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A Dynamic Voltage Restorer with Voltage Sag Compensation at Medium Voltage Level Using PI Control Scheme

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ABSTRACT--- The increment of voltage – sensitive load equipment has made the industrial process must more susceptible to degradation in the power quality. Voltage deviation, often on the form of voltage sag, can cause severe process, result in economical loss. Among the Custom Power Device (CPD), the application of Dynamic Voltage Restorers (DVRs) in the distribution system is the recent invention. DVR's are used to protect sensitive loads from the effects of voltage sags on the distribution feeder. DVR normally installed between the source voltage and critical or sensitive load. This paper describes DVR using Proportional Integral (PI) control technique. The simulations are performed using Matlab/Simulink's SimPowersystem Toolbox.

KEYWORDS: Dynamic Voltage Restorer (DVR), Power Quality (PQ), Proportional Integral (PI), voltage sag.

I. INTRODUCTION

Power Quality problems like voltage sag, voltage swell and harmonic are major concern of the industrial and commercial electrical consumers due to enormous loss in terms of money and time. For high power sensitive loads, the DVR shows promise in providing more cost effective solution than the energy storage capabilities of Uninterrupted Power Supply (UPS) [1]-[4]. The DVR can be implemented both in Low Voltage (LV) level [5]-[9] as well as Medium Voltage (MV) level [10]-[15] and DVR protect high power application from voltage sag. A DVR uses series-connected topology; it injects a voltage on the system in order to compensate any disturbance affecting the load voltage. This aims to protect critical loads against voltage sag/swell.

Voltage sag/swell that occur more frequently than any other power quality phenomena is known as the most important power quality problem in power distribution system. Voltage sag is defined as a sudden reduction of supply voltage down 90% to 10% of normal. On the other hand, voltage swell is defined as a sudden increasing of supply voltage up 110% to 180% in rms voltage at the fundamental frequency with duration from 10ms to 1 minute. According to IEEE 519-1992 and IEEE 1159-1995 standards, a typical duration of voltage sag and swell is 10ms to 1 minute [16]. Faults at distribution level causes voltage sag or swell, which can cause sensitive equipment to fail as well as create a large current unbalance that could blow fuses or trip breakers.

Table 1 shows the voltage variations events in 230 kV bus at Mettur Thermal Power Station (MTPS) [17]. From the table, it is observed that there is voltage sag will be observed during summer season and voltage swell will be observed during winter season. The voltage variation in 230 kV bus is reflecting on 230 V residential distribution system in the same way. The voltage sags and swells are normally caused by starting of large induction motors, energizing a large capacitor bank and short circuit faults in power network [18], [19] such as single line to ground fault, three phase to ground fault, double line to ground fault on the power distribution system. Voltage sag and swell in power systems produce an important effect on the behaviour of sensitive loads. The ensuing adverse consequences are a reduction in the energy transfers of electric motors and the disconnection of sensitive equipment and industrial

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processes brought to a standstill. This will result in loss of time and production, or damaged equipment may cause significant economical losses. To solve the above problems a new method is proposed in this paper.

TABLE 1
Voltage variation events in 230 KV bus at MTPS

Day	Voltage variation in summer (April 2010) in KV		Voltage variation in winter (December 2010) in KV	
	Maximum	Maximum	Maximum	Minimum
1.	227	217	234	226
2.	225	217	233	227
3.	229	222	232	224
4.	227	220	233	227
5.	227	220	233	229
6.	227	219	235	227
7.	228	216	234	227
8.	228	221	233	227
9.	229	220	233	227
10.	229	223	233	226
11.	227	219	233	227
12.	226	214	234	227
13.	228	214	234	225
14.	228	221	233	226
15.	228	223	233	226
16.	228	220	231	225
17.	228	220	231	227
18.	230	224	231	225
19.	230	221	231	229
20.	228	224	233	226
21.	230	223	233	226
22.	230	224	233	227
23.	231	224	234	224
24.	231	226	234	226
25.	231	225	232	224
26.	230	225	231	226
27.	229	223	232	226
28.	230	225	231	225
29.	230	225	231	225
30.	230	225	231	224
31.	-	-	231	225

In general, the voltage injection from DVR compensates the voltage sag, swell and outage. However, it needs a high capacity DC storage system. In the proposed DVR design, Proportional Integral (PI) controller is used to boost the DC storage system to compensate the voltage sag.

II. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic voltage restorer was first built in U.S for the Electric Power Research Institute (EPRI) by Westinghouse. To protect an automated yarn manufacturing and weaving factory it was first installed in 1996 on Duke Power Company grid system. DVR is a series connected solid state device that is used for mitigating voltage disturbances in the distribution system. It is used to regulate the load side voltage by injecting voltage into the system.

