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Novel Hybrid High Gain Buck Boost Converter based Energy Saving PI Controller with Photovoltaic Fed Dynamic Voltage Restorer (PV-DVR) System

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Abstract

Energy consumption and utilities have increased in the last two decades due to diversified applications in the field of science and engineering. Thus, energy saving have become an active research. It has become an essential criterion to take out system faults to ensure the efficient functioning of the overall system. The power quality issues concerned with voltage sag and they frequently cause serious power interruptions, if suitable care will not be taken in time. This work presents a novel PhotoVoltaic fed Dynamic Voltage Restorer (PV-DVR) model to alleviate deep voltage sags and outages on a low voltage residential distribution system. The application of low step up and high step up DC–DC converters used in the existing DVR system results in high conversion loss. Moreover, two control loops are required to control the two separate converters which results in higher control complexity. Thus, in this proposed work, two port hybrid high gain buck boost converter (TPHGC) is integrated in the existing PV-DVR system. Two converters used in the existing system are replaced with single battery charging bidirectional converter. Simulation results are presented to validate the advantage of the proposed system.

Keywords: DVR, Reactive Power, Compensation, Controller, Maximum Power Point Tracking (MPPT) Algorithm.

I. Introduction

In modern technology, there are two major challenges that power system must deal with: one is voltage fluctuations and the other is short circuit faults. Nowadays, many power loads have become more sensitive to the disturbances due to voltage fluctuations that are produced because of wide use of non-linear loads. Because of these disturbances or fluctuations quality of power being distributed or transmitted has become low. Faults in power system can cause voltage sag or swell in the entire system or major part of it. In addition, harmonics, voltage transients, flickers are also one of the voltage quality problems [1]. Voltage sag can occur at any instant of time ranging from 0.1 to 0.9 p.u and that lasts for half a cycle to one minute [2]. Voltage sag can be either balanced or unbalanced which mainly depends on type of fault. The main sources of voltage sag are any type of fault in power system or by the starting of large motor loads. Mainly, voltage sags are considered as major threats to the power quality. Similarly voltage swells occurs at any instant of time ranging from 1.1 to 1.8 p.u and that lasts for half a cycle to one minute. But voltage swells are less frequent compared to that of voltage sags which are mainly produced because of sudden switching off of large loads or energization of capacitor banks [3]. Due to these faults, under full load conditions, it may cause severe or high voltage drops in the system. Due to these disturbances, system may undergo shutdown or fail including large voltage and current imbalances in the system. Various techniques can be adopted or used by the customer in order to mitigate these voltage sags / swells to have better quality of power supply to the equipment for its effective functioning. But, the effects that are caused by the voltage sag or swell to the equipment may be expensive to the customer. But, there are many techniques available for compensation of voltage sag and swell, in which installation of custom power device is the adequate method for mitigation of voltage sag and swell. This concept of installing custom power device is being introduced by N.G Hingorani in 1995 [3]. Installation of custom power device means use of power electronic controllers in power system to deal with various power quality problems. The main intension to deal with various power quality problems is to ensure the users get a good quality and trust worthy supply. There are many custom power devices available for providing solution to the different power quality problems, but DVR is considered as the most apt solution for the mitigation of voltage sag and swells in the power system [4,5].

The concept illustrated in [6] is DVR usage address issues of voltage sags and outage improvement in the absence of the PV system. In [7] shows the series injection transformer's architectural design and its rating. There are several researches that have been conducted that focus on the designing and control system of DVR [8]. The on-line kind of DVR as discussed in [9] has been offered in lieu of compensating the system's voltage sag. In the electrical distribution system, the DVR which does not have the PV system, is additionally propped up by the energy storage tool which is the super capacitor and aids in power quality enhancement as presented in [10]. The PV operated DVR here plays the role of compensating for the system's voltage sag as presented in [11]. In the above mentioned DVR models, there are no monetary customer benefits. So, proposed a PV-DVR model which overcomes the limitations of the above mentioned models. This work has been taken as the motivation of this research work. The main objective of this research work is to design a modified converter section presented in [12].

Ramasamy et al (2013) [12] designed a conventional PV-DVR which is shown in Figure 1. In this existing PV_DVR system, two types of converters namely low step up and high step up have been used [13, 14]. To control the low step up DC–DC converter, the P&O MPPT algorithm is used [15, 16, 17]. Similarly, in order to control the high step up DC-DC converter, outer voltage control based closed loop system is used. These two conversions results in high conversion loss as two converters are used in the existing system. The battery presented in this existing system charges through low step up converter where as the discharging operation takes place through high step up converter. Thus, two converters are used in this existing system. Moreover, a charging controller has also been used to state of charge (SOC) of the battery as shown in Figure 1. Three controlling techniques are used. The battery charger controller with two bypasses switches R_1 and R_2 has been used in the existing system. Considering a scenario, wherein the battery gets fully charged, the excess voltage from the PV array may not be utilized by the battery which results in wastage of power. Thus, in the existing system, the efficiency gets reduced with increased control complexity. On the other hand, the cost and system size also gets increased.

