Power Quality Improvement in PV System Using SPVI-DVR

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Abstract*: Power Quality is the major concern and causes many issues for power companies and customer. The investigation of major power disturbance qualities and finding the result for power quality complications have out-turned an increased attentiveness towards power quality .Power quality issues like voltage sag ,swell and interruptions are deviation in current, voltage and frequency which results damage or failure in end user equipment .Mostly these days load equipment are more sensitive and could not tolerate slight variations in power which also causes considerable outages and even result in solid economical losses .For increasing power quality among all custom power devices (CPDs) ,Dynamic Voltage Restorer (DVR) is widely recommended for cost-efficient solution. DVR is a power electronic based outcome to alleviate and recoup voltage sags. So in the proposed PV based SPVI-DVR power quality improvement using fuzzy logic controller. A broad equipment range is encompassed by these loads which are influenced by disturbances in voltage. The Dynamic Voltage Restorer (DVR) was recently introduced to safeguard sensitive loads from voltage sags and disturbances. The increasing load demand is met by the incorporation of DVR with PV system. For delivering inverted AC voltage, the three phase voltage source inverter is controlled by a cascaded fuzzy algorithm in conjunction with a PWM generator. The suppression of harmonics is achieved using an LC filter. The simulation process is done by MATLAB for investigating the functioning of the method proposed.

***Index Terms*: Power quality, sags, PWM generators, inverter AC voltage, harmonics.**

I. INTRODUCTION

The rise in the number of loads sensitive to power disruptions made power quality issues are a major concern in most sectors today. Power quality is a factor to determine the current and voltage offered to industrial, commercial, and residential electricity users. The issue affects both utilities and customers. Because of changes in user equipment and expectations, providing appropriate power quality is a moving target for utilities. Problems arising from the vulnerability of electrical equipment to voltage quality may have severe effects for users. The topic of power quality covers a wide range of issues. On one hand, spikes or surges, sags, swells, outages, under and over voltages, harmonics, flicker, frequency deviations, and electrical noise are all issues in power quality. As a result, various measurements and analysis tools are needed to explore such events, and various corrective activities can be taken to compensate for or mitigate their impacts. Many electronic devices, on the other hand (such as computers, process controllers, adjustable speed drives, solid-state-relays, and optical devices) are sensitive to power quality to varying degrees. The tactics for consuming the least amount of active power during the voltage compensation stage and absorbing the most active power during the energy self-recovery stage. Deliver smooth transition in dynamic process to ensure the flexible switching between two stages [1]. To create the instantaneous reference voltages to adjust the load voltages with direct power flow management, a generalised control technique based on instantaneous space phasor and dual P-Q theory has been presented [2]. Two bidirectional dc/dc converters and a series-connected three phase voltage source inverter are employed to regulate AC voltage and control energy storage system charge, discharge respectively. During short-duration, high-power voltage sags, DC bus level signalling and voltage droop management were employed to autonomously control power from the magnetic energy storage system[3]. A novel fault-tolerant control paradigm for a micro grid-connected doubly fed induction generator (DFIG)-based wind energy system to achieve ride through during any kind of voltage sag conditions including deep sags and enable the strict satisfaction of recent grid code requirements [4].

Effective mitigation of power quality disturbance in secondary distribution networks as a result of voltage variation and voltage imbalance using a very effective power electronics-based custom power controller [5]. A series compensation philosophy to improve the voltage property of loads using three-phase voltage ellipse parameters intended for optimal utilization of a dynamic voltage restorer [6].A dual buck stage can produce the full, two-thirds, and one-third of the dc link voltage, respectively.. Including the zero voltage provided by the two-level inverter, the output of the proposed inverter can be four levels [7]. A dynamic voltage restorer topology based on the adaptive noise cancelling technique, which can be used for both voltage compensation and harmonic mitigation [8]. Custom power devices (CPDs) are recommended to improve power quality, among all the Dynamic Voltage Restorer (DVR) being the best and most cost-effective option[9]. Two dc ports are connected by an integrated dc-dc converter that aims to provide a high dc-link voltage while preserving voltage injection capabilities even if the energy-storage voltage is lower than the injected ac-line voltage's peak value[10]. Here a dynamic voltage restorer based on a photovoltaic solar inverter (SPVI-DVR) is used. Usage of non-linear loads causes various issues in power quality like sags/swells of voltage, imbalance, distortion in harmonics, and minimal interruption. A broad equipment range is encompassed by these loads which are influenced by disturbances in voltage .Recently, the Dynamic Voltage Restorer (DVR) is introduced for protecting sensitive loads from sags and disturbances in voltage. The increasing load demand is met by the incorporation of DVR with PV system.

II. OVERVIEW OF SPVI-DVR SYSTEM

The rapid developments in the manufacturing industry, power quality becomes very important because the sensitive loads are tied in the industry. The quality of power can be defined as current and voltage quality with respect to frequency variation. The power quality issue that can affect the distribution side that results in the failure or malfunction of the sensitive load. It can be classified as short-term voltage variations, long-distance voltage fluctuations, waveform distortion, crossover, voltage imbalance and voltage flicker. The proposes system shows a Cascaded Fuzzy Logic Control of PV Fed DVR for Power Distribution Systems**.**

