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Voltage Profile Improvement of Distribution System with Grid Connected Solar Plant Using PV-DVR

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***Abstract*— The proposed work presents a photovoltaic (PV) array fed three-phase three-wire dynamic voltage restorer (DVR) for voltage regulation in a low voltage (LV) distribution system with use of a new nine switch converter technique than two different voltage source converters are used. Besides the voltage regulation, the proposed DVR reduces the energy consumption from three-phase utility grid by utilizing the rated inverter capability after excessive or equal real power generation to load demand during daytime. Voltage sag is currently the most severe power quality problem encountered because of its adverse financial impact on customers. In the proposed DVR design, a photovoltaic (PV) system is incorporated to function as a DC voltage source.**

***Index Terms*—renewable energy, power quality, nine switch converter, voltage sag, dynamic voltage restorer**

I. INTRODUCTION

Most of the electrical and electronic equipment are designed to function from a power supply with a specific arrangement that usually defines the minimum and maximum limits for RMS (root mean-square) voltage and frequency. There is an expectancy on the part of the user that the supply will be offered and within tolerance for 100% of the time. This is not guaranteed by the supplier and would be essentially impossible to realize at an economic price level [1]. The concept of utilizing PV solar system inverter as DVR, for the mitigation of voltage variations with power saver capability at the load side for three phase is the main aim of project work. Fig. 1 shows the solar PV plant is connected with the grid, the six switches voltage source Inverter (VSI) is converts DC power to AC power [3], Fig. 2. shows the components of dynamic voltage restorer.

The DVR (Dynamic Voltage Restorer) is a series connected solid state device that injects additional voltage into the system in order to adjust the load side voltage to the desired magnitude and waveform even when the source voltage is unbalanced or distorted [2][3]. This process involves injection of active/reactive power from DVR to distribution feeder. To achieve combine operation of photovoltaic and dynamic voltage restorer, here the nine switch converter is used. The main advantage of nine switch converter is it is a compact device, it is also a multifunction device, and the switch count is reduced to nine from twelve so, the switching loss is less [5].