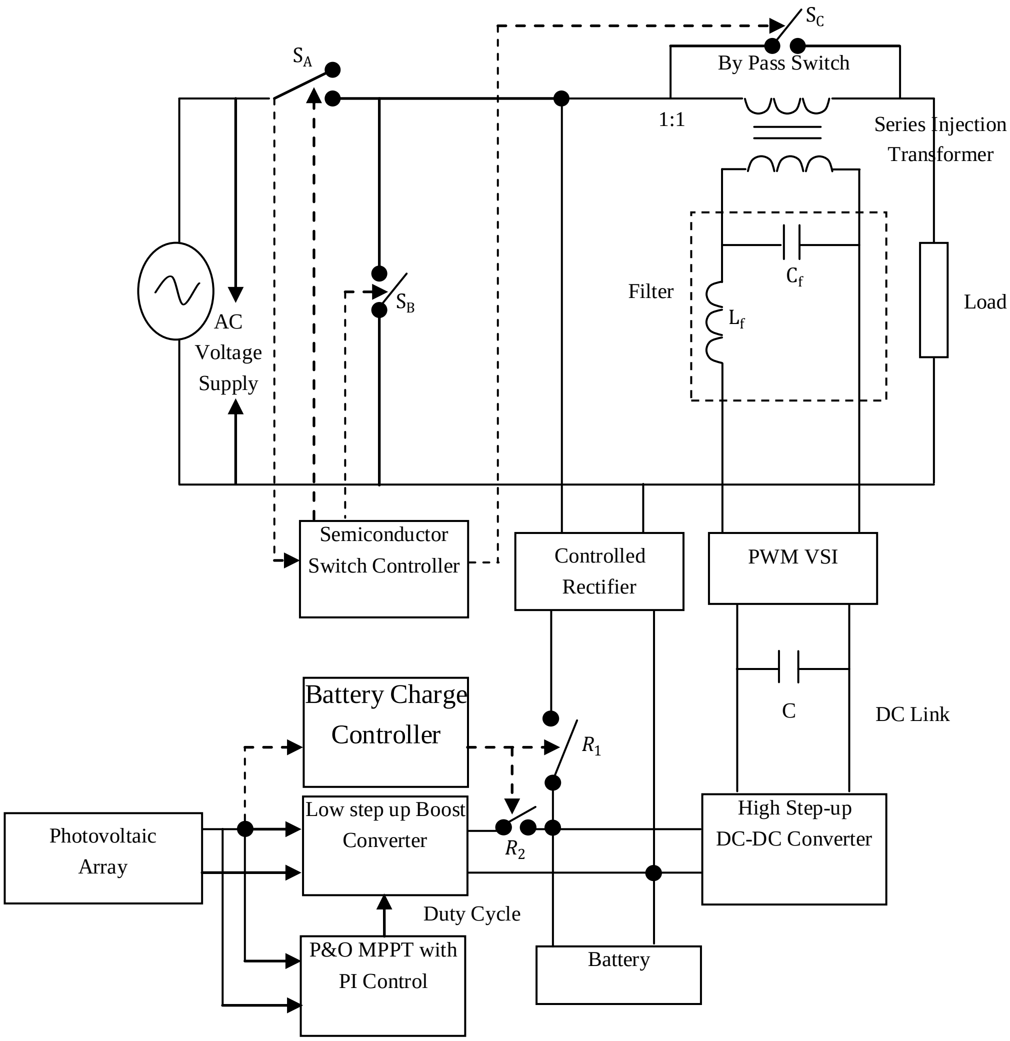


Figure 1: Block Diagram of Conventional PV-DVR

The battery charge control logic is shown in Table 1.

Tab 1: Battery Charge Control

PV voltage in volts	Control Signal		Battery charging unit
	R_1	R_2	
>6	0	1	PV array
<6	1	1	Rectifier and PV array

In this research work, in order to overcome the drawbacks of the existing system, two port hybrid high gain buck boost converter (TPHGC) is integrated in the existing PV-DVR system. In this proposed PV-DVR system, PV array and battery represent the two port section. Two converters used in the existing system are replaced with single battery charging bidirectional converter as shown in Figure.2. The proposed PV-DVR system operates in three modes of operations as described below.

1. PV Power = Output Power (Ideal)
2. PV Power > Output Power (Battery Charging)
3. PV Power < Output Power (Battery Discharging)

II. System Description

Figure 2 shows the proposed PV-DVR architectural design with the novel TPHGC. The proposed PV_DVR system comprises of the battery, a PV array, PWM inverter, and series injection transformer, TPHGC and semiconductor switches marked as S_A, S_B& S_C. Normally S_A and S_C are closed and S_B open when grid voltage is a state of normal. On the other hand, when S_A and S_C are open and S_B is closed, then system acts in UPS mode. Similarly, sag compensation mode occurs when S_A is closed, S_B& S_C are open.

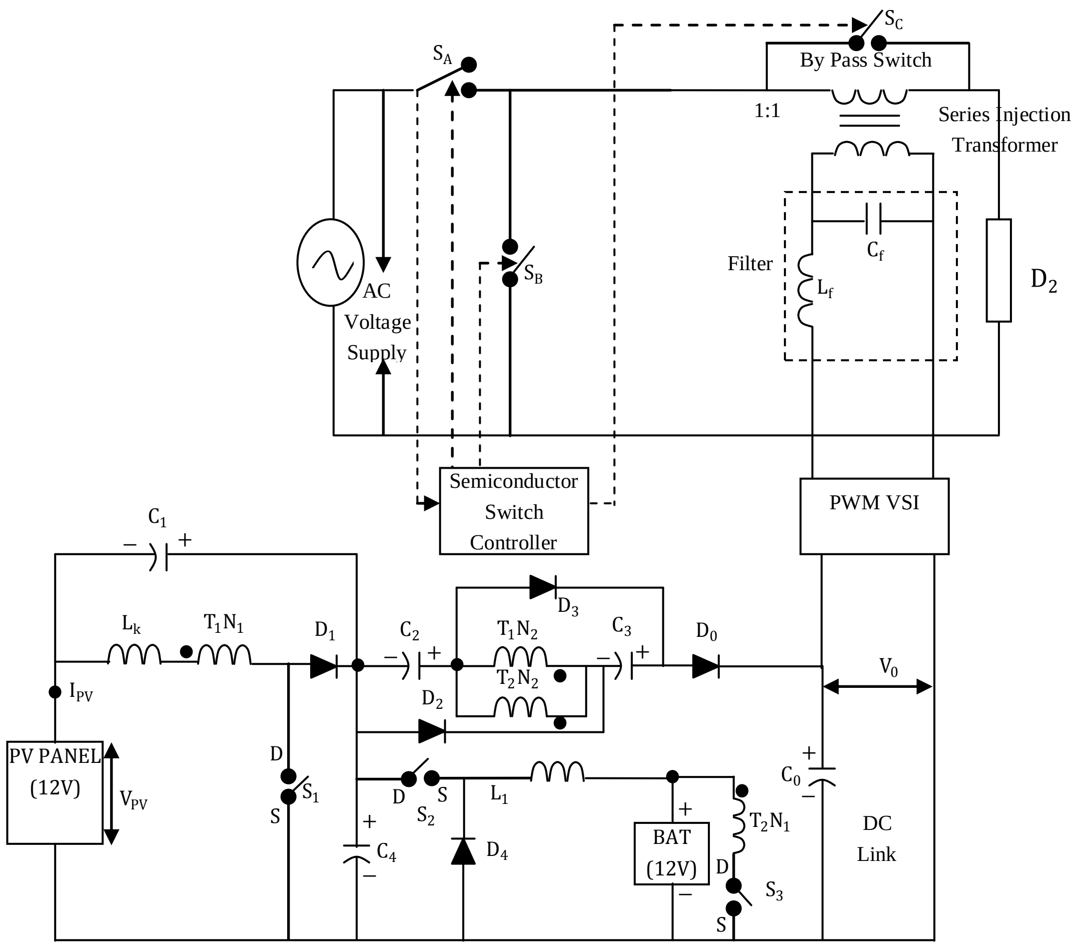


Figure 2: Proposed Two Port Hybrid High Gain Buck Boost Converter based PV-DVR System

Table 2 shows the semiconductor's control signals as switches S_A, S_B& S_C. The functioning of the proposed PV-DVR in three modes is discussed in detail:

1. The idle or maintenance mode: The PV-DVR during this mode is completely disconnected in the semiconductor switchS_C. This is done in the secondary by passing the injecting transformer wherein maintenance is required by the DVR.
2. The compensation mode also known as DVR mode: Proposed PV-DVR in the compensation mode is used to bring in a state of voltage regulation in the load side. In this process the load basically compensates voltage sags are configured sequentially in the series injection transformer.
3. Uninterruptible Power Supply (UPS) mode: During the UPS mode, PV-DVR series injection transformer is basically configured again as parallel so that it supplies the load with an uninterruptible power supply both during the day as well at night.