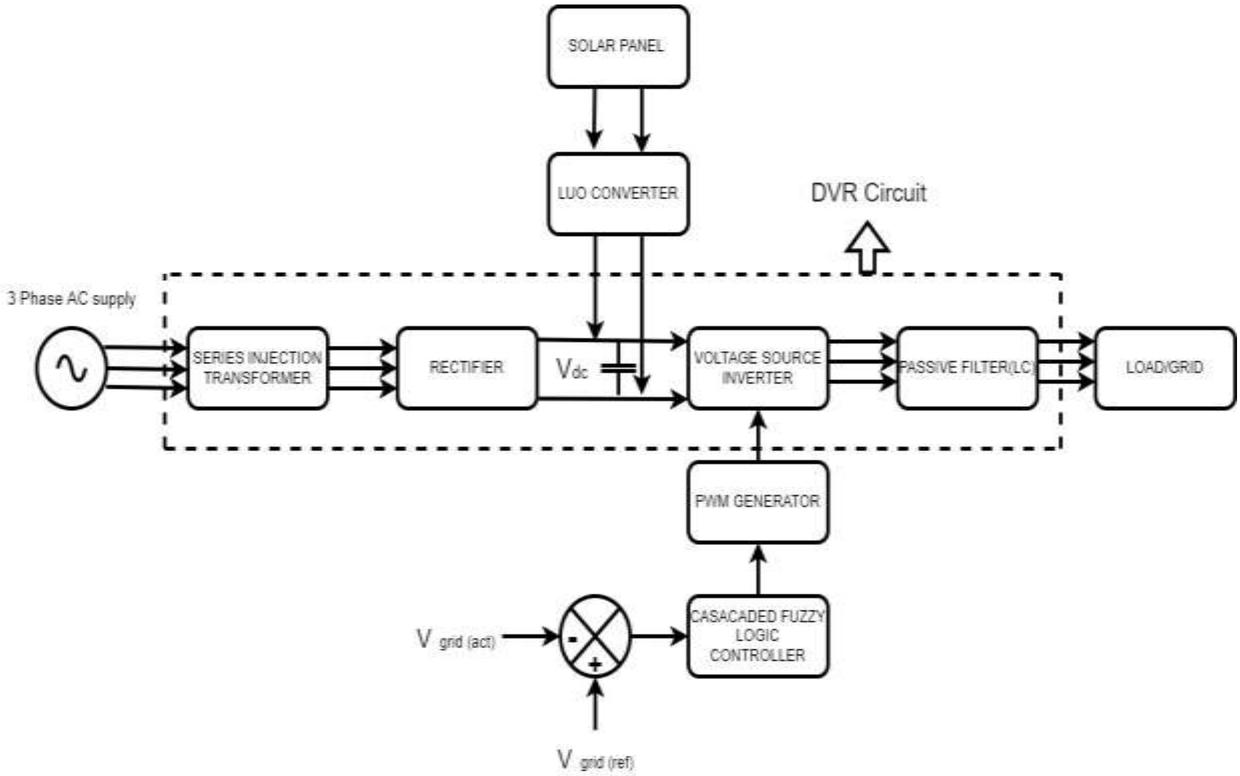

Fig 1 : Block diagram of SPVI-DVR system

Usage of non-linear loads causes various issues in power quality like sags/swells of voltage, imbalance, distortion in harmonics, and minimal interruption. A broad equipment range is encompassed by these loads which are influenced by disturbances in voltage. The Dynamic Voltage Restorer (DVR) was recently introduced to safeguard sensitive loads from voltage sags and disturbances. The increasing load demand is met by the incorporation of DVR with PV system. For creating inverted AC voltage, the three phase voltage source inverter is controlled by a cascaded fuzzy algorithm in conjunction with a PWM generator. Harmonic suppression is achieved with an LC filter.

Due to massive economic losses caused by various voltage disruptions in the grid, power quality is a topic that is gaining a lot of attention. Voltage sag is the most serious of the voltage disturbances, and it has a negative impact on the system's output. The DVR is one such effective and dependable solution for power quality issues. It is a series compensator which is static in nature that regulates the voltage at load side with the injection of voltage in series into the distributed system. DVR is linked within the supply as well as the responsive load for compensating the reducing transients, harmonics at line voltage, and compensating for voltage swells and sags. The simulation process is done by MATLAB for investigating the functioning of the method.

III. DYNAMIC VOLTAGE RESTORER (DVR)

DVR: Principle

The DVR is the best option for preventing power outages induced by voltage sag, especially in sensitive loads. DVR's performance principles mandate that it injects the desired voltage and mitigates all balanced/imbalanced voltages [40]. The DVR gets its active power from a Direct Current (DC) power supply and injects its reactive power into the system as a result. Furthermore, until abnormal network conditions arise, DVR operates in standby mode in normal situations. The DVR is responsible for supplying the voltage differential between lines (during voltage sag) and maintaining the nominal voltage value at the load-side.In general, it can be used to protect sensitive loads by preventing unexpected voltage changes.

Injection transformers, a protective circuit, a bypass thyristor, passive filters, a voltage source inverter (VSI), and energy storage make up the DVR . When a voltage sag/swell happens, the DVR injects a series voltage (Vinj) into the network via the transformer. As a result, the magnitude of the load voltage can be kept constant. The injected voltage is expressed below (Figure 2) [41]:

$$VL = Vs + Vinj \qquad (1)$$

where VL, VS, and Vinj are the load, the sagged supply, and the injected voltages, respectively. The load power of each phase under reasonable voltage condition is [41]:

$$SL = VL * IL = PL - j\,QL \quad (2)$$

PL and QL represent the load's active and reactive power during sags/swells, respectively, and IL is the load current. Once the DVR restores the desired voltage to normal, Equation (2) can be expressed as below [33]:

$$SL = PL - j\,QL = (Ps - j\,Qs) + (Pinj - j\,Qinj) \quad (3)$$

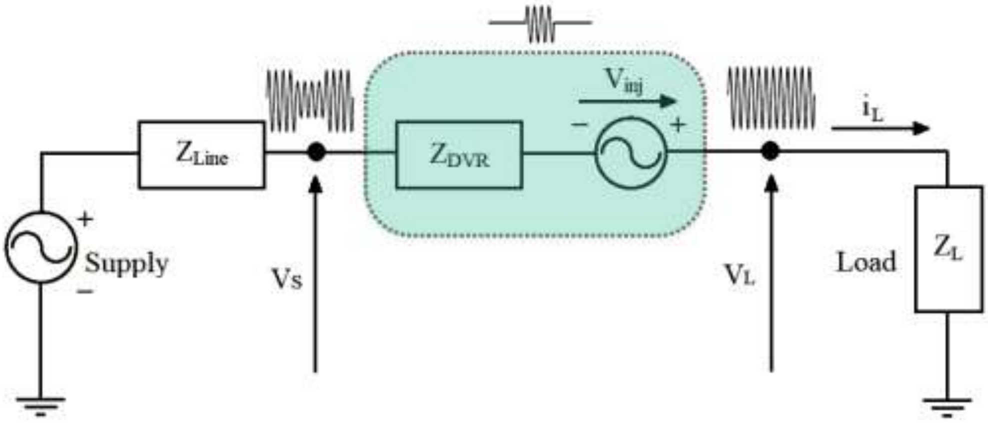

Fig 2. Equivalent circuit diagram of DVR. Based on data from [33]

Operation Modes

The DVR operates in three modes which are the protection mode, the standby mode, and the injection mode.

Protection Mode

DVR is protected from high current on the load side that exceeds an allowable limit in this mode of operation. The DVR may be damaged by the excessive current induced by malfunctions on the load side. As a result, such fault currents must be safeguarded from the DVR. Breakers and thyristors, can provide an alternative avenue for this. Overvoltage occurs in the injection transformers when this alternative path is not considered.

Standby Mode ($Vinj$ = 0)

The DVR does not inject electricity in this mode because no voltage disturbances are observed. As a result, the bypass switch turned off the DVR, preventing any possible voltage injection. When a voltage disturbance is detected, the injection transformer's low voltage winding is short-circuited using the VSI.

Injection Mode (Vinj > 0)

If a voltage disruption is detected, the DVR changes from standby mode to this mode of operation. The DVR then injects the desired voltage into the injection transformer until the voltage is completely minimised and returned to normal.

DVR: Power Circuits

As can be seen in Figure 1, a typical DVR, in general, includes injection transformers, VSI, energy storage unit, passive filters.

Energy Storage Unit and DC-Link

Throughout the compensation stage, the energy storage device and DC-link deliver the real power and required energy for the DVR. AC/DC rectifiers (topology without energy) or rechargeable storage systems (topology with energy storage) use this energy storage unit. If the grid to which the DVR linked is insufficient, the latter topology is employed, which includes technologies like as BESS, UCAP, SMES, and FESS.

Although BESS has a limited lifetime, which necessitates a costly maintenance system and raises the storage system's cost, UCAPs cover the entire voltage range, have a quicker charge time, and a longer lifetime. As a conclusion, employing UCAPs is a viable option. When the grid is stable, the voltage that remains on every side (supply or load) is used to supply the DVR with the voltage it requires .In this topology, AC/DC/AC converters are employed.

