DISTRIBUTION SYSTEM WITH DVR AND DG

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Abstract: *This paper presents the performance of the Dynamic Voltage Restorer (DVR), a custom power device with and without Distributed Generation (DG). The maximum amount of real power that the DVR can provide to the load is a deciding factor in determining the performance of the restorer. This paper examines the combined operation of DVR with DG. DG is connected to DC link through rectifier. Wind turbine driven induction generator is used as DG. The effectiveness of the proposed system has been verified by simulation. The proposed system can improve the power quality problems at the point of installation in distribution system or industrial power systems.*

Key words: *DVR, Custom Power Devices, DG, Power Quality, Distribution System.*

1. Introduction

The new technology known as Custom Power, using power electronics-based concepts have been developed to provide protection from power quality problems in distribution system. FACTS use power electronic devices and methods to control the high-voltage side of the network for improving the power flow. Custom Power is for low-voltage distribution, and to improving the poor power quality and reliability. At present, a wide range of flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Some of these Custom Power Devices are: Series-connected compensator like DSTATCOM (Distribution Static Compensator), DVR (Dynamic Voltage Restorer), Shunt-connected compensator like Series and shunt compensator like UPQC (Unified Power Quality Conditioner) and SSTS (Solid State Transfer Switch). Different solutions have been developed to protect sensitive loads against such disturbances. Among these, DVR is the most effective device. DVR injects a voltage in series with the system voltage to correct the voltage sag and swell. In this paper the Performance of DVR is analyzed.

Wind power has become the fastest growing energy source in the world and the leading source among various renewable energy sources in the power industry. Asynchronous generator i.e. induction generator is used as DG which is connected to wind turbine. The performance of the DVR with and without DG is analyzed in this paper.

2. Distributed Generation (DG)

DGs are small modular electric generation and storage technologies that provide electric capacity when and where needed and are connected to the grid at a distribution voltage level. The interest in DG has been increasing rapidly. Clean and conventional energy is becoming more and more attractive at various power levels. There are several DGs. Among them wind power generation has been significantly developed and is one of the forms of power generation of fastest growth in the world. Wind energy generation is one way of electrical generation from renewable sources that uses wind turbine generators (WTGs) to convert the energy contained in flowing wind into electrical energy.

The most common generator type is asynchronous generator. Induction Generator is connected to wind turbine. If IG is directly connected, a soft starter is needed in order to minimize the large currents at the generator startup. By applying the modern inverter technology, which is allowing variable speed systems the power output can be hold relatively constant independently from the wind speed variations.

3. Dynamic Voltage restorer (DVR)

A DVR is a device that injects a dynamically controlled voltage V_{inj} in series to the bus voltage by means of a booster transformer. The Dynamic Voltage Restorer employs series boost technology using solid state switches to correct the load voltage amplitude as needed.

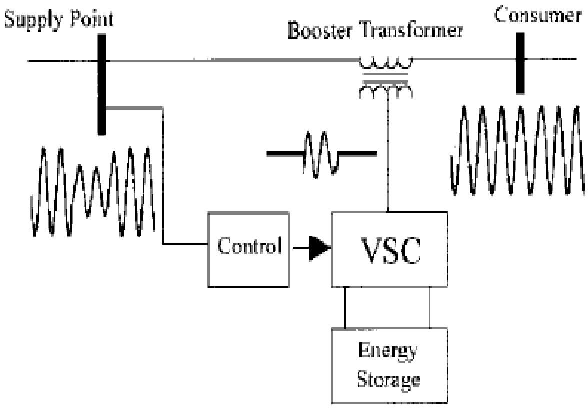

Fig. 1. Structure of DVR

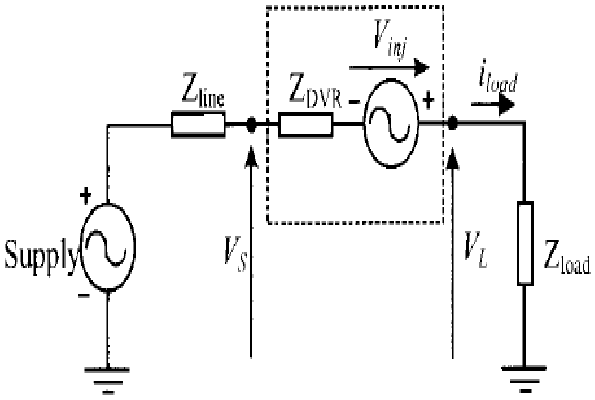

Fig. 2. Equivalent circuit of DVR

A DVR consists of a voltage source converter and is shown in Fig. 1. An equivalent circuit diagram of the DVR and the principle of series injection for sag/swell compensation is depicted in Fig. 2. The load voltage is given by

$$V_L = V_S + V_{inj} \qquad \text{--------- (1)}$$

Where V_S is the supply voltage and V_{inj} is the voltage injected by the mitigation device.

