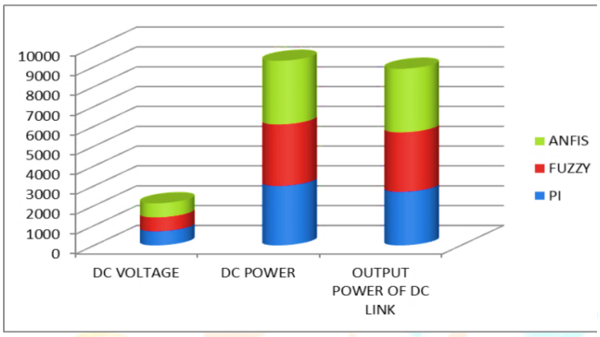



Fig 14 comparison of PI, FUZZY and ANFIS

**CONCLUSION**

Under the circumstance of confounded force quality issues like sounds, voltage grows and hangs, and voltage interference under unequal and mutilated voltage network conditions, the plan of three-stage UPQC has been explored. By joining the Battery Energy Storage System and PV with the Unified Power Quality Conditioner, the organization acquires dynamic force capacity. The vital advantages of consolidating Battery Energy Storage System with UPQC is that it permits the framework to supply and assimilate dynamic force from the PV. Since sustainable power is innately questionable because of its ecological reliance, joining a BESS will ease the deficiency of sustainable power assets. In view of the ANFIS regulator and steady stockpile from the PV-BESS framework, the DC-connect voltage is steady. To make reference current and voltage, the Self Tuning Filter -Unit Vector Generation approach for synchronization stages is effectively used in the shunt and series Active Power Filter compensator. Subsequently, the UPQC is created without depending on PLL parts, and current and voltage relief are effectively accomplished because of network conditions, guaranteeing framework security and accomplishing nearly solidarity power factor.

## REFERENCES

[1] IEEE Standards Coordinating Committee 22 onPower Quality, IEEE Recommended Practice for Monitoring Electric Power Quality, vol. 2009, no. June. 1995.

[2] D. De Yong, S. Bhowmik, and F. Magnago, “Optimized Complex Power Quality ClassifierUsing One vs. Rest Support Vector Machines,” Energy Power Eng., vol. 09, no. 10, pp. 568–587, 2017.

[3] A. Javadi, A. Hamadi, L. Woodward, and K. Al-Haddad, “Experimental Investigation on a Hybrid Series Active Power Compensator to Improve Power Quality of Typical Households,” IEEE Trans. Ind. Electron., vol. 63, no. 8, pp. 4849–4859, 2016.

[4] A. Javadi, L. Woodward, and K. Al-Haddad, “Real-Time Implementation of a Three-Phase THSeAF Based on a VSC and a P+R Controller to Improve the Power Quality of Weak Distribution Systems,” IEEE Trans. Power Electron., vol. 33,no. 3, pp. 2073–2082, 2018.

[5] M. A. Mansor, M. M. Othman, I. Musirin, and S. Z. M. Noor, “Dynamic voltage restorer (DVR) ina complex voltage disturbance compensation,” Int. J. Power Electron. Drive Syst., vol. 10, no. 4, pp. 2222–2230, 2019.

[6] A. Ghosh and G. Ledwich, “Compensation of distribution system voltage using DVR,” IEEE Trans. Power Deliv., vol. 17, no. 4, pp. 1030–1036, 2002.

[7] S. Jothibasu and M. K. Mishra, “A control scheme for storageless DVR based on characterization of voltage sags,” IEEE Trans. Power Deliv., vol. 29, no. 5, pp. 2261–2269, 2014.

[8] A. Farooqi, M. M. Othman, A. F. Abidin, S. I. Sulaiman, and M. A. M. Radzi, “Mitigation of power quality problems using series active filter ina microgrid system,” Int. J. Power Electron. Drive Syst., vol. 10, no. 4, pp. 2245–2253, 2019.

[9] C. Kumar and M. K. Mishra, “Operation and Control of an Improved Performance Interactive DSTATCOM,” IEEE Trans. Ind. Electron., vol. 62,no. 10, pp. 6024–6034, 2015.

[10] Y. Hoon, M. A. M. Radzi, M. K. Hassan, and N. F. Mailah, “Control algorithms of shunt active power filter for harmonics mitigation: A review,” Energies, vol. 10, no. 12, 2017.

[11] L. B. Garcia Campanhol, S. A. Oliveira da Silva, and A. Goedtel, “Application of shunt active power filter for harmonic reduction and reactive power compensation in threephase four-wire systems,” IET Power Electron., vol. 7, no. 11, pp. 2825–2836, 2014.