Series Booster/Injection Transformer

The injection transformers connect the DVR to the grid via HV windings, transforming and coupling the injected voltages created by the VSI to the supply voltage, and isolating the load from the grid. However, in other topologies, the DVR does not have a transformer. Transformer-less DVR (TDVR) is a DVR topology that has no saturation or inrush current concerns. The configuration of the transformers can be open-delta or open-star. When a delta-star transformer is used, zero-sequence voltages do not travel through the transformer. As a result, voltages in the positive and negative sequences must be balanced. An open-delta injection transformer that can maximise the usage of DC-link voltage is highly suggested for this purpose. Zero-sequence voltages must be regulated for an earthed star–star transformer. An open-star injection transformer is utilised to do this.

Voltage Source Inverter

The VSI is used in the DVR to convert DC voltage (energy storage or DC-link) to any desired magnitude, frequency, or phase angle. The load voltage is therefore kept balanced. The VSI's voltage must be introduced into the transformers in a controlled and sensible manner. In the DVR, there are numerous power converter topologies that will be discussed in Section.

Harmonic Filter Unit

Because high-frequency switching harmonics are present in the inverter's output as a result of applying high-frequency switching techniques, a low-pass harmonic filter is utilised to reduce or eliminate these harmonic contents. These filters can be used on the injection transformer's low voltage LV (inverter) or high voltage HV (load) sides. High-order harmonics do not propagate into the transformer in the former; as a result, the transformer's rating does not increase. Although the voltage load on the transformer is reduced, phase shift and voltage sag may occur .As a result, when the filter is used on the low-voltage (inverter) side, the filter's design is critical .In the latter, the filter is applied on the load side, which implies that no phase shift occurs, but harmonics can propagate into the HV side of the transformer, resulting in higher transformer rates.

DVR: System Topologies

Depending on energy storage, or the lack thereof, there are two topologies of the DVR Figure 3 shows the categorization of the DVR that has or lack energy storage.

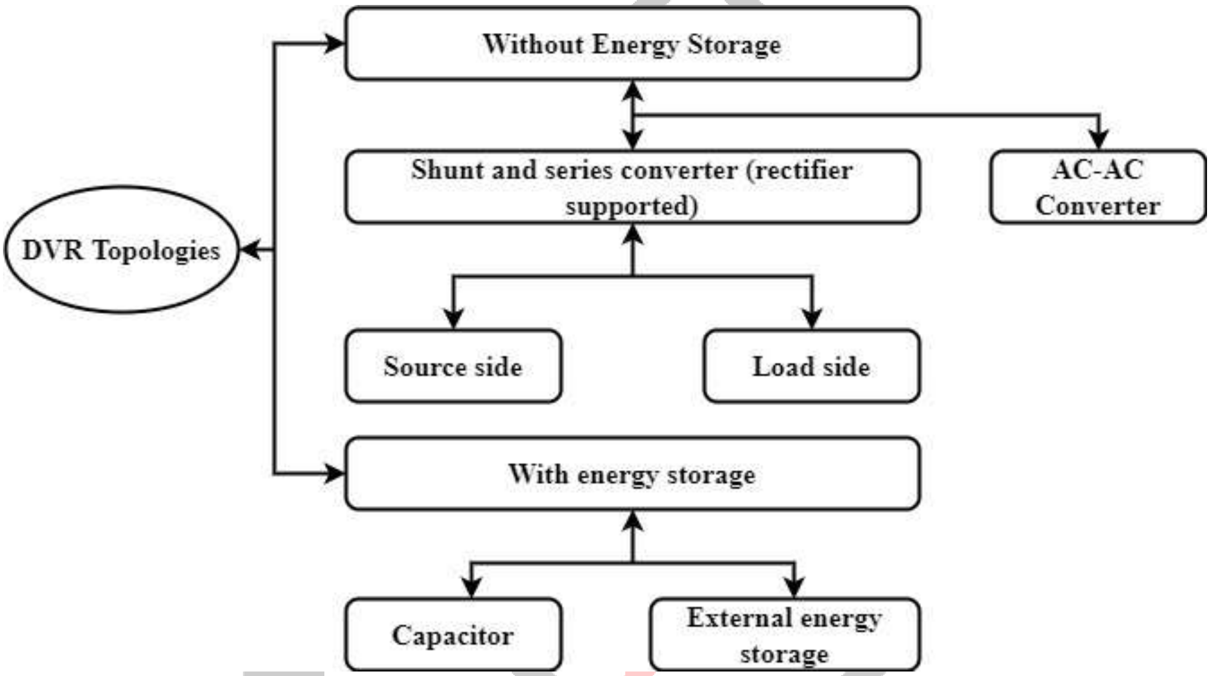

Fig 3: DVR topologies from the energy storage perspective

DVR: Control Unit

The fundamental function of the control unit in DVR as an integral aspect of DVR is to control the magnitude, frequency, and phase angle. From selecting the operation mode and detecting voltage disturbances to pulse generation for VSI and injecting the necessary Energies voltage, the control unit comprises various stages .