Under nominal voltage conditions, the load power on each phase is given by

$$S_L = V_L I_L^* = P_L - jQ_L \qquad \text{--------- (2)}$$

Where I_L is the load current, P_L and Q_L are the real and reactive power taken by the load respectively during sag/swell.

When the compensating device is active and restores the voltages back to normal, then

$$S_L = P_L - jQ_L = (P_{Sag} - jQ_{Sag}) + (P_{inj} - jQ_{inj}) \qquad \text{---- (3)}$$

Where the sag subscript refers to the sagged supply quantities, the inject subscript refers to quantities injected by the compensator device (DVR).

4. Control Scheme

The aim of control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system of a DVR plays an important role, with the requirements of fast response in the face of voltage sags and variations in the connected load. Here converter is directly controlled i.e., both the angular position and the magnitude of the output voltage are controllable by appropriate on/off signals.

The direct control analyzed in this paper is exhibited in Fig. 3, which employs the dqo rotating reference frame, a PLL and four proportional-integral (PI) regulators. In this, V_{ABC} are the three-phase terminal voltages, I_{ABC} are the three-phase current injected by the custom power device into the network, V_{rms} is the Root Mean Square (RMS) terminal voltage, V^*_{rms} is the reference value. V_{dc} is the DC voltage measured in capacitor and V^*_{dc} is the reference DC Voltage. Finally V^*_{abc} are the three-phase voltages desired at the converter output.

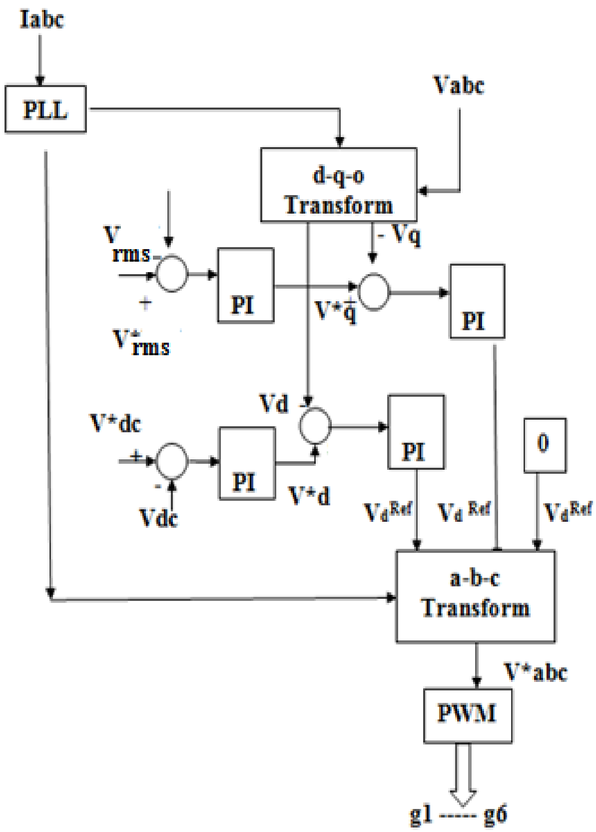

Fig. 3. Direct Control Scheme of DVR

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_m \sin(wt) \\ V_m \sin(wt - 120^\circ) \\ V_m \sin(wt + 120^\circ) \end{bmatrix} \quad \text{-----(4)}$$

$$V^*_{rms} - V_{rms} = V^*_q$$

$$V^*_q - V_q = V^{ref}_q$$

$$V^*_{dc} - V_{dc} = V^*_d$$

$$V^*_d - V_d = V^{ref}_d \quad \text{------ (5)}$$

The voltage in the *d-q-o* reference frame has the followingnvalue.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = T^{dqo}_{abc} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

After passing through Proportional Integral (PI) controller, the voltages are finally transformed to the *a-b-c* synchronously rotating frame using equation (6).

$$\begin{bmatrix} V_a^* \\ V_b^* \\ V_c^* \end{bmatrix} = T^{abc}_{dqo} \begin{bmatrix} V_d^{ref} \\ V_q^{ref} \\ V_o^{ref} \end{bmatrix} \quad \text{------ (6)}$$

V^*_{abc} are the three-phase voltages desired at the converter output. The available voltages in the *a-b-c* coordinates are compared with the triangular wave provided by PWM generator. The output provides suitable switching pattern. The schematic diagram of DVR with DG is shown in Fig. 4.