Tab 2: Control Signal for S_A, S_B and S_C

Supply Voltage in %	Control Signal			Mode of Operation
	S_A	S_B	S_C	
100	1	0	1	idle
<100	1	0	0	DVR
0	0	1	0	UPS

Mode of Operation

i. PV Power=Load Power

Five Mode of operation is shown in Figure 3. This mode of operation clearly describes the condition when the load power is met (satisfied) by the PV power.

Mode 0

In this mode ($S_1 = ON$), initially the current from PV flows through the transformer T_1N_1 and the switch S_1 to get neutralized. Thus, the current flow through the transformer T_1N_1 , creates a flux which in turn generates the current flow in the secondary winding of the transformer T_1N_2. At this point of time, two circulating paths are created which charges capacitor C_2 and C_3.

The current flowing path for charging the capacitor C_2 is initiated from the secondary winding of the transformer T_1N_2 and charges the capacitor C_2 then flows through the diode D_2 which completes the circulating path.

Similarly, the current flowing path for charging the capacitor C_3 is initiated from the secondary winding of the transformer T_1N_2 and flows through the diode D_3 and then charges the capacitor C_3 which completes the circulating path.

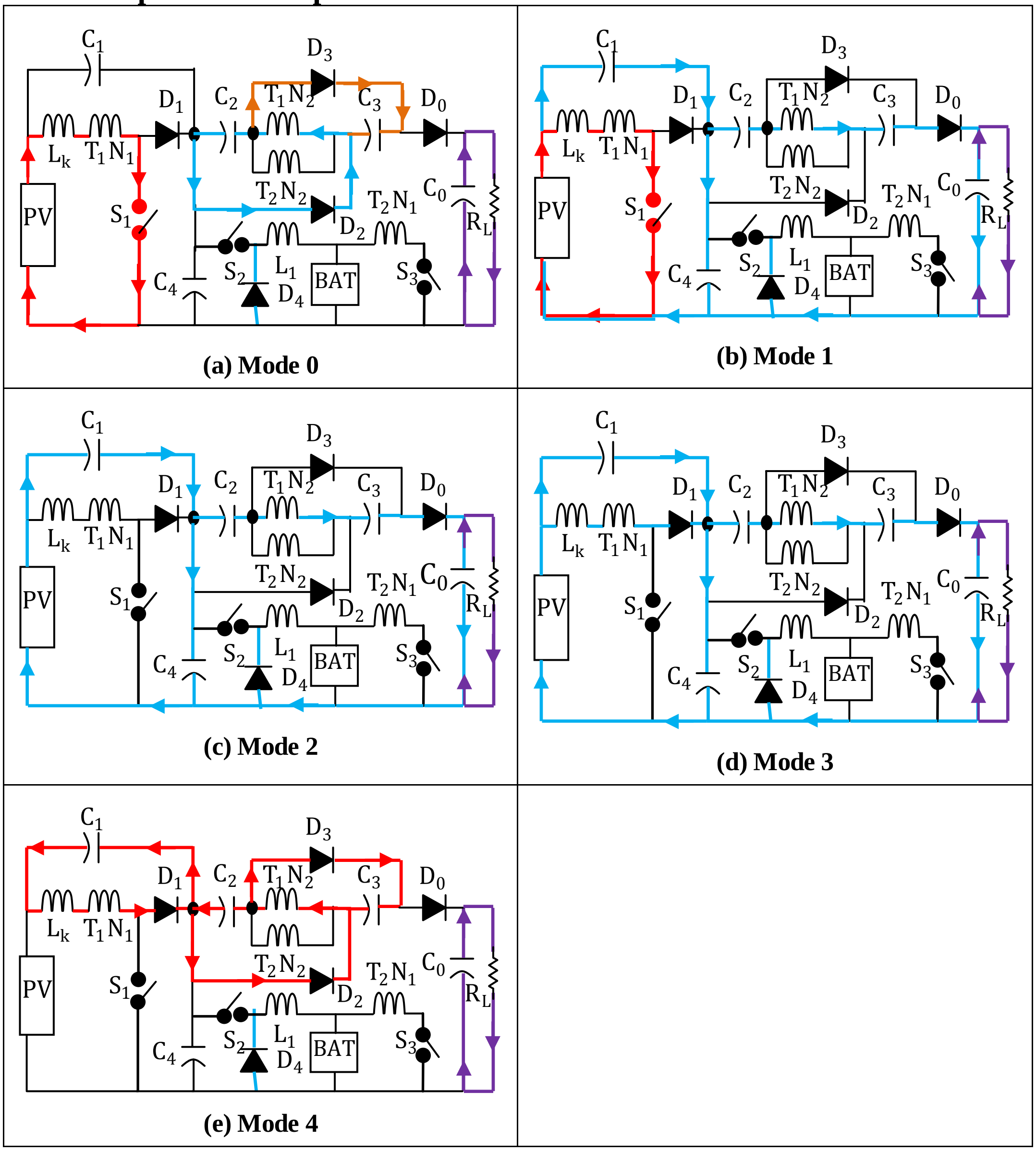
Mode 1

The initial current flowing path of Mode 1 is same as discussed in Mode 0. At this time, extra current in the inductance flows through the capacitors C_1 and C_2 and energies the secondary winding of the transformer T_1N_2. Then the current flows through capacitor C_3. Thus, the capacitor C_1, C_2 and C_3 are in series and stores the voltage in capacitor C_0 which results in high gain mode operation.

At this point, a circulating path is created which charges the capacitor C_4 through the capacitor

C_1 and gets neutralized at PV.

ii. PV power=Load power



(a) Mode 0 **(b) Mode 1**

(c) Mode 2 **(d) Mode 3**

(e) Mode 4

Figure 3: Mode of Operation PV power=Load Power

Mode 2

In this mode S_1 is in OFF condition. This mode is almost similar to the mode 1, which is based on the linear discharge of T_1N_2 as shown in Figure 3(c).

Mode 3

This mode is also called as leakage inductor discharge mode. This is same as the mode 2 but leakage inductance of the transformer gets discharged through diode D_1 and stores the voltage across the capacitor C_0 and gets neutralized at PV as shown in Figure 3(d).