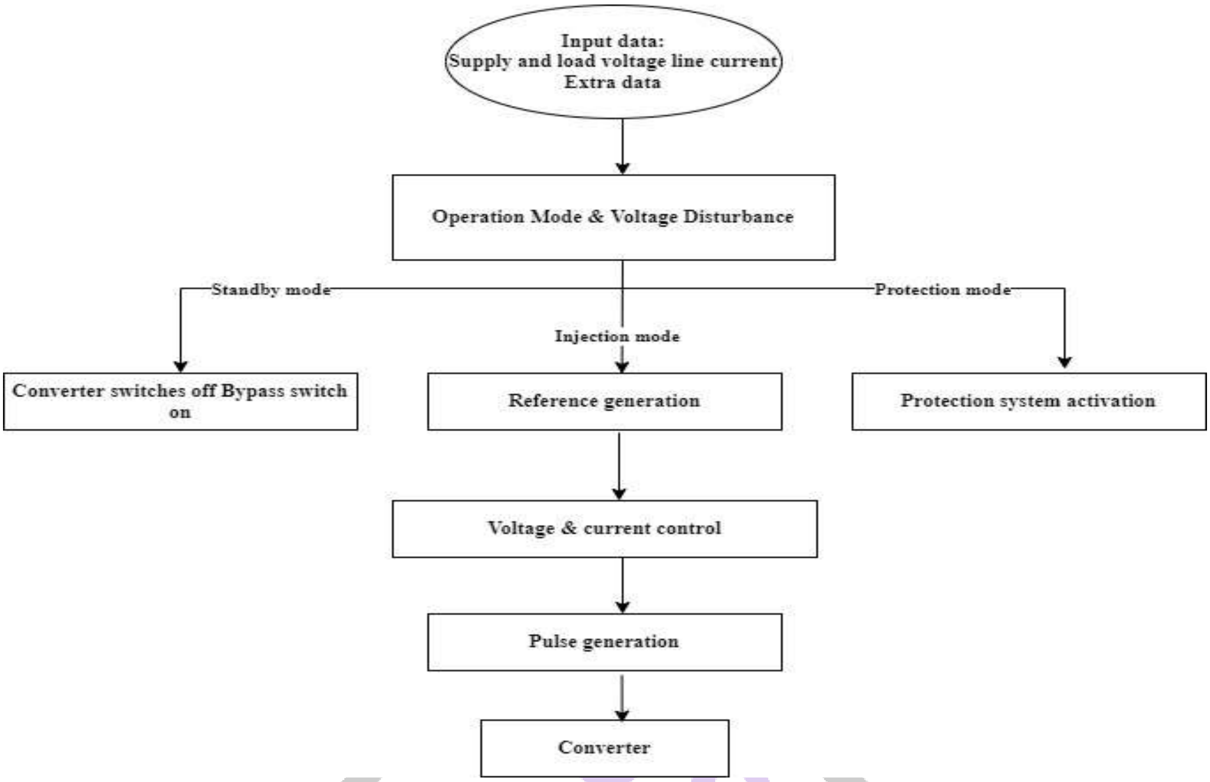

Fig 4: Different stages of the control unit in the DVR

IV. Series Injection Transformer

It offers the device with electrical isolation and boosting of voltage. In a three-phase configuration, either three 1Ø isolating transformers or a 3Ø isolating transformer is utilized for injection of voltage. The estimated potential output voltage is determined when choosing an injection transformer, both technically and economically. The turn ratio of the series injection transformer is determined by minimum voltage at DC-link before the distribution system level is balanced by DVR and the largest sag is balanced by VSI. The direction of the filter system, i.e. filter side system at inverter & filtering at line side, affects the influences in transformer of increased order harmonics. The proposed system employs three single-phase isolating transformers with a ratio of unity. On the inverter side, LC style filters are used to deliver filtered and regulated VSI voltage to the injection transformer.

The injected voltages are introduced into the distribution system through an injection transformer connected in series with the distribution feeder. It is known that in order to guarantee the maximum reliability and effectiveness of this restoration scheme, clever selection of the injected transformer is a prerequisite. In order to carefully select a suitable injection transformer the following issues should carefully be addressed:

- The MVA value
- The voltage and current ratings of the primary winding
- The secondary winding voltage and current rating are determined by the turn-ratio
- The impedance of a short circuit The following system parameters are used to determine the above parameters:

➢ The MVA rating of the safeguarded sensitive load
➢ The maximum voltage drop across the transformer that can be tolerated,
➢ The features of the voltage sags intended to be balanced for,
➢ The harmonic filter system's design
➢ The switching devices that were chosen
➢ The voltage restoration control technique and energy storage capacity

V. PHOTO VOLTAIC SYSTEM

The sun is a renewable energy source that is both environmentally beneficial and long-lasting. The sun's energy is directly received for electricity generation via photovoltaic cells .Photovoltaic (PV), which converts sunlight into energy using the photovoltaic effect, is one of the most important solar power techniques. Solar cells are the fundamental component of photovoltaic modules that generate electricity from light energy via the photovoltaic effect. The efficiency of a PV module is determined by the material used in photovoltaic cells and the method used to assemble the solar cells into a module. The conversion of sunlight to electric energy efficiency of solar modules is around 12-29 percent . Solar cells made of gallium arsenide have a maximum efficiency of 29 percent, while solar cells made of silicon have a maximum efficiency of 12-14 percent. Temperature in the PV module and load circumstances can both reduce PV module performance. As a result, optimal power point operating of the PV module is critical for increasing power derivation. This controller, known as the maximum power point tracker, is required to achieve this goal. PV cells are made from a variety of materials.

The most common silicon processes are mono-crystalline and polycrystalline. Because a conventional solar cell produces less than 2W around 0.5V, a solar panel is constructed by connecting several cells in series to produce the requisite voltage.As a result, the panels are arranged in an array. An array's series connection produces a high output voltage. If the PV cell does not receive any solar radiation during the process, it becomes a p-n junction diode. Due to the interaction of light photons with the cell atom, pairs of electron holes are generated when solar radiation falls on the PV cell. The photogenerated electron-hole pair is divided by the electric field produced by the cell junction, with electrons and holes migrating to the n and p regions of the cell. This movement generates a photo current that is mostly dependent on the intensity and wavelength of solar light. If solar radiation does not fall on a PV cell, it becomes inactive and works as a p-n junction diode, as previously stated. PV cells do not generate current or voltage in this state. When a cell is connected to an external large supply, it creates a currentI D, which is known as dark current.

The power conversion PV system includes of a series and parallel combination of PV modules, a tracking controller, and power converters such as DC-DC converters and inverters. As a result, the DC voltage created can be amplified using a DC-DC converter and then converted to AC using an inverter. The PV panel should be chosen based on the load rating.

The electrical equivalent diode model of PV cell is given below:

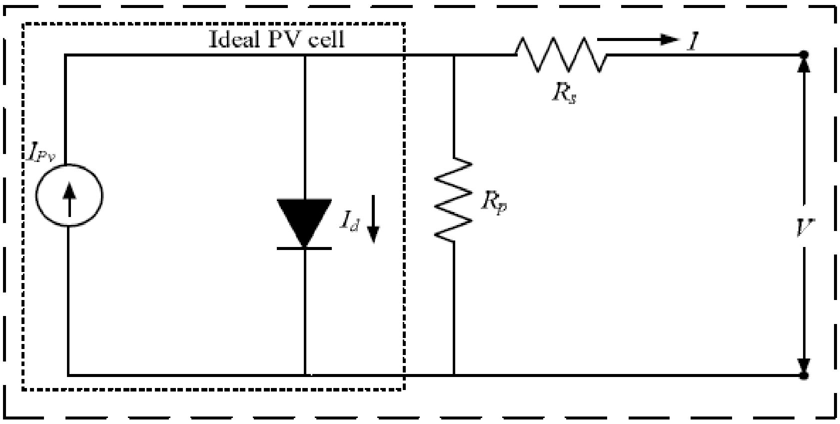

Fig 5 Equivalent circuit of PV cell

The PV model constitutes current sources, diode Shunt resistanceR_{sh}, Series ResistanceR_s. Shunt Resistance R_{sh} represent the cell surface leakage through the edges.

The total current I is the difference of the light generated current I_{ph}, diode current I_d and current through R_{sh}

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

Diode current I_d and Shunt Resistance current I_{sh} is presented by Equations (2) and (3)

$$I_d = I_0\left\{\exp\left[\frac{q}{mkT_c}(V + IR_s)\right] - 1\right\} \quad (2)$$

$$I_{sh} = \frac{V+IR_s}{R_{sh}} \quad (3)$$

m = Idealizing factor
K = Boltzmann constant
T_c = Absolute temperature of cell
q = Charge of electron
V = Potential across cell
I_0 = Cell reverse saturation current

By utilizing Equations is shown below

$$I = I_G - I_0\left\{exp\left[\frac{q}{mkT_c}(V + IR_s)\right] - 1\right\} - \frac{V+IR_s}{R_{sh}} \quad (4)$$

Usually shunt Resistance R_{sh} in PV cells is high hence $\frac{V+IR_s}{R_{sh}}$ is eliminated