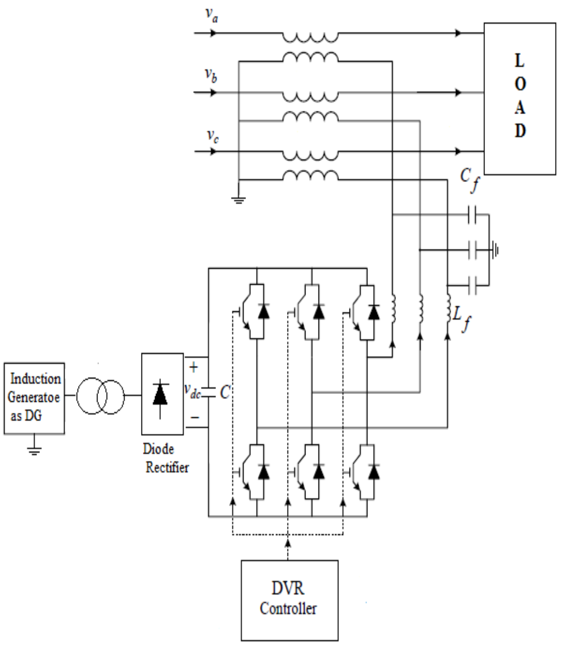

Fig .4. Schematic diagram of DVR with DG

5. Test System

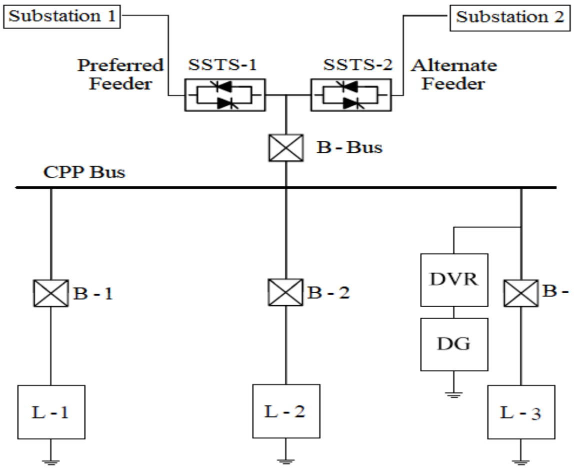

Fig. 5. Test System

Single line diagram of the test system is shown in Fig. 5. The proposed system consists of DVR, DG, Solid State Transfer Switch (SSTS), the loads and circuit breakers. Such system is composed of two feeders of each 11-KV, 45 MVA, 50Hz substation. It is represented by Thevenin equivalent and is feeding a distribution network having loads at load bus. The DVR has been used to compensate for sensitive load (L-3). The induction generator is used as DG. The induction generator is represented by sixth-order-phase model in the d-q rotor reference frame. The generator is equipped with an automatic voltage regulator represented by the IEEE-Type 1 model. The mechanical power is considered constant.

Table I shows the on – off states of devices in the test system. The voltage variation of $\pm$ 5% of nominal value of supply voltage is allowed and the distribution system for voltage variations of $\pm$5 %is assumed as faultless. DVR has been operated when this voltage exceeds from this value. Combined operation of DVR and DG has been designed to compensate maximum 50% sag. The sags higher than 50% voltage sag are considered as an interruption. The SSTS have been designed to apply two different feeders. If voltage sag or swell is less than 5% of rated supply voltage in feeder-1 occurs, SSTS-1 does not operate and the sensitive load (L3) is supplied by the same feeder-1. When voltage sag or swell higher than 5% (5% to 50%) in feeder 1, SSTS operates (Case: 3 in Table I) and transfer the sensitive load L3 from feeder-1 to feeder-2. The proposed DVR can compensate maximum 50% of voltage variations. If the voltage sag is higher than 50%, the compensation is done by entering DG along with DVR. For the cases 1 & 2 in Table-I, DVR is switched off as the voltage variations are less than 5%. For the cases 3 & 4 as the sag is less than 50%, DVR is connected to compensate voltage sag and for cases 5 & 6 DVR and DG are connected as the voltage variation is higher and more than 50%.