Mode 4

In this mode, capacitor C_1 is in full discharged condition. Now, the voltage stored in the capacitor C_1 gets discharged and energies the transformer T_1N_1 and flows through the diode D_1 and gets neutralized. At this point, current through the transformer T_1N_1 creates a flux which in turn generates the current flow in the secondary winding of the transformer T_1N_2 which in turn produces two circulating paths (C_2 & C_3 capacitor charging) as mentioned in mode 0 as shown in Figure 3(e).

iii. PV power>O/P power

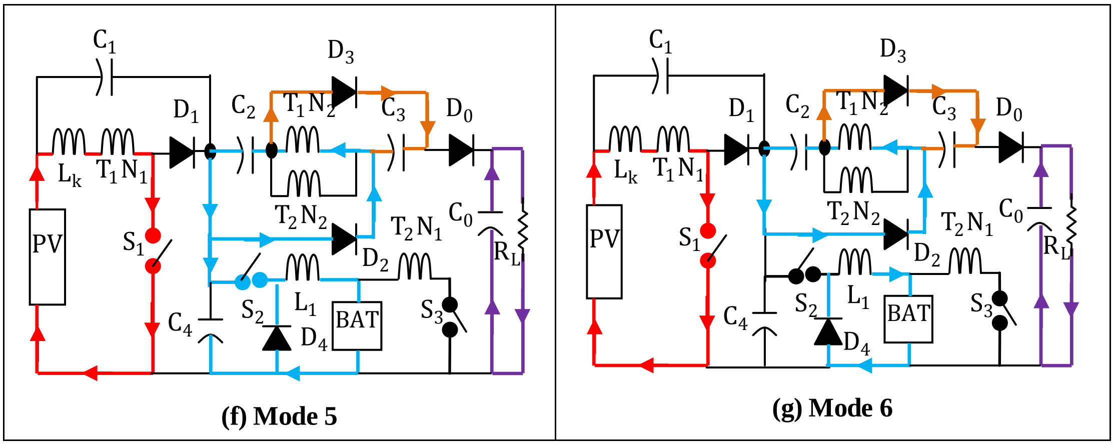


Figure 4. Mode of Operation PV Power>Load Power

In this 'PV power>O/P power' condition, the generated PV power is greater than the load power and now, this excess PV power is efficiently stored in the battery through the buck mode of operation. All modes of operations (Mode 0 to Mode 4), occurred in PV power=load power condition, is same for this operation. Moreover, controlling the switch S_2 in the proposed converter is the main aspect which makes the change over from the previous "PV power=load power" condition. At the time when excess power is sensed in the system, switch S_2 is in ON condition. Based on the previous mode of operation, capacitor C_4 is in fully charged condition and when the switch is closed it results in increase of current, and an opposing voltage across its terminals is generated by the inductor due to the varying current. This voltage drop cancel outs the voltage of the source and thus minimizes the net voltage across the battery. In the mode (5), the current from C_4 flows through the inductance L_1 and charges the battery which then gets neutralized at capacitor C_4 as shown in Figure 4 (f) mode 5. In mode 6, when switch S_2 is in OFF condition, the inductance L_1 completely discharges through the diode D4 to charge the battery as shown in Figure f (g) mode 6.

iv. PV power<O/P power

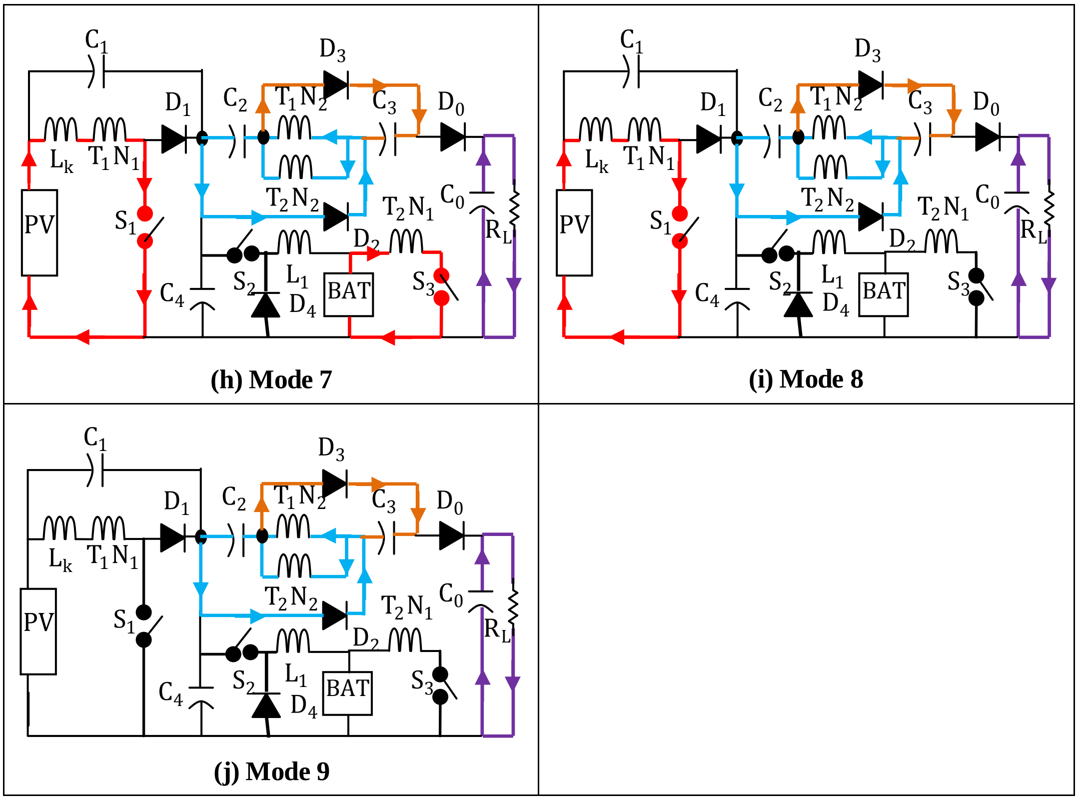


Figure 5. Mode of Operation PV Power<Load Power

In this ‘PV power<O/P power’ condition, the generated PV power is lesser than the load power and now, in order to meet the load demand, the stored power from the battery is discharged to meet the required load demand based on the controlling technique as shown in Figure 3 (b). At this discharging condition, boost operation is carried out to meet the load demand.

All modes of operations (Mode 0 to Mode 4), occurred in PV power=load power condition, is same for this operation. This mode of operation initiates with switch S_3 in ON condition. Thus, the current from the battery flows the primary winding of the transformer T_2N_1 and then flows through the drain source of switch S_3 and gets neutralized.

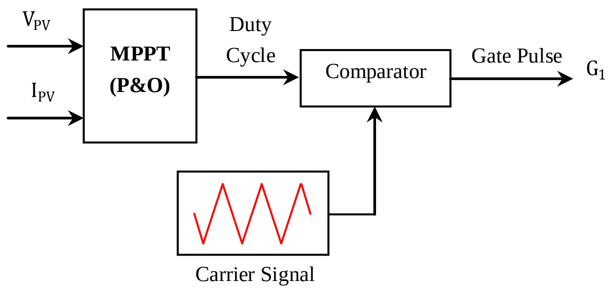
Due to the current flow in the primary winding of the transformer T_2, flux is created at the secondary winding of the transformer T_2. Based on the previous modes, when the switch S_1 is in ON condition, the flux gets generated at the transformer T_1. Now, the flux generated at T_1 and T_2, simultaneously charges the capacitors C_3 and C_2 respectively which acts in series connection and support the load demand as shown in Figure 5 (h) (mode 7).