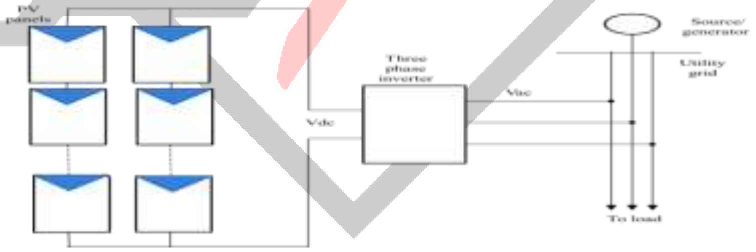

Fig. 1. Solar PV plant connected with grid

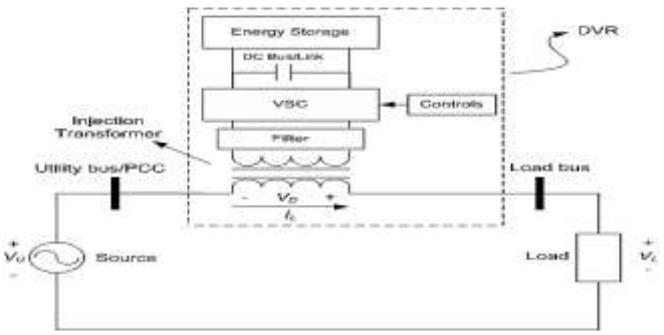

Fig. 2. Dynamic Voltage Restorer Components

II. COMBINED PHOTOVOLTAIC AND DVR CONFIGURATION

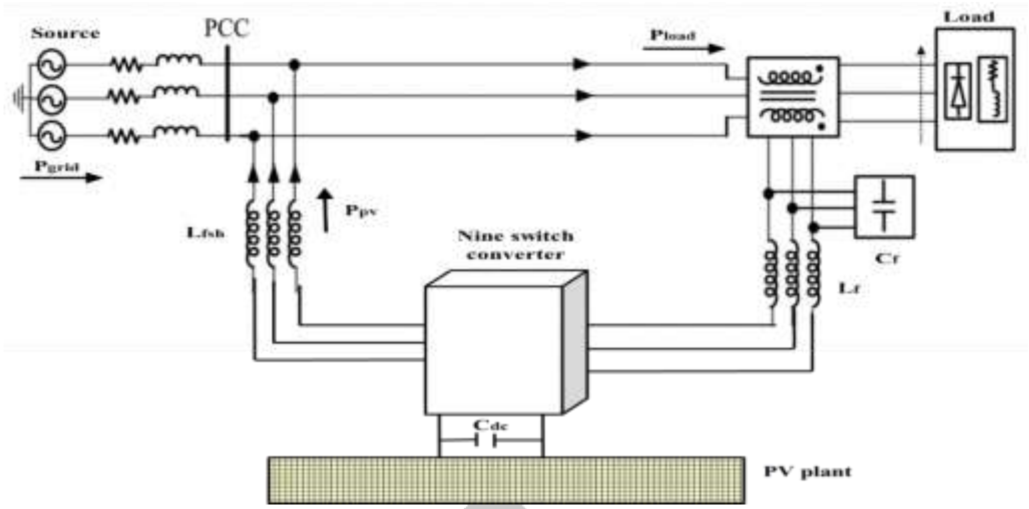

Fig. 3. Nine Switch Converter (PV-DVR)

The three phase inverter converts DC power to AC power for the consumer use. The three phase converter having six switches for power conversion, as well as the dynamic voltage restorer is also require the six switch VSI for the conversion DC link voltage to AC. Whenever the distribution system has photovoltaic power generation and dynamic voltage restorer requirements then if we see the ordinary configuration, two separate voltage source inverter is require one is for PV and other is for DVR [7].

The proposed system configuration is shown in Fig. 3. In this configuration, nine semiconductor switches are used to combine operation of PV and DVR at same time. The main modification between the recommended configuration and the system is the dual output nine switch converter whose six output terminals is divided into two set of outputs. The left three ports shunt connected to PCC are designated as the output of PV-VSI, while the right three ports series connection with grid are designated as output of DVR-VSI.

III. PV- DVR CONTROL

The nine switch converter has three switches common between PV and DVR-VSIs. In the standard condition, PV-VSI injects active power into grid while DVR-VSI is standby. The modulation index is unity for PV-VSI and zero for DVR-VSI [6]. During sag the PV-VSI remains to inject active power. The increase in DVR-VSI reference is always accompanied by the corresponding decrease in PV-VSI reference and hence the crossover does not happen. Thus, the proposed configuration naturally overcomes the constraint of reference crossover.

To achieve the above operation in the proposed configuration, the procedure to generate nine gate pluses is discussed below. The two reference signals can be expressed as

$$\left.\begin{aligned} V^*_{pv\text{-}a} &= m_{pv}\cos(w_{pv}t + \emptyset_{pv}) \\ V^*_{pv\text{-}b} &= m_{pv}\cos(w_{pv}t - 120^\circ + \emptyset_{pv}) \\ V^*_{pv\text{-}c} &= m_{pv}\cos(w_{pv}t - 240^\circ + \emptyset_{pv}) \end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned} V^*_{dvr\text{-}x} &= m_{dvr}\cos(w_{dvr}t + \emptyset_{dvr}) \\ V^*_{dvr\text{-}y} &= m_{dvr}\cos(w_{dvr}t - 120^\circ + \emptyset_{dvr}) \\ V^*_{dvr\text{-}z} &= m_{dvr}\cos(w_{dvr}t - 240^\circ + \emptyset_{dvr}) \end{aligned}\right\} \quad (2)$$

In the nine switch converter, since the middle row switches are common, their gate pulses are generated by logical OR operation of PWM signals corresponding to right three switches of PV-VSI, i.e., Gpv4−6 and left three switches of DVR-VSI, i.e., Gdvr1−3. The final nine gating signals Gs1−9 are obtained, which is given in Eq. 3 [7].