Table 1
On – OFF States of Devices and Loads

	Case	SSST1	SSST2	DVR	DG	L1 & L2	L3
1	Voltage sag or swell less than 5% in feeder 1	On	Off	Off	Off	On	On
2	Voltage sag or swell less than 5% in feeder 2	Off	On	Off	Off	On	On
3	Voltage sag or swell between 6% t0 50% in feeder 1	Off	On	On	Off	On	On
4	Voltage sag or swell between 6% t0 50% in feeder 2	Off	Off	On	Off	On	On
5	Voltage sag or swell more than 50% in feeder 1	Off	On	On	On	Off	On
6	Voltage sag or swell more than 50% in feeder 2	On	Off	On	On	Off	On

Table 2
System Parameters

Source Voltage	11KV, 50 Hz
	45 KVA
AC Generator	30KW
Type	Squirrel Cage
Frequency	50Hz
Voltage	0.69KV
Transformer	690V / 700V
Rectifier	700V DC
PWM Carrier Frequency	4000Hz

Firstly voltage sags between 5% to 50 % are considered. A voltage sag of 25% is considered. Voltage sag is introduced during t=50 ms to t=100 ms. Fig. 6(a) & Fig. 6(b) shows the load (L- 3) voltage waveforms without and with DVR. Without DVR the voltage drops from 11KV to KV, where as with DVR introduction the voltage recovers to 11KV rapidly.

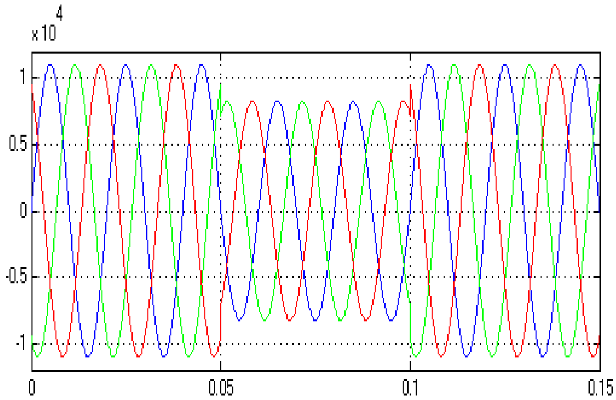

Fig. 6(a). Load Voltage (L-3) without DVR (25% Voltage Sag)

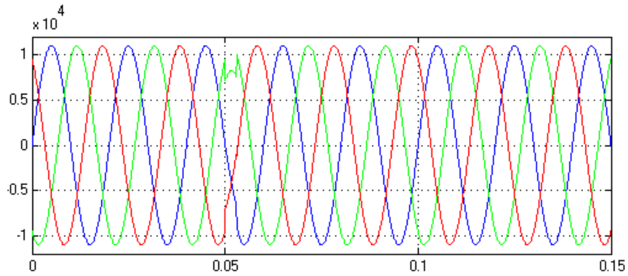

Fig. 6(b). Load Voltage (L-3) with DVR (25% Voltage Sag)

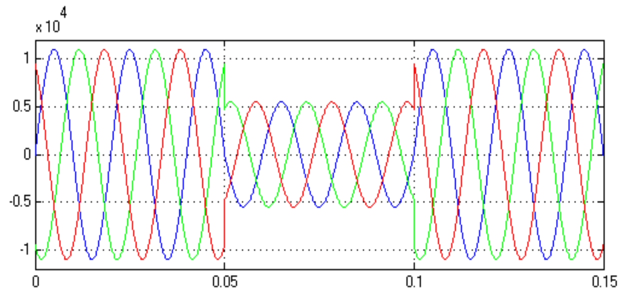

Fig. 7(a). Load Voltage (L-3) without DVR (50% Voltage Sag)

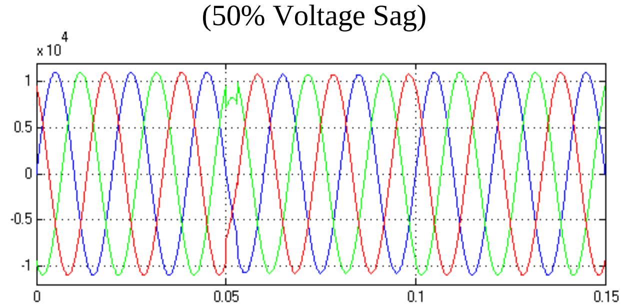

Fig. 7(b). Load Voltage (L-3) with DVR (50% Voltage Sag)