In mode (8), switch S_3 is in OFF condition, remaining flux in transformer T_2 gets discharged and simultaneous, switch S_1 becomes OFF state which in turn makes the remaining flux in transformer T_1 to get discharged fully to support the load demand. The end of this cycle leads to the beginning of the next cycle (PV power = Load power).

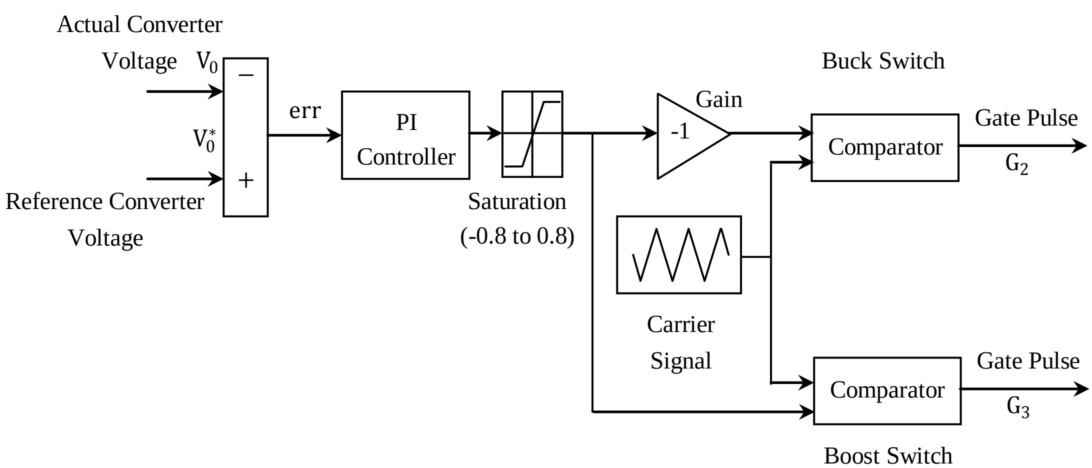
Two Port Hybrid High Gain Buck Boost Converter (TPHGC) Control

In this MPPT conversion, P&O algorithm has been used for attaining the maximum power from the PV panel. The working of this P&O algorithm is mainly based on voltage and power. P&O algorithm works on the principle that, if there is increase in power, then the perturbation is maintained in the same direction and on the other hand, if there is decrease in the power, then the perturbation should be maintained in the opposite direction. This process is iterated until the maximum power point is reached.

A triangular carrier signal is generated with a switching frequency of 10 KHz as depicted in Figure 6 (a). Duty cycle from the P&O algorithm and the carrier signal is compared to generate the PWM pulse. Based on this control operation, the PV voltage is boosted up through the MPPT to meet up the load voltage demand.



(a) Maximum Power Point Tracking (MPPT) Control



(b) Outer Voltage Control Loop

Figure 6. Closed Loop Control of TPHGC

Figure 6(b) shows the outer voltage control with battery charging and discharging control loop. The battery charging and discharging is based on the load voltage. Thus, when the load voltage is high, the battery discharging operation is carried out by controlling the switch S_3. On the other hand, when the load voltage is lower, the battery charging operation is carried out by controlling

the switch S_2 which is clearly depicted in Figure 6(b).
In this work, the actual and reference TPHGC voltage is compared and output error is given to the PI controller for controlling operation. The voltage error from the proposed converter is taken as feedback to control the dc link voltage of the inverter. Thus, with this closed loop control system, the input voltage of inverter in the DVR is maintained constant.
A proportional Integral (PI) is control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct that error between a measured process variable and desired set point by calculating and then outputting corrective action that can adjust the process accordingly.
The PI controller calculation involves two separate modes the proportional mode, integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller is widely used in industry due to its ease in design and simple structure. PI controller algorithm can be implemented as

$$output\ (t) = K_P\ err\ (t) + K_I \int_0^t err\ (\tau) d\tau \tag{1}$$

Where,

$$err\ (t) = set\ voltage - actual\ voltage$$

The output error from the controller is limited through a saturation limit unit which is assigned between (-0.8 to +0.8). In this work, a positive carrier signal is generated with 0 to 1 amplitude. Now, when the error output is negative, then error is multiplied with the negative Gain factor. Now, the negative error and the negative gain are multiplied to generate a positive error and are compared with the positive carrier to generate a G_2 gate pulse which acts in buck switching (charging) mode.
On the other hand, when there is positive error from the controller, then error is compared with the positive carrier signal and there is no need to multiply the gain factor in at scenario. Now, the positive error is compared directly with the positive carrier to generate a G_3 gate pulse which acts in boost switching (discharging) mode. Thus it is to be concluded that the gate pulses G_2 and G_3 are always in inverse active mode wherein when switch S_2 is ON, switch S_3 would be in OFF state and vice verse.

1. Photovoltaic Array Modeling

A system which comprises of solar cells that produce electricity through the process of conversion of sunlight forms a PV array or a photovoltaic array. Through the MPPT algorithm new efficient solar cells have been developed which has led to the increase of the solar panel use as an alternate renewable source of energy. The PV array along with the MPPT methodology through the low step up DC converter in the proposed DVR has become the DVR inverter's DC voltage source. This lies between DC link's battery bank and the PV.
Designing of the PV array is carried out by deploying the photovoltaic cells' basic equations along with solar irradiation level and effects of changes in temperature [18, 19]. The PV cell's output voltage is basically one of the photo current's functionalities and which is primarily determined by amount of load current which in turn depends on the level of solar radiation [20]. PV cell output voltage is calculated as per the following:

$$V_c = \frac{AkT_c}{e} ln\left(\frac{I_{ph} + I_0 - I_c}{I_0}\right) - R_s I_c \tag{2}$$

$$V_{PV} = V_c \times N_s \tag{3}$$

$$I_c = \frac{I_{PV}}{N_p} \tag{4}$$

Here e refers to the electron's charge $(1.602 \times 10^{-19}\mathrm{c})$, V_c the output voltage of PV cell in volts, I_0 refers to the reverse saturation current of diode $(48.10 \times 10^{-19}\,\mathrm{A})$, k is Boltzmann constant (1.38 $\times$ 10^{-23}J/0K), I_c is the cell output current in A, N_s is the number of series cell (9), R_s is the cell internal resistance $(0.210\,\Omega)$, A refers to the curve fitting factor (1.23), I_c is the operating temperature of the reference cell (25 0C), V_{pv} is the output voltage of PV array, I_{ph} is the photo current in A (8.07 A), I_{pv} is the output current of the PV array and N_p is the number of parallel cells (6).