[12] Y. Hoon, M. A. M. Radzi, M. K. Hassan, and N. F. Mailah, “Operation of Three-Level Inverter- Based Shunt Active Power Filter under Nonideal Grid Voltage Conditions with Dual Fundamental Component Extraction,” IEEE Trans. Power Electron., vol. 33, no. 9, pp. 7558–7570, 2018.

[13] E. Hossain, M. R. Tur, S. Padmanaban, S. Ay, and I. Khan, “Analysis and Mitigation of Power Quality Issues in Distributed Generation Systems Using Custom Power Devices,” IEEE Access, vol. 6, no. c, pp. 16816–16833, 2018.

[14] H. Fujita and H. Akagi, “The unified power quality conditioner: The integration of series- and shunt-active filters,” IEEE Trans. Power Electron., vol. 13, no. 2, pp. 315–322, 1998.

[15] S. K. Khadem, M. Basu, and M. F. Conlon, “Intelligent islanding and seamless reconnection technique for microgrid with UPQC,” IEEE J. Emerg. Sel. Top. Power Electron., vol. 3, no. 2, pp. 483–492, 2015.

[16] J. M. Guerrero, P. C. Loh, T. L. Lee, and M. Chandorkar, “Advanced control architectures forintelligent microgridsPart II: Power quality, energy storage, and AC/DC microgrids,” IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1263–1270, 2013.

[17] B. Han, B. Bae, H. Kim, and S. Baek, “Combined operation of unified power-qualityconditioner with distributed generation,” IEEE Trans. Power Deliv., vol. 21, no. 1, pp. 330–338,2006.

[18] K. Hasan, M. M. Othman, N. F. A. Rahman, M. A. Hannan, and I. Musirin, “Significant implication of unified power quality conditioner in power quality problems mitigation,” Int. J. Power Electron. Drive Syst., vol. 10, no. 4, p. 2231, 2019.

[19] C. K. Sundarabalan, Y. Puttagunta, and V.Vignesh, “Fuel cell integrated unified power quality conditioner for voltage and currentreparation in four-wire distribution grid,” IET Smart Grid, vol. 2, no. 1, pp. 60–68, 2019.

[20] S. Devassy and B. Singh, “Design and Performance Analysis of Three-Phase Solar PV Integrated UPQC,” IEEE Trans. Ind. Appl., vol. 54,no. 1, pp. 73–81, 2018.

[21] L. B. G. Campanhol, S. A. O. Da Silva, A. A. De Oliveira, and V. D. Bacon, “Power flow and stability analyses of a multifunctional distributed generation system integrating a photovoltaicsystem with unified power quality conditioner,” IEEE Trans. Power Electron., vol. 34, no. 7, pp. 6241–6256, 2019

[22] A. M. Gee, F. Robinson, and W. Yuan, “A Superconducting Magnetic Energy Storage- Emulator/Battery Supported Dynamic Voltage Restorer,” IEEE Trans. Energy Convers., vol. 32, no. 1, pp. 55–64, 2017.

[23] W. U. Tareen and S. Mekhilef, “Transformer- less 3P3W SAPFthree-phase three-wire shunt active power filter) with line-interactive UPS (uninterruptible power supply) and battery energy storage stage,” Energy, vol. 109, pp. 525–536, 2016.

[24] S. K. Kollimalla, M. K. Mishra, and N. L. Narasamma, “Design and analysis of novel control strategy for battery and supercapacitor storage system,” IEEE Trans. Sustain. Energy, vol. 5, no. 4,pp. 1137–1144, 2014.

[25] S. B. Karanki, N. Geddada, M. K. Mishra, and B. K. Kumar, “A modified three-phase four-wire UPQC topology with reduced DC-link voltage rating,” IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3555–3566, 2013.

[26] A. Teke, L. Saribulut, and M. Tumay, “ novel reference signal generation method for power quality improvement of unified power- quality conditioner,” IEEE Trans. Power Deliv., vol. 26, no. 4, pp. 2205–2214, 2011.

[27] V. G. Kinhal, P. Agarwal, and H. O. Gupta, "Performance investigation of neural-network- based unified power-quality conditioner," IEEE Trans. Power Deliv., vol. 26, no. 1, pp. 431–437, 2011.

[28] M. Kesler and E. Ozdemir, "Synchronous-reference-frame-based control method for UPQCunder unbalanced and distorted load conditions," IEEE Trans. Ind. Electron., vol. 58, no. 9, pp. 3967–3975, 2011.

[29] S. Golestan, J. M. Guerrero, and J. C. Vasquez, "Three-Phase PLLs: A Review of Recent Advances," IEEE Trans. Power Electron., vol. 32, no. 3, pp. 1897–1907, 20