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It is used to compensate the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the point of common coupling [20]. Its main function is to rapidly boost up the load side voltage in the event of a disturbance in order to avoid any power disruption to load.

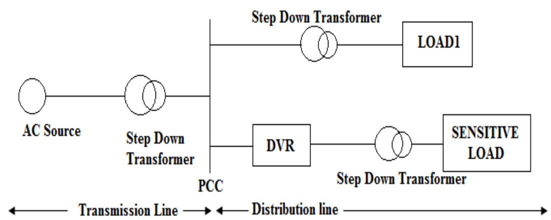

Fig. 1 Location of DVR

It is generally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Fig. 1 shows the location of the DVR. The general configuration of DVR consists of an injection/ booster transformer, a harmonic filter, a Voltage Source Converter (VSC), DC charging circuit and a control and protection system.

In most sag correction techniques, the DVR is required to inject active power into the distribution line during the period of compensation. Hence, the capacity of the energy storage unit can become a limiting factor in the disturbance compensation process especially for sags for long duration. Voltage sags caused by unsymmetrical line-to line, line to ground, double-line-to-ground and symmetrical three phase faults is affected to sensitive loads.

III. IN-PHASE VOLTAGE COMPENSATION METHOD

In general, there are three techniques such as presag, in-phase and minimal energy injection techniques are utilized to calculate the injection voltage of DVR. In this paper, in-phase compensation technique is used to calculate the injection voltage of DVR due to its simple implementation and fast response in calculating the compensating voltage. A DVR can compensate the voltage drop across a load by injecting a voltage through a series injection transformer in-phase with the source voltage [21]. The injected voltage across the secondary of the series injection transformer is in-phase with supply voltage, as shown in Fig. 2.

In normal condition, the supply voltage (Vpresag) is equal to the load voltage with zero phase angle. During the voltage sag/swell, the supply voltage decreases or increases to a value less than or greater than its nominal value. The DVR reacts to the sag/swell events and injects the compensating voltage Vinj in-phase with the supply voltage to restore the voltage at nominal value.

The injected voltage of a DVR (Vinj) can be expressed as

$$|V_{inj}| = |V_{presag}| - |V_{sag}| \quad (1)$$

$$V_{DVR} = V_{inj} \quad (2)$$

$$|V_{DVR}| = |V_{presag}| - |V_{sag}| \quad (3)$$

The angle of the injected voltage can be calculated as follows:

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$$\angle V_{inj} = \theta_{inj} = \theta_s \qquad (4)$$

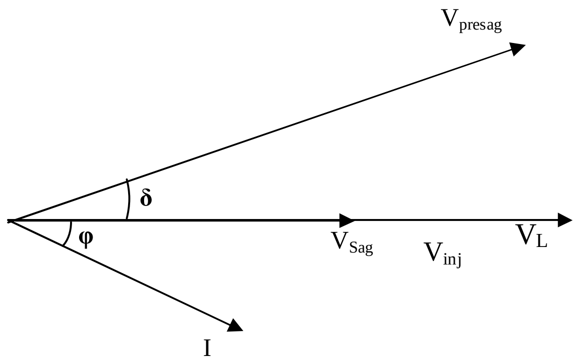

Fig. 2 In–Phase compensation

IV. CONTROL OF DVR

Voltage sag is created at load terminal via a three-phase fault. Load voltage is sensed and passed through a sequence analyzer. The magnitude component is compared with reference voltage (Vref). Pulse width modulation (PWM) control technique is applied for inverter switching to produce a three-phase 50 Hz sinusoidal voltage at load terminals [22]. Chopping frequency is in the range of few KHz. The IGBT inverter is controlled with PI controller in order to maintain 1 per unit voltage at the load terminals.

PI controller is a closed loop controller, which drives the plant to be controlled with a weighted sum of the error and the integral of that value. An advantage of a proportional plus integral controller is that the integral term in a PI controller causes the steady state error to be zero for a step input. PI input is an actuating signal which is the difference between the V_{ref} and V_{in} output of the controller which is shown in Fig. 3.

Output of comparator=V_{ref}-V_{in} (5)
V_{ref} - Equal to Base voltage
V_{in} – Voltage in pu at the load terminals

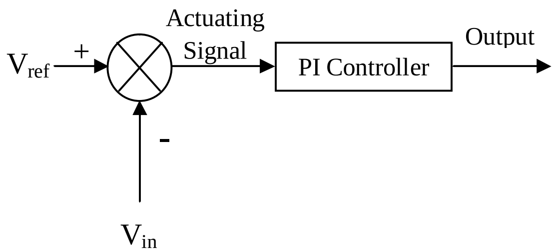

Fig. 3 PI Controller

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The modulated signal Vinv_ref is compared against a triangular signal in order to generate the switching signals for the VSC valves as shown in Fig. 4. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index of signal and the frequency modulation index of the triangular signal. The VSC switching strategy is based on PWM techniques that offer simplicity and good response[23]-[26]. During sag condition, the correct voltage must be injected so that the load voltage become normal again.