2. DVR PI Controller

The control scheme used to maintain a constant voltage magnitude at the load point, under system disturbance, is shown in Fig. 7. In the proposed controller, a discrete single phase PLL is used to track the phase angle of the source voltage to perform the parks transformation on the measured single phase voltage. The measured p.u. value of supply voltage is converted into |Vs|, and the error is obtained from the difference of |Vs| and reference voltage (Vref). The PI controller designed by the Ziegler–Nicholstuning method processes the error and generates required angle d to drive the error to zero. The modulating angle d is applied to the reference voltage generator to generate the Vref for the Sinusoidal Pulse Width Modulation (SPWM). The reference voltage calculation is obtained by the following equation

$$V_{ref} = |V| * Sin(\omega t + \delta) I_c \tag{5}$$

The generated Vref is utilized to produce switching pulses for Voltage Source Inverter (VSI). The basic idea of Sine Pulse Width Modulation (SPWM) is to compare a sinusoidal control signal (Vref) of normal frequency 50 Hz with a triangular carrier waveform (Vcarrier) with 20 kHz signal to produce the PWM pulses. When the control signal is greater than the carrier signal, the switches are turned on, and their counter switches are turned off. The output voltage of the inverter mitigates the voltage sag.

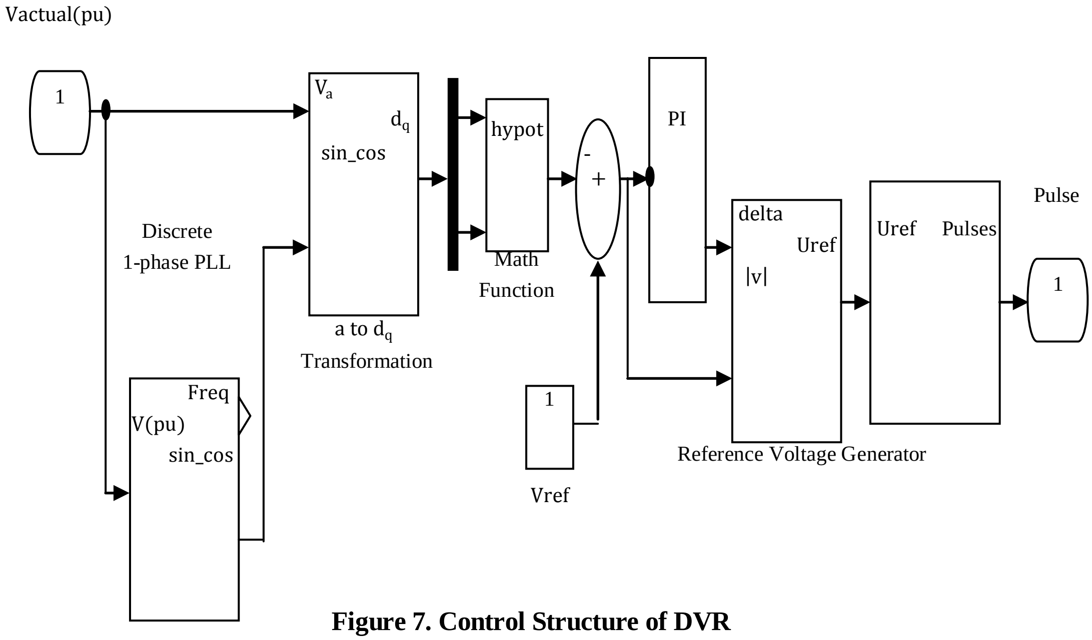


Figure 7. Control Structure of DVR

3. In-phase Voltage Compensation Method

In general, there are essentially three techniques deployed that include in-phase, the minimal energy injection method and presage so that DVR injection voltage maybe calculated. The paper basically discusses the in-phase compensation method deployed so that DVR. The injection voltage can be measured, as it is simple in terms of the implementation and also quick responsive nature when computing the compensating voltage. The DVR capabilities to be able to compensate for the voltage drop through the process of injecting voltage through deploying the source voltage in the in-phase series injection transformer [21]. As in Figure 8 injected voltage in the secondary that runs through the series injection transformer is actually in the in-phase along with the supply voltage.

In a state of normalcy, in an angle of zero phase, load and supply voltage (V_{presag}) are equal. At the time of voltage sags, the supply voltage decreases to a value less than or greater than the existing nominal value. As a result DVR counteracts to voltage sags and then injects required compensating in-phase voltage V_{inj} in- along with the supply voltage so that the voltage may be restored to normalcy as at its nominal value. Injected DVR (V_{inj}) voltage may be expressed as follows:

$$|V_{\text{inj}}| = |V_{\text{presag}}| - |V_{\text{sag}}| \tag{6}$$

$$V_{\text{DVR}} = V_{\text{inj}} \tag{7}$$

$$|V_{\text{DVR}}| = |V_{\text{presag}}| - |V_{\text{sag}}| \tag{8}$$

Calculation of injected voltage angle may be done as per the following equation:

(9)

$$< V_{\text{inj}} = \theta_{\text{inj}} = \theta_s$$

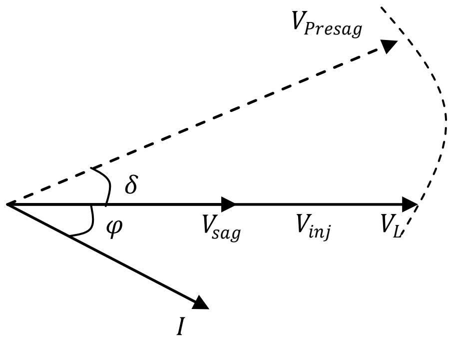


Figure 8. In-Phase Compensation to Presag Voltage

4. Voltage Sag Detection using d-q Transformation

V_a is the supply voltage gets transformed as positive sequence's d-q values in the proposed sag detection method. V_{smax} is acquired by deploying single-phase d-q transformation theory [22]. The component referred to as d which is part of the d-q transformation is equal to the DC value equivalent to the AC source voltage peak. Assuming that line voltage being the ideal sinusoidal waveform, the d-q theory assumes the generation of real and imaginary signal as follows:

$$V_{real}\,(t) = V_{smax}\ \sin(\omega t) \tag{10}$$

$$V_{image}\,(t) = -V_{smax}\ \cos(\omega t) \tag{11}$$

Here
$V_{real}\,(t)$, $V_{image}\,(t)$is the real and imaginary part of $V_s(t)$, V_{smax} is the AC source voltage peak value.
The d-q transformation can be expressed as

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -cos(\omega t) \\ cos(\omega t) & sin(\omega t) \end{bmatrix} \begin{bmatrix} V_{real} \\ V_{image} \end{bmatrix} \tag{12}$$

From the transformation as shown above we obtain the following values $V_d = V_{smax}$ and $V_q = 0$. There is an inherent delay that is an outcome under natural circumstances; however the delay is minimal in comparison to system response under voltage swells, sags or outages. Monitoring of V_d, returns the voltage drop and rise and the manipulation of Vq will return the initial phase jump information.