Hence,

$$I = I_G - I_0\left\{exp\left[\frac{V+IR_s}{A}\right] - 1\right\} \quad (5)$$

Where A=curve fitting parameter

$$A = \frac{mkT_c}{q} \quad (6)$$

Determination of phase current I_{ph}

According to Figure 4.1 output current at standard test condition is

$$I = I_{ph} - I_0 \left[exp\left(\frac{V}{a}\right) - 1\right] \quad (7)$$

When PV cell is short circuited

$$I_{sc} = I_{ph} - I_0 \left[exp\left(\frac{0}{a}\right) - 1\right] = I_{ph} \quad (8)$$

Only in ideal case Equation (8) is valid. Hence the equality is not accurate. Equation (9) is written as

$$I_{ph} \approx I_{sc} \quad (9)$$

The photocurrent depends on both irradiance and temperature

$$I_{ph} = \frac{G}{G_{ref}}(I_{ph} + \mu_{sc}.\Delta T) \quad (10)$$

G=irradiance

G_{ref}=irradiance at standard testing conditions

Determination of I_0

The shunt Resistance is usually high for all applications and hence eliminated by using 3 standard conditions

Open circuit voltage $(\mathrm{I} = 0, \mathrm{V} = V_{oc})$

Short circuit current $(\mathrm{V} = 0,\ \mathrm{I} = I_{sc})$

The voltage (V_{mp}) and current (I_{mp}) at maximum power the following equation are written as

$$I_{sc} = I_{ph} - I_0 \left[exp\left(\frac{I_{sc}.R_s}{A}\right) - 1\right] \quad (11)$$

$$O = I_{ph} - I_0 \left[exp\left(\frac{V_{oc}}{A}\right) - 1\right] \quad (12)$$

$$I_{pm} = I_{ph} - I_0 \left[exp\left(\frac{V_{pm}+I_{pm}R_s}{A}\right) - 1\right] \quad (13)$$

Term (-1) is eliminated as it is very small compared to exponential term. According to Equation (10) substituting (I_{ph}) in Equation (13)

$$0 \approx I_{sc} - I_0 exp\left(\frac{V_0}{A}\right) \quad (14)$$

Hence

$$I_0 = I_{sc}\ exp\left(\frac{-V_{oc}}{A}\right) \quad (15)$$

VI. PWM GENERATOR

PWM (pulse-width modulation) or PDM (pulse-duration modulation) is a technique for decreasing the average power produced by an electrical signal by splitting it up into discrete parts. By rapidly flicking the switch between supply and load on and off, the average value voltage and current provided to the load can be regulated. The higher the overall power supplied to the load, the longer the switch is on relative to the off times. It is one of the principal methods of decreasing the output of solar panels to that which can be used by a battery, along with maximum power point tracking (MPPT).PWM is especially well suited for running inertial loads like motors, which are less affected by discrete switching due to their inertia. The PWM switching frequency must be high enough to avoid affecting the load, which means the waveform seen by the load must be as smooth as possible.

The rate (or frequency) at which the power supply must switch might vary significantly depending on the load and application. An electric stove, for example, must switch several times per minute; a lamp dinner must switch at 100 or 120 Hz (double the utility frequency); a motor drive must switch between a few kilohertz (kHz) and tens of kHz; and audio amplifiers and computer power supplies must switch at tens or hundreds of kHz. The fundamental benefit of PWM is that it reduces power loss in switching devices. When a switch is turned off, there is almost no current, and when it is switched on and power is passed to the load, there is almost no voltage drop across the switch . Because power loss is the product of voltage and current, it is near to zero in both circumstances. PWM also works well with digital controls, which can quickly establish the required duty cycle due to their on/off nature. PWM has also been utilised in communication systems where the duty cycle is employed to transmit data over a communication channel.

VII. LUO CONVERTER

A voltage divider was the simplest kind of DC-DC conversion. Different modern DC-DC conversion technologies are now accessible. It includes everything from voltage lift to super-lift and ultra-lift techniques. Luo converters are a type of DC-DC converter that uses the voltage lift technique to work. These Luo converters work in a push-pull mode and are available in two types: switched capacitor and switched inductor. There are no inductors or transformers in the switching capacitor type Luo converter. It permits the controlled transfer of energy from an uncontrolled source to a regulated output voltage. This converter does a positive to positive DC-DC rising voltage conversion with a higher power density, higher efficiency, and a simpler architecture.

VIII. SIMULATION AND RESULTS

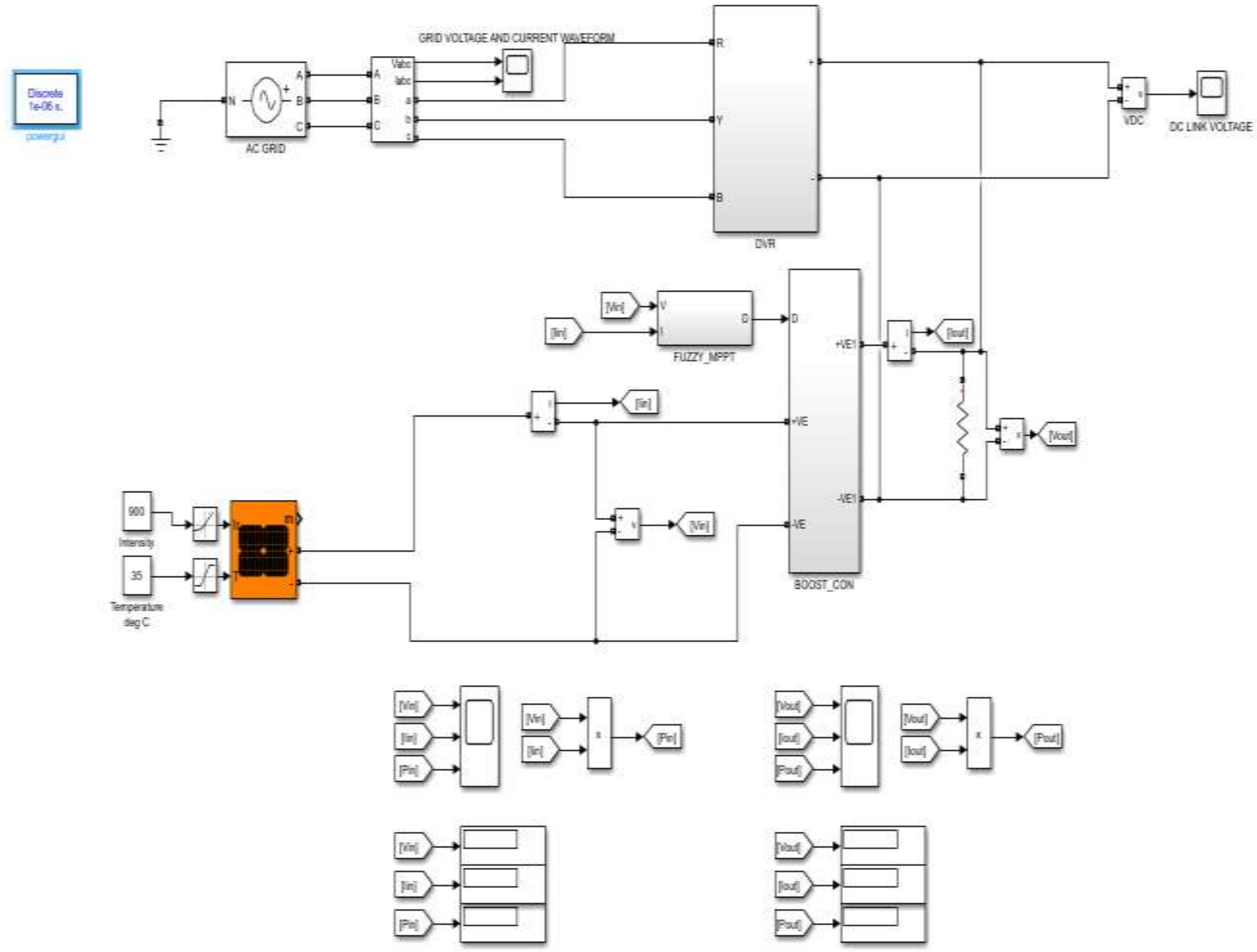

Fig 6: Simulation of Power Quality improvement in PV system using SPVI-DVR

The simulation results are examined using a software MATLAB/SIMULINK.