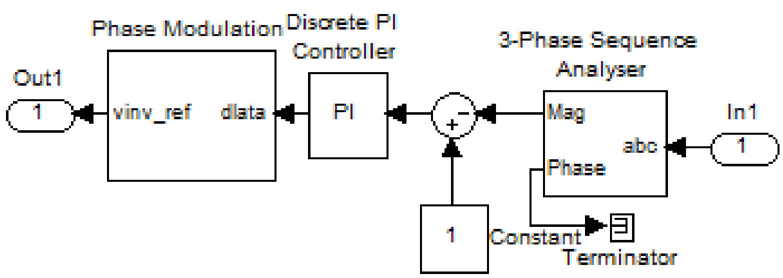

Fig. 4 Simulink model of PI controller

V. SIMULATION RESULTS AND DISCUSSION

The overall simulation diagram of the proposed Dynamic Voltage Restorer with PI controller is shown in Fig. 5.In this Simulink model we have a system in which two parallel feeders are shown. In second feeder further load is connected in series. In one feeder DVR is connected with line. PI controller is used for control purpose. Here DVR system is connected to the distribution system using a injection transformer.

TABLE 2
System Parameters

S.No.	System Quantity	Specification
1	Source	3-Phase, 13KV, 50 Hz
2	Transmission line parameters	R=0.001 Ohms, L=0.005 Henry
3	Inverter specifications	IGBT Based, 3 Arms, 6 Pulse, Carrier Frequency=1080Hz, Sample time=5μsec
4	PI controller	Kp= 0.5, Ki = 50 Sample time=50μsec
5	Fault resistance	0.44Ω
6	Capacitance	750μF
7	TRANSFORMER Three phase transformer Two phase transformer	 13/115/115KV 115/11KV
8	Load	30KW, 100VAR

The test system Table 2 employed to take out the simulations regarding the DVR actuation. The system composed by a 13KV, 50 Hz generating system, feeding two transmission lines through a three winding transformer connected using above system parameters.

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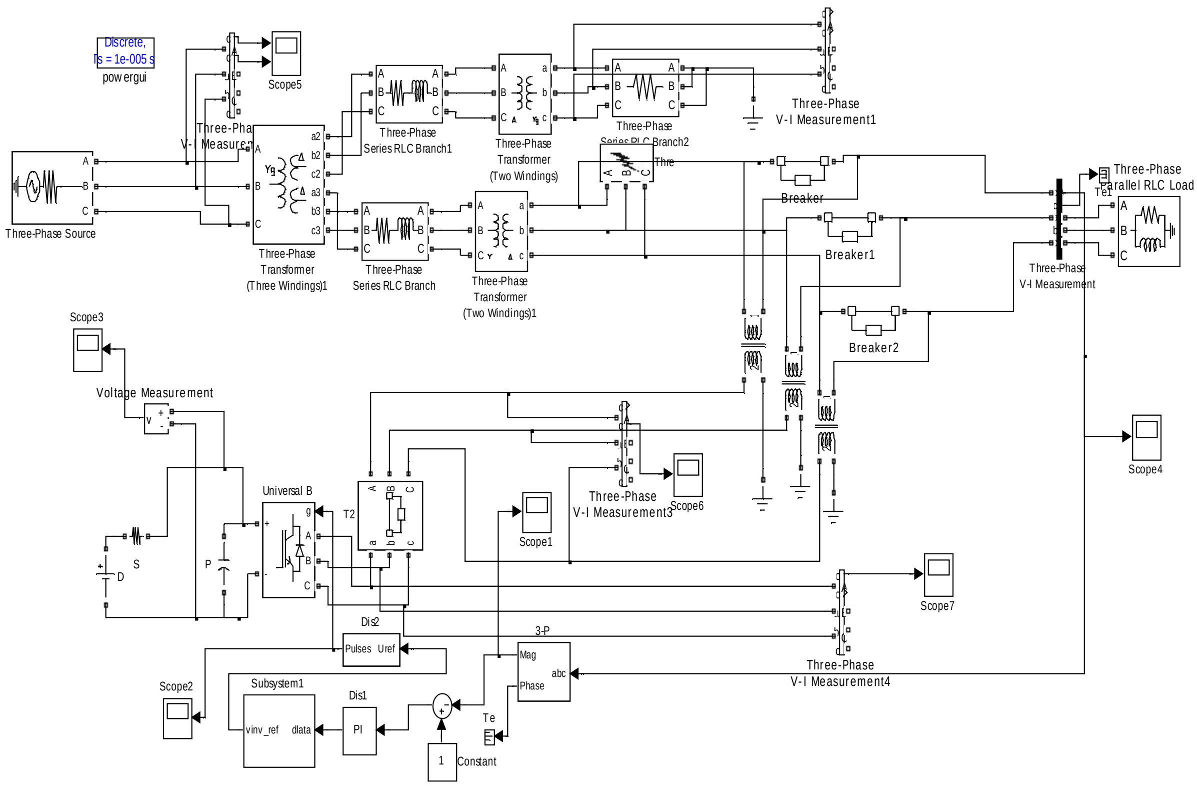