III. Simulation Results

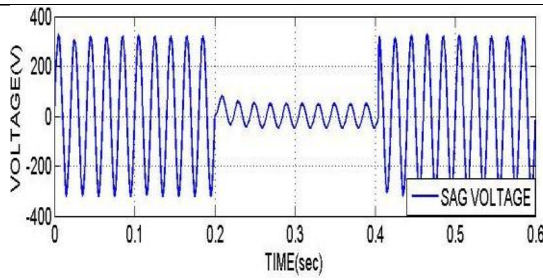
This Simulation of the proposed work has been carried out in MATLAB. Results from the simulation have further been evaluated. During the initial phase evaluation of the park transformation results has been performed.

V_{smax} is the distorted voltage where the voltage suddenly drops which would result in SAG voltage.

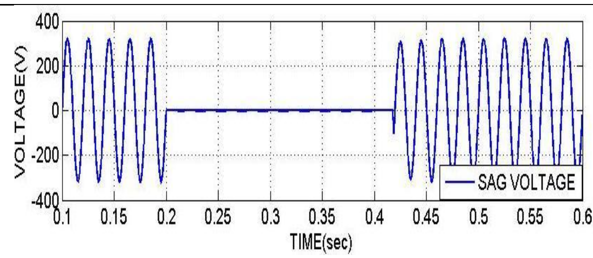
Figure 9 shows the voltage sag compensation of the proposed system in both DVR and UPS mode. In DVR mode, the proposed system acts as DVR wherein the voltage sag is compensated in the presence of input AC supply.

Figure 9 shows the resultant waveforms of the proposed system as a DVR. Figure 9 (a) shows the SAG voltage waveform of the proposed system. It is observed from the figure that, at time 0.2 second, voltage sag of 50 V_{rms} is observed in the system. So, it means that, 250 V_{rms} has to be injected in the system to compensate the voltage sag. This injected voltage waveform is clearly shown in Figure 9 (b). Figure 9 (c) shows the load voltage waveform at the voltage sag condition. It is observed that, at 0.2 second, there is sudden drop in load voltage due to the voltage sag. But, suddenly at 0.23 second, the voltage sag is compensated due to the injected voltage. Figure 9 (d) shows the State Of Charge (SOC) battery at the voltage sag condition. It is clearly shown that, at the voltage sag condition, the battery is in discharging condition from (0.2 to 0.4 seconds). The battery operates in charging condition except in sag condition.

When there is no input AC supply, the proposed system acts as UPS wherein the DVR will inject the voltage in this condition in order to make the load voltage constant. Figure 9 (e) shows the deep SAG voltage (0 V) waveform of the proposed system. It is observed from the figure that, at time 0.2 second, deep voltage sag of 0 Volt is observed in the system. So, it means that, 300 V_{rms} have to be injected in the system to compensate the deep voltage sag. This injected voltage waveform is clearly shown in Figure 9 (f). Figure 9 (g) shows the load voltage waveform at the deep voltage sag condition. It is observed that, at 0.2 second, load voltage is zero due to the deep voltage sag condition. But, suddenly at 0.23 second, the voltage sag is compensated due to the injected voltage. Figure 9 (h) shows the state of charge (SOC %) of the battery at the voltage sag condition. It is clearly shown that, at the deep voltage sag condition, the battery is in discharging condition from (0.2 to 0.4 seconds). The battery operates in charging condition except in sag condition. Figure 9 (i) shows the SOC of battery comparison of the two different conditions. It is observed that, in the UPS mode, battery discharging is higher when compared with the DVR mode to maintain the load voltage constant.



(a)



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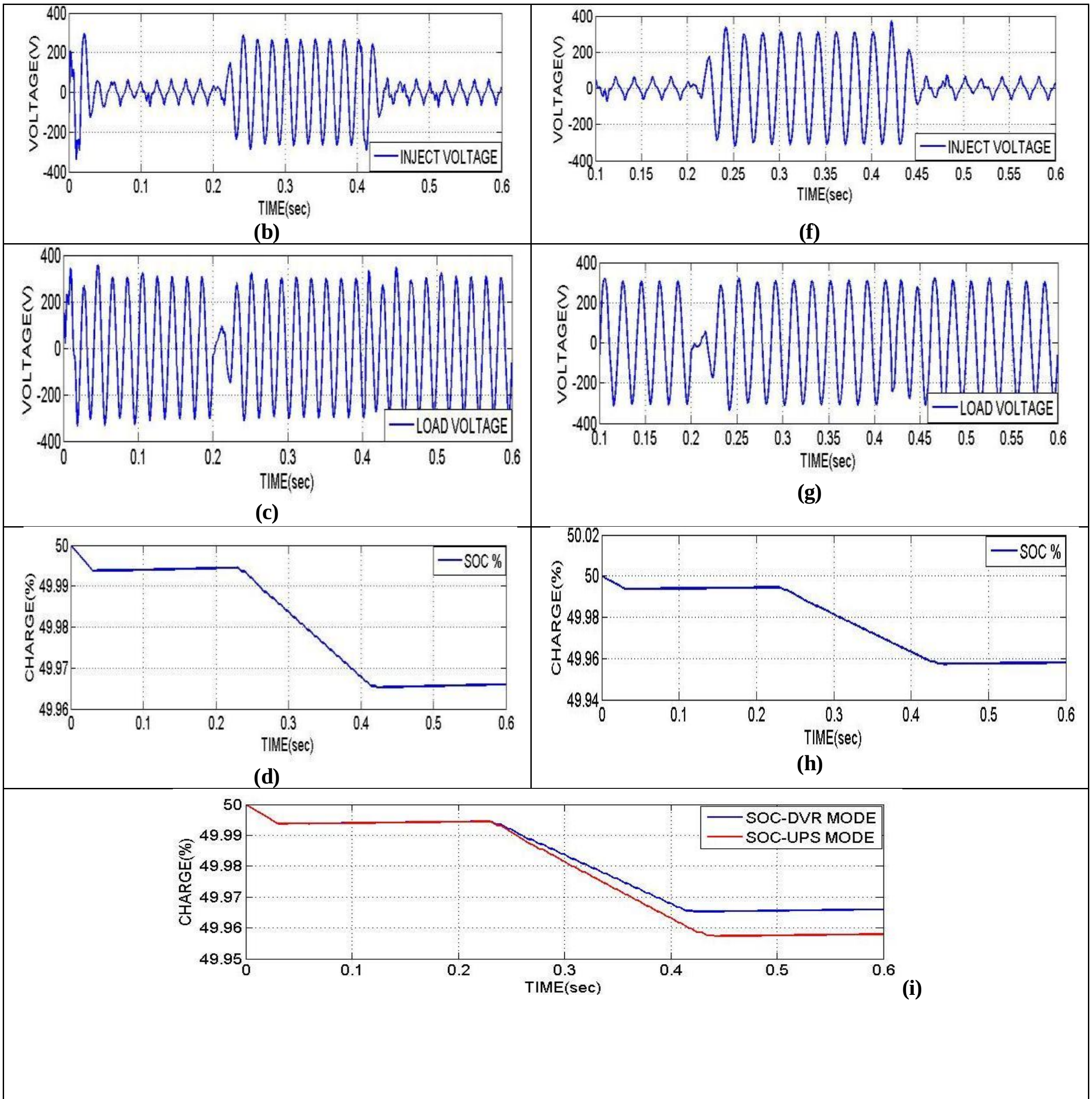