$$\left.\begin{aligned} Gs1\text{-}3 &= Gpv1\text{-}3 \\ Gs7\text{-}9 &= Gdvr4\text{-}6 \\ Gs4\text{-}6 &= Gpv4\text{-}6 + Gdvr1\text{-}3 \end{aligned}\right\} \quad (3)$$

By using the voltage oriented control, the reference frame d axis is line up with positive sequence PCC voltage, i.e. $V_d = V_{pcc}$. Hence, $i^*_{d\text{-}pv}$ which gives directs measure of PV power. The q-axis reference current i^*_q is set to zero as per IEEE 1547 [8]. The difference between reference and actual DVR voltage is processed by PI controller in the synchronous reference frame. $V^*_{dvr\text{-}dq}$ can be directly used to control DVR-VSI in open loop by converting it in to stationary reference frame. However, it will not be able to compensate the drop across DVR-VSI switches, interfacing filter and series transformer. It is, therefore, added as feed forward signal to the output of PI to compensate for system losses. The resulting signal is converted into stationary frame, $V^*_{pv\text{-}abc}$ and $V^*_{dvr\text{-}xyz}$ reference modulating signals for PV and DVR VSIs are obtained, they are processed by modulator to generate nine gate signals.

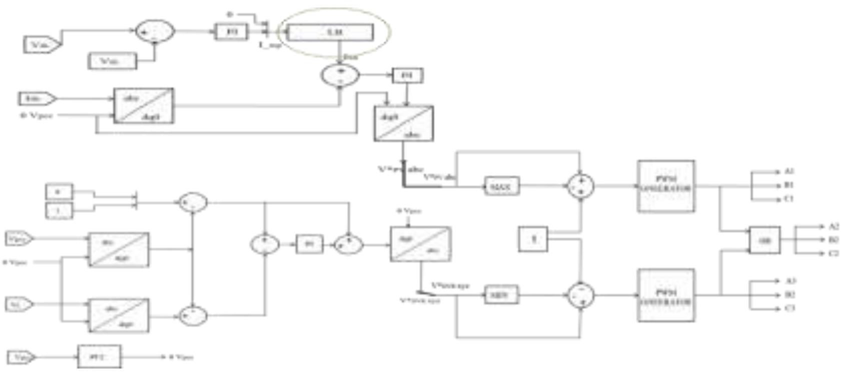

Fig. 4. Control System for PV-DVR

Table 1 Limit Block Function

Sag depth	Sag duration		
	0 <= t <= 0.16s	***0 <= t <= 0.16s***	***0 <= t <= 0.16s***
$\Delta V_{sag} < 0.5$ pu	$I_{sh\text{-}ref} = 3I_{mp}$	$I_{sh} = 3I_{mp}$	$I_{sh} = 0$
$\Delta V_{sag} >= 0.5$ pu	$I_{sh\text{-}ref} = 3I_{mp}$	$I_{sh} = 0$	$I_{sh} = 0$

IV. SIMULATION AND RESULTS

The Fig. 5. Shows the MATLAB simulation of proposed system, the nine switch converter is gives both the operation i.e. photovoltaic and dynamic voltage restorer.