Now a voltage sag of 50% is introduced during t=50 ms to t=100 ms. Fig. 7 (a) & Fig. 7 (b) shows the load (L- 3) voltage waveforms without and with DVR. Without DVR the voltage drops from 11 KV to 5.5 KV, and in the presence of DVR, the voltage sag is compensated effectively as shown in Fig. 7(b). For the cases 5 & 6 voltage sag is higher than 50%

which is considered as interruption. As the DVR cannot compensate the load voltage interruption completely, the DG is connected to DC bus of DVR. The combined operation of DVR and DG used to compensate higher voltage sags. Voltage sag higher than 50% is considered as an interruption. Fig. 8(a) and Fig. 8(b) the load (L- 3) voltage waveforms without and with DVR. Fig. 8(b) shows that DVR cannot compensate the load voltage interruption. Fig. 8(c) shows the compensation of interruption using DG connected to DC bus of DVR.

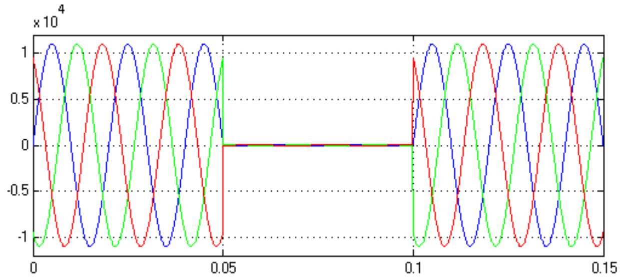

Fig.8(a). Load Voltage (L-4) without DVR (Voltage Interruption)

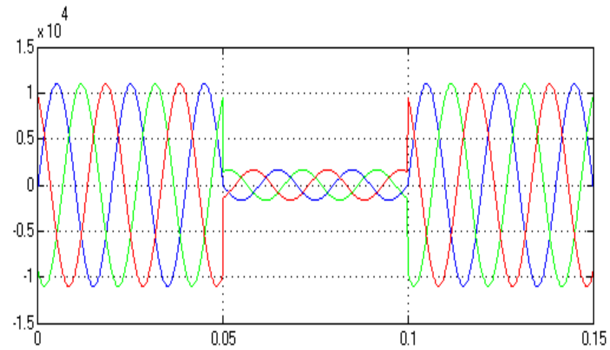

Fig.8(b). Load Voltage (L-4) with DVR (Voltage Interruption)

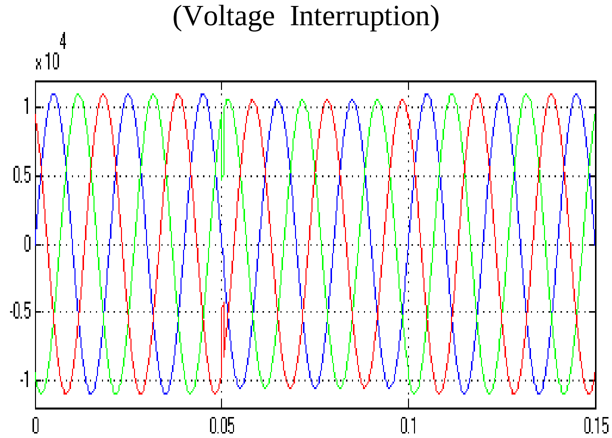

Fig.8(c). Load Voltage (L-4) with DVR & DG (Voltage Interruption)

Though the supply voltage has a voltage interruption, the load voltage is constant by the combined operation of the DVR and DG in distribution system.

6. Conclusion

In this paper, the power quality is improved in distribution using the combined operation of DVR with DG. The SSST is applied to increase the reliability of sensitive and critical load against voltage sags, swells and interruptions. The DVR itself can not compensate high sags of voltage and voltage interruptions. The DVR itself is able to compensate the voltage sags between 6% to 50% in distribution system with sensitive loads. The DVR alone cannot compensate the voltage sags more than 50% in the distribution system. The combined operation of DVR with DG enables the system to compensate for its voltage interruption. The simulation results show that high voltage quality is achieved using the combined operation of DVR and DG.

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