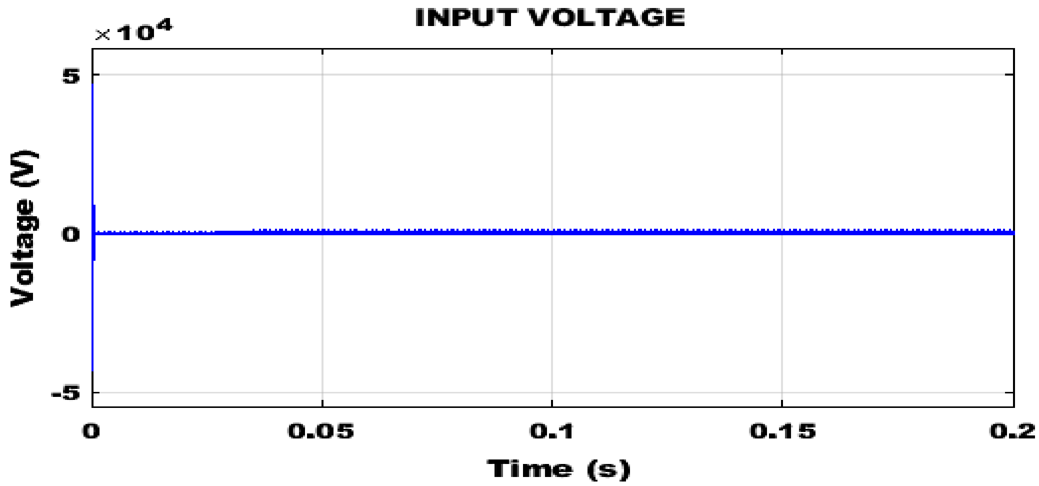

Figure 7 Input Voltage Waveform

Figure 7 indicates the waveform for voltage and it represents a constant Input voltage.