Figure 9. Evaluation Results of Proposed System in (1) DVR Mode and (2) UPS Mode

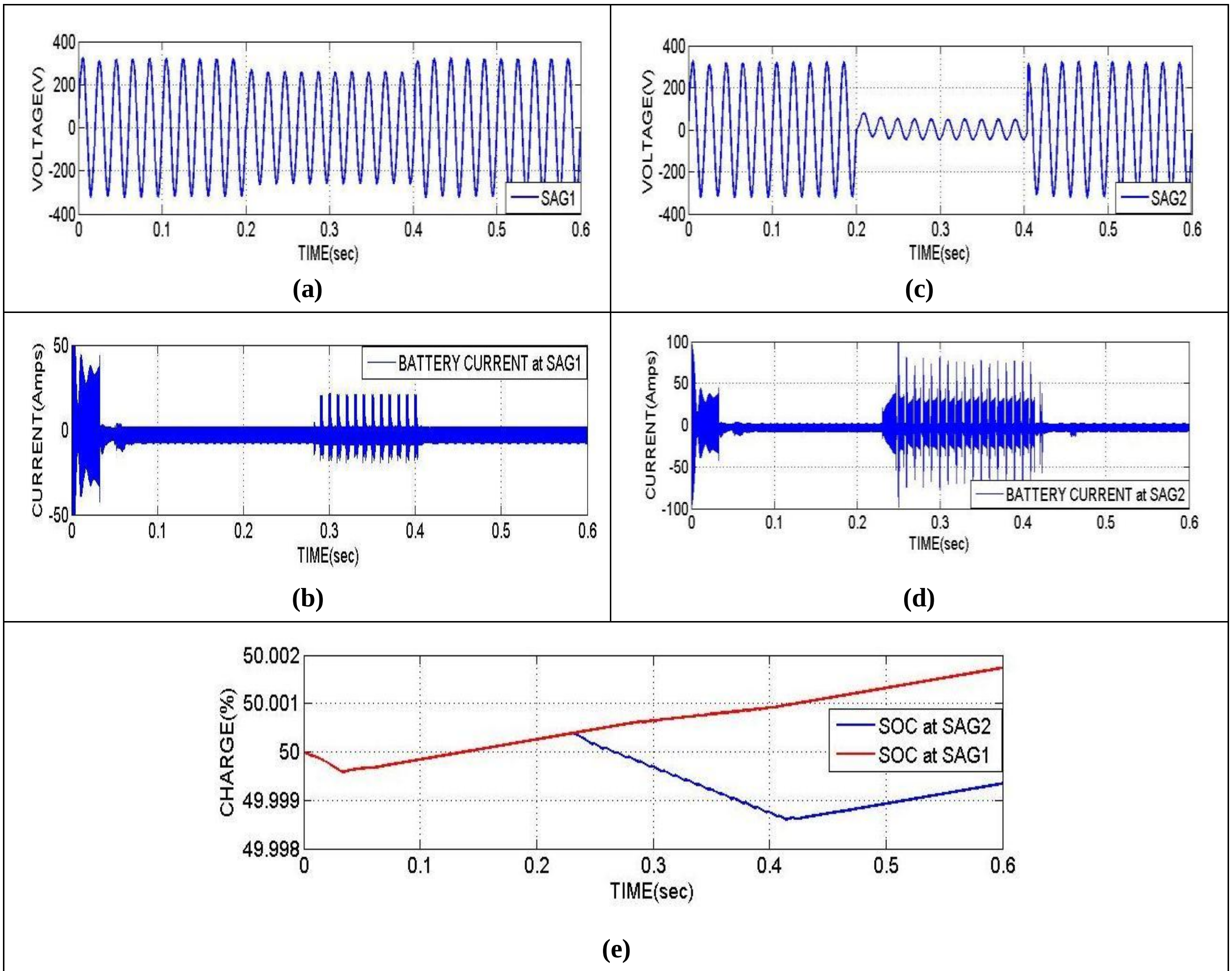

Figure 10. Evaluation Results of Battery Current and SOC% at Different SAG Conditions

Figure 10 shows the evaluation results of the battery current and SOC at two different SAG conditions. Figure 10 (a) shows the SAG1 condition waveform of the proposed system wherein 25% sag is created. Thus, 75 V_{rms} have to be injected in the system to compensate the voltage sag. Figure 10 (b) shows battery current waveform at the SAG condition. It is observed that, charging and discharging condition takes place at particular interval. Discharging takes place to compensate the sag condition. Since, 25% sag is created, only minimal injected is required and thus, the remaining voltage is effectively stored in the battery in the charging condition as depicted in Figure 10 (b).

Figure 10 (c) shows the SAG2 condition waveform of the proposed system wherein 75% sag is created. Thus, 200 V_{rms} have to be injected in the system to compensate the voltage sag. Figure 10 (d) shows battery current waveform at the SAG2 condition. It is observed that, charging and discharging condition takes place at particular interval. Maximum discharging takes place to compensate the sag condition. Since, 75% sag is created, maximum injection is required and thus, the only minimal voltage is stored in the battery in the charging condition as depicted in Figure 10 (d).

Figure 10 (e) shows the State of Charge (SOC) of the battery at the voltage sag1 and Sag2 conditions. It is clearly shown that, at the voltage sag1 condition, the battery is in charging condition from (0.2 to 0.31 seconds). This is due to the minimal injection required, but at 0.32 second, there is a slight discharging condition which is depicted in the figure. But after 0.4 second, there is again a linear increase in the system which is due to the charging condition of the battery. Similarly, for the SAG2 condition, since maximum injection is required due to the sag, discharging takes place from the battery till 0.4 seconds, then after 0.4 seconds, charging takes place which is depicted by the increased linear curve.

IV. Conclusion

This paper presents a novel approach and application that deploys a PV solar system to address voltage swells, sags and outage improvement through DVR for both residential and small scale industrial purposes. A novel TPHGC with single battery charging bidirectional conversion operation has been proposed in this work to overcome the limitation of the existing DVR system. The PV-DVR has been designed such that it reduces consumption of energy consumption from the main utility grid by basically detaching the utility grid from the load using several semiconductor switches. This is carried out once the PV array produces real power that is an equivalent amount or in excess in terms of the required load demand. Additionally, it has a twofold benefit as it reduces panel tariff and also aid in avoiding UPS and stabilizer use for personal individual residential use, small scale industrial purposes and at other educational institutions. The results from the experiments conducted and the simulation process show PV-DVR capability in terms of mitigating variations in voltage.

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