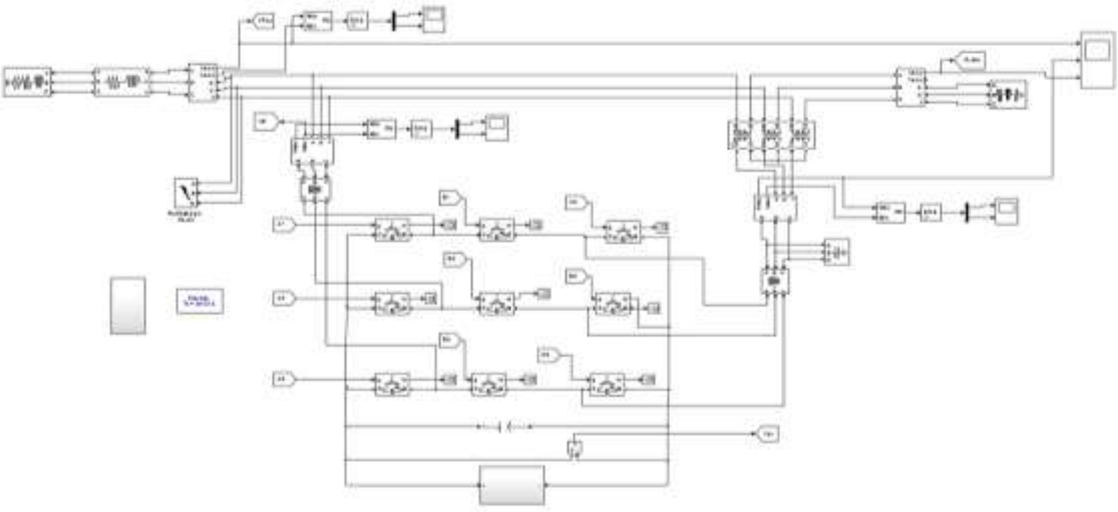

Fig. 5. MATLAB Simulation of Proposed System

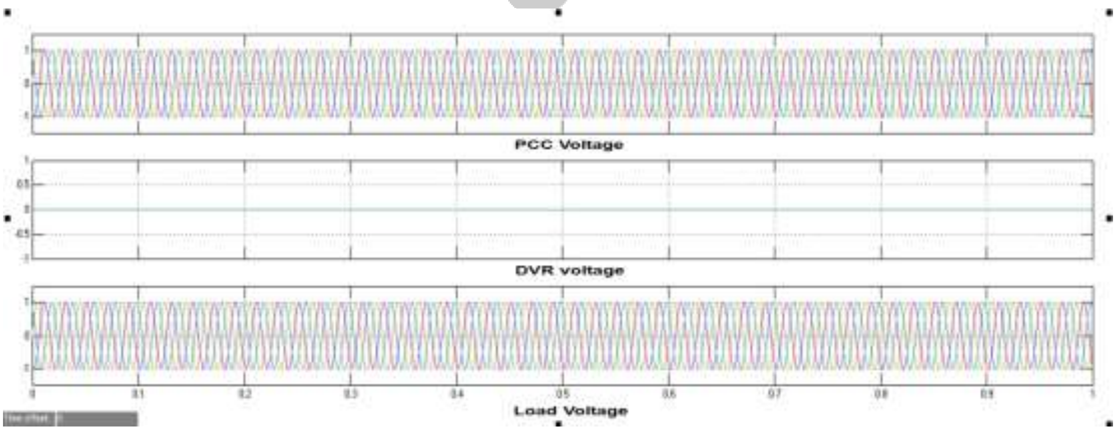

Fig. 6. System Operation at healthy grid condition

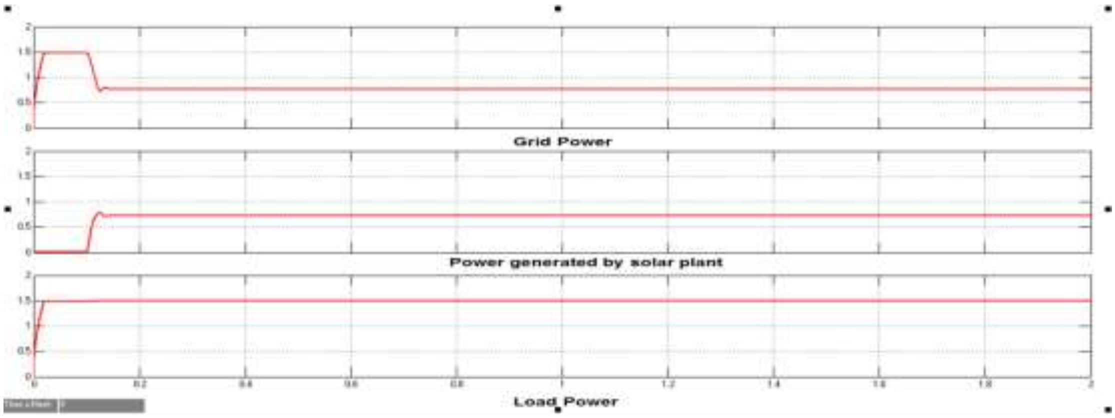

Fig. 7. Reduction in Power Consumption from Grid Due to Solar Power Generation

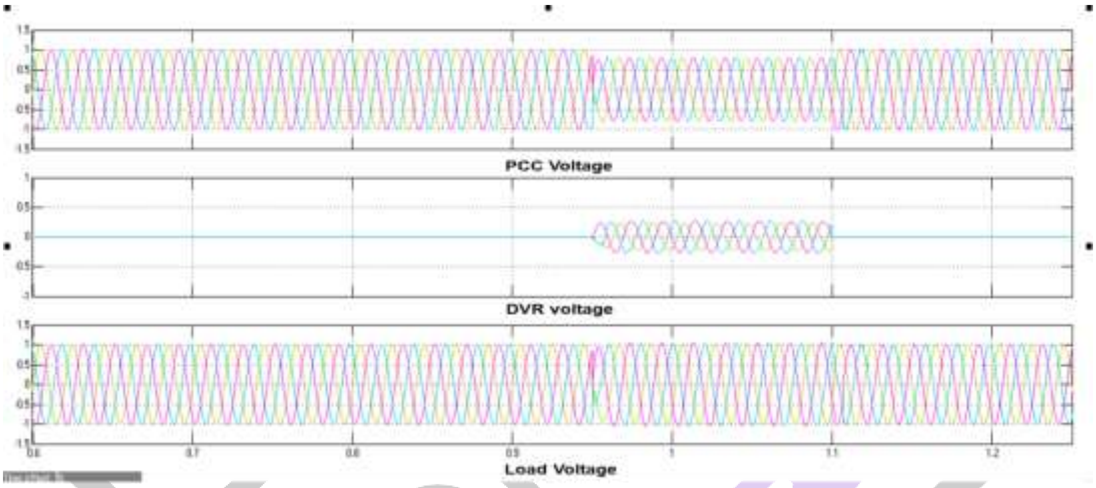

Fig. 8. Waveform of sag remove at Sag = 0.2 pu depth

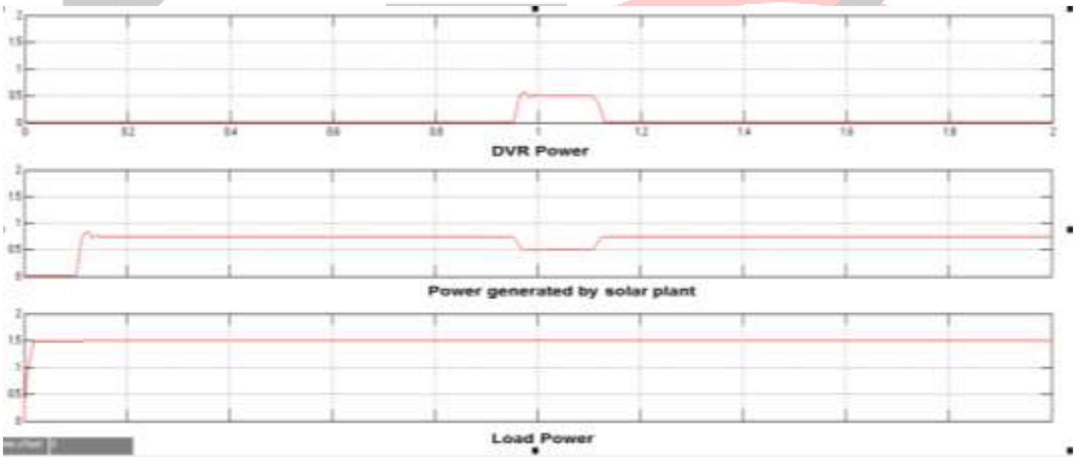

Fig. 9. System Operation at Sag Condition

V. CONCLUSION

The simulation is carried out in MATLAB and according to the waveform it is verified that sag is removed by PV-DVR, also the photovoltaic power generation reduces energy consumption from the grid. The photovoltaic based dynamic voltage restorer is a device which is very useful for the voltage profile improvement especially removing sag. The use of custom power devices with photovoltaic systems in which photovoltaic power generation is provides effective DC link support and gives multiple applications of PV.

VI. ACKNOWLEDGMENT

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