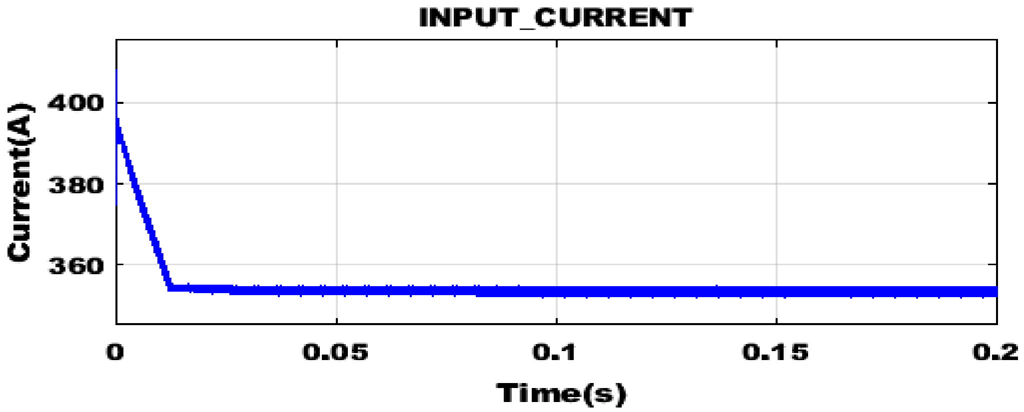

Figure 8 Input Current Waveform

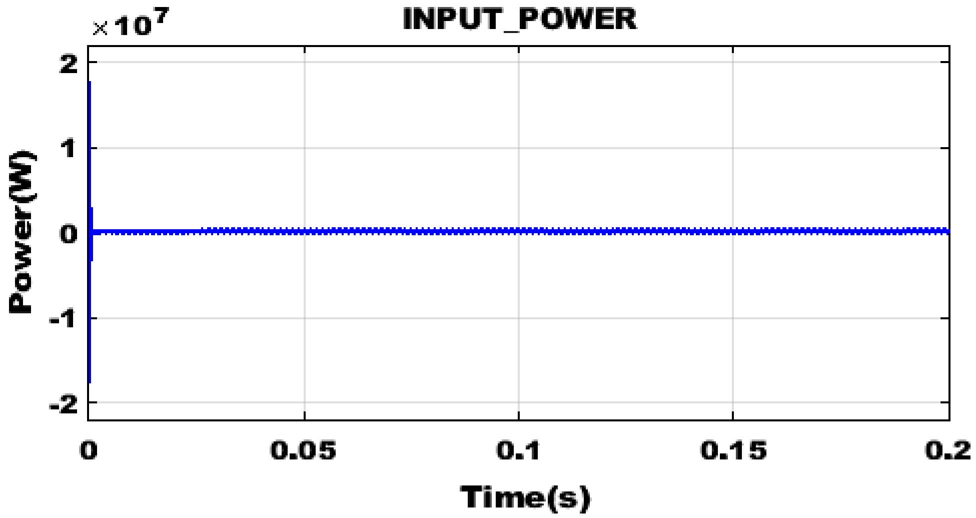

Figure 9 Input Power Waveform

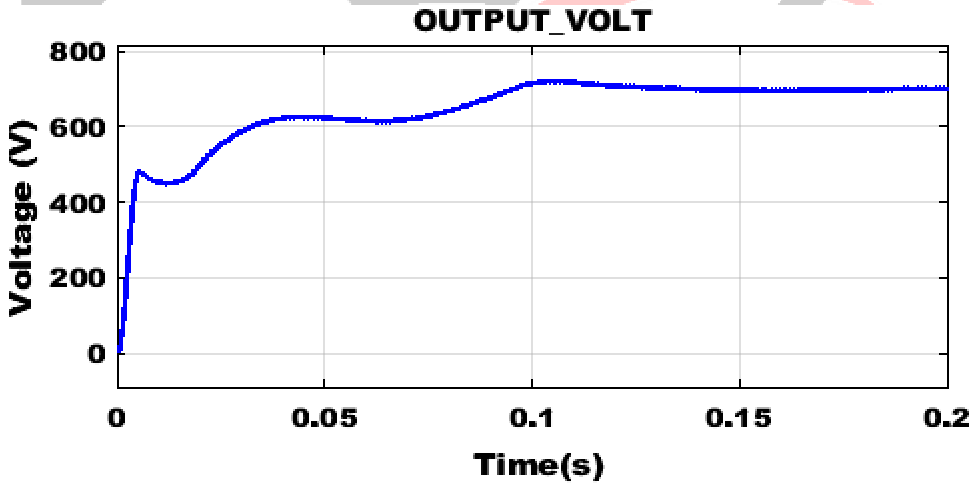

Figure 10 Output Voltage Waveform

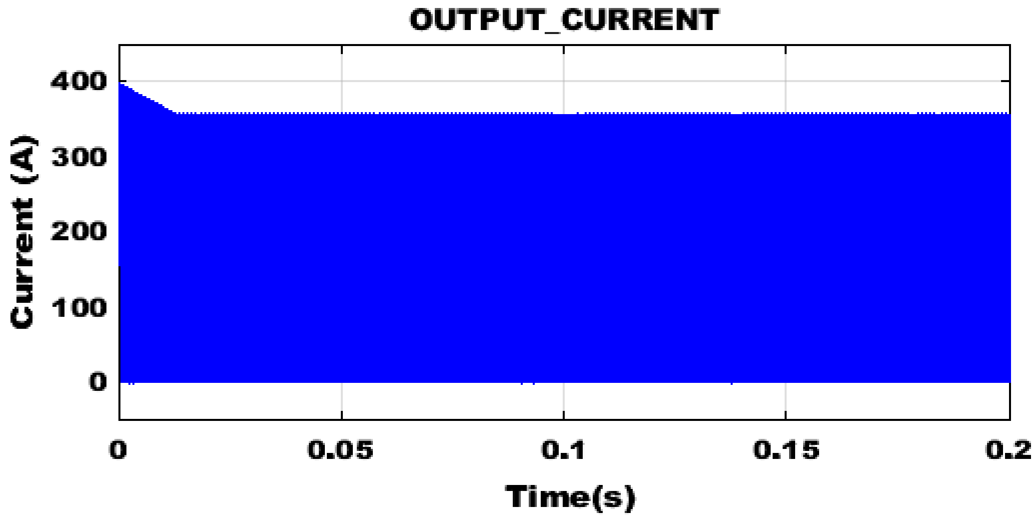

Figure 11 Output Current Waveform

The Figure 10 and 11 show the output voltage and current waveform of the LUO converter respectively, the Output Current waveform, the output will be a square wave.

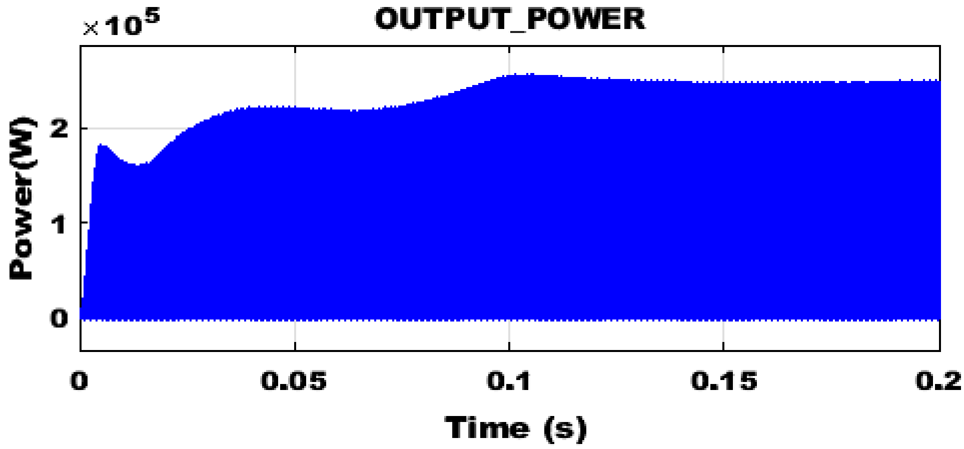

Figure 12 Output Power Waveform

The output power is around 2.5* 10^5 W, which is influenced by temperature and solar insolation variations.

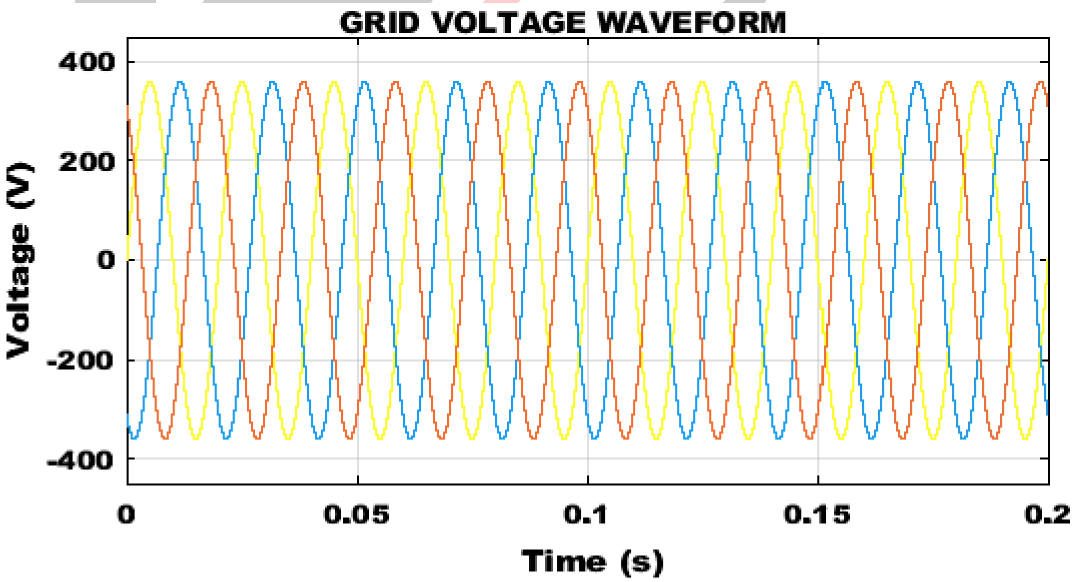

Figure 13 Grid Voltage Waveform

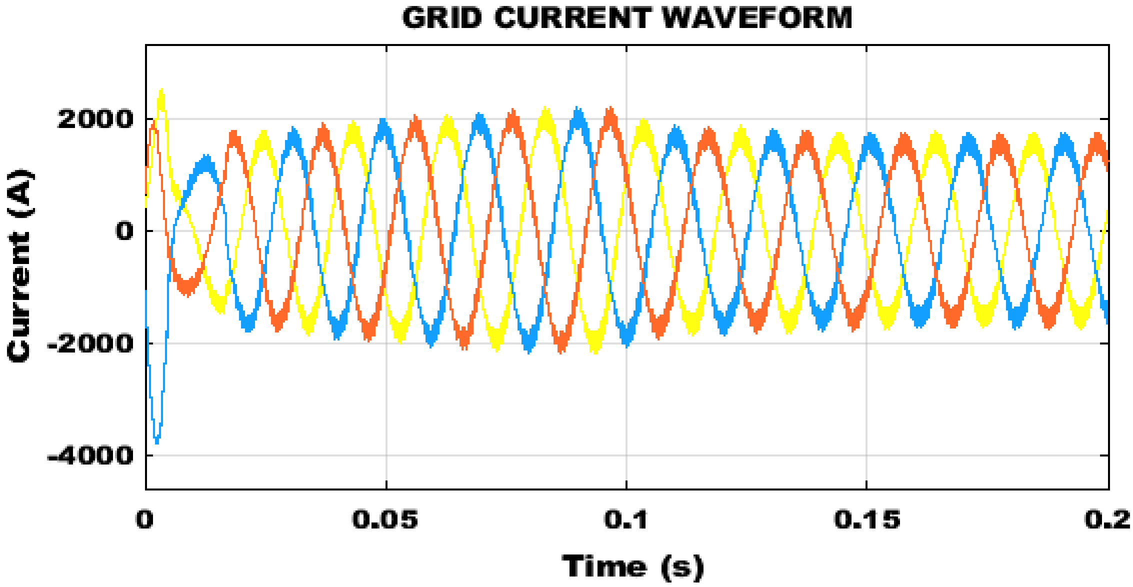

Figure 14 Grid Current Waveform

Figure 13, 14 shows the Grid voltage and current waveform, the voltage value ranges from $+380V$ to $-380V$ for varying period of time in seconds, and the Current value ranges from $+1800V$ to $-1800V$ for varying period of time in seconds .The Cascaded fuzzy logic controller based grid synchronization achieves reactive power compensation.

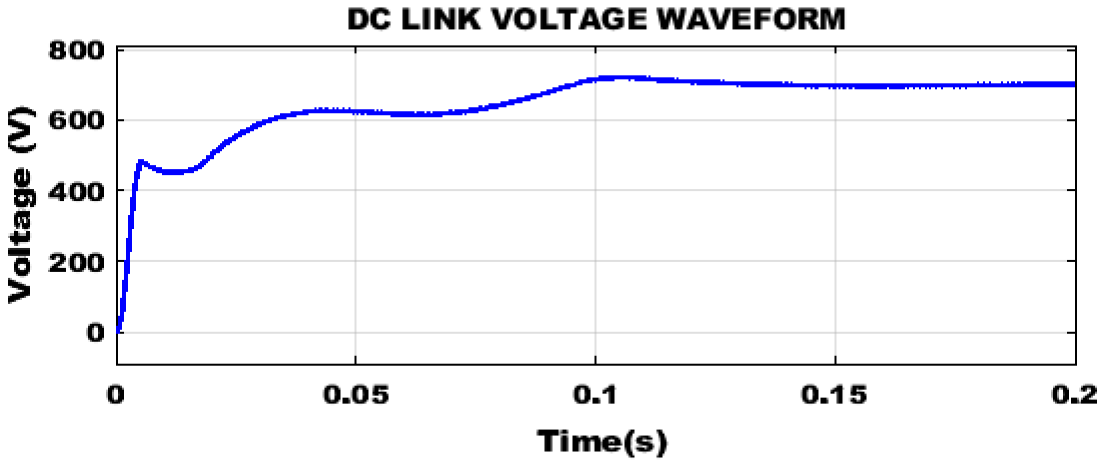

Figure 15 DC link Voltage Waveform

The DC link voltage produced by controlling the converter operation using Cascaded fuzzy logic controller is shown in Figure 12. When the converter is controlled by a conventional Cascaded fuzzy logic controller, the DC link voltage fluctuates and a stable voltage is not achieved. By implementing crow search optimized PI controller, the converter operation is effectively controlled and a constant voltage of $700\ V$.

IX. Hardware Prototype

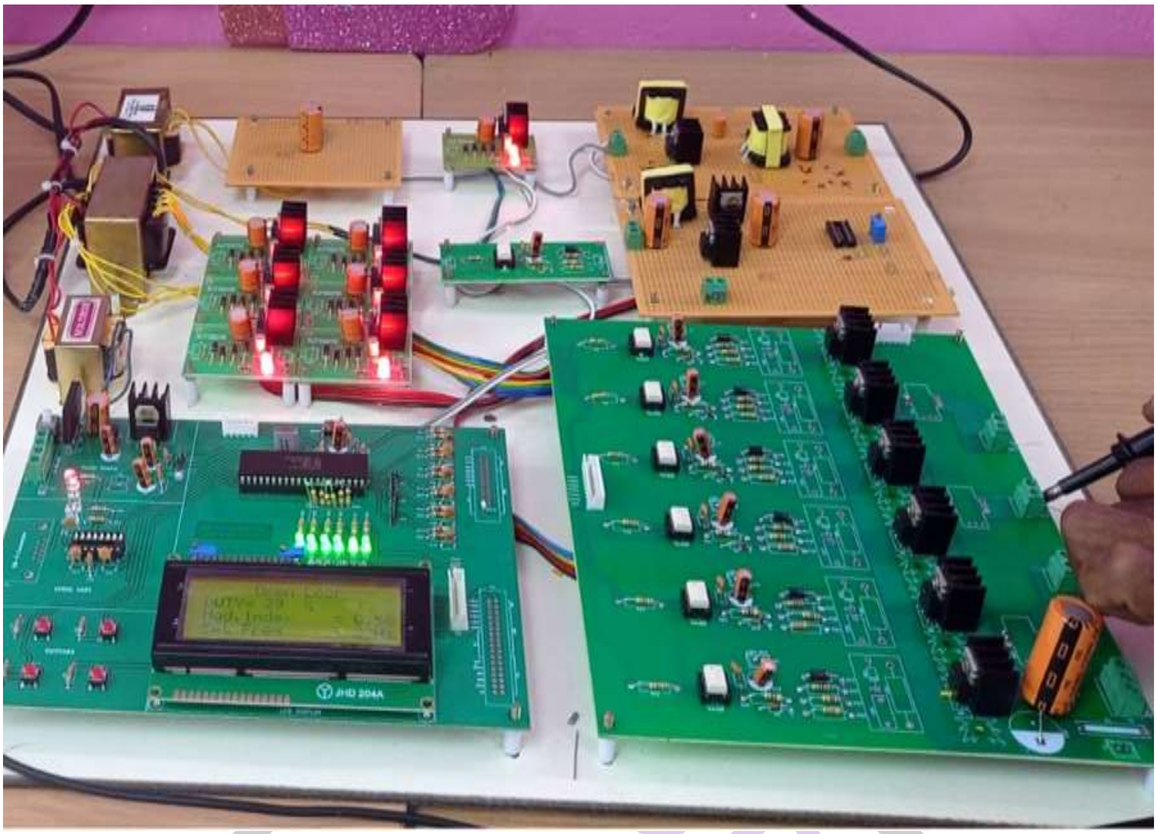

Figure 16 Hardware image

X. Conclusion

The DVR is one such effective and dependable solution for power quality issues. Because of the development of power electronics, major types of industrial load, like manufacturing of semiconductor and chemicals, are now vulnerable to fluctuations in power. The power companies as well as customers regard such cases when determining how to balance fluctuations in power while staying in the prescribed level. It is accomplished by utilizing custom power devices (CPD) at the sensitive load side, which is connected in shunt, series, or combining both, and DVR is a series style CPD, which is the major cost-effective operational option. The maximum power from the PV is monitored by the cascaded fuzzy logic controller, and the three phase inverter is operated by the fuzzy logic controller in this Project. The results are obtained after the proposed method is implemented in MATLAB.

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