Fig. 5 Overall simulation diagram of DVR

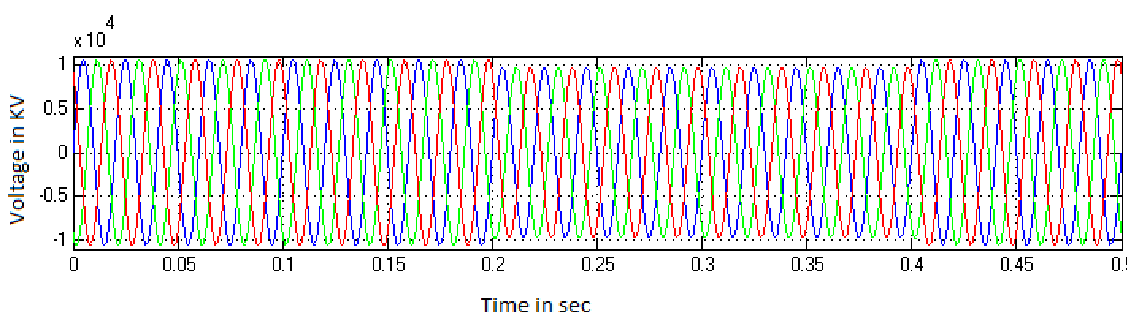

Fig. 6 Supply Voltage

The proposed DVR responds to the sag within one cycle, and injects the appropriate amount of missing voltage during the sag event. On detection of voltage recovery, the DVR switches off to keep conduction losses to minimum.

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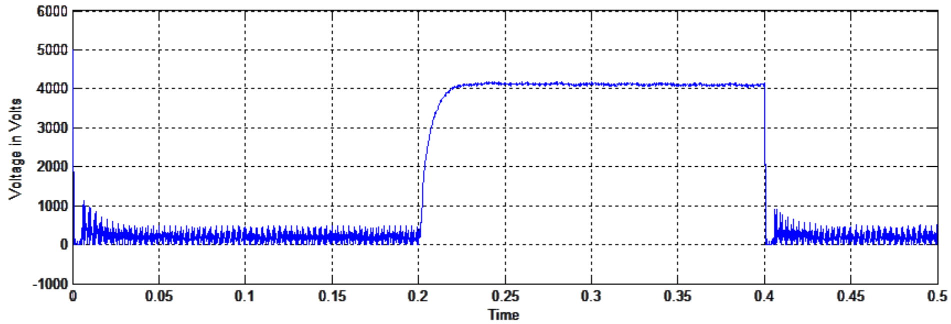

Fig. 7 Injected Voltage

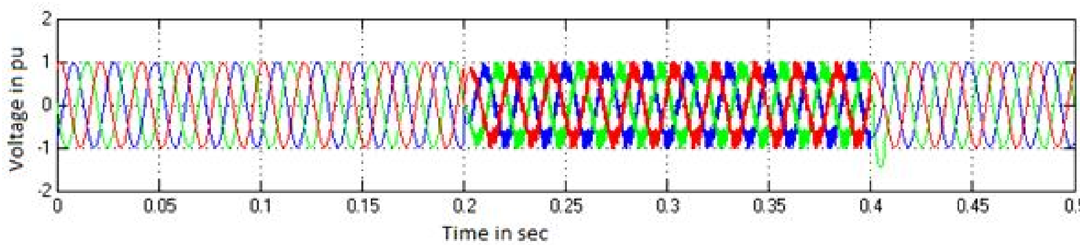

Fig. 8 Load Voltage

The simulation is carried out by using DVR with PI controller. The three phase to ground fault is applied to the system at the point with fault resistance of 0.66 ohm which result voltage sag as shown in Fig. 6 the above graph describes the event of sag takes place for the time duration of 0.2s to 0.4s. When there is a sudden interruption, the nominal voltage reduced from 1pu to 0.8pu also it gets constant up to some time period; here the fault is set for 2s. The injected voltage of DVR from 0.2s to 0.4s is shown in Fig. 7.The proposed DVR using PI controller responds to this sag within one cycle, and injects the appropriate amount of missing voltage during the sag event t=0.2s to 0.4s as shown in Fig. 8. The above graph shows the voltage magnitude at load point, whereas the time period from 0.2s to 0.4s, the voltage sag is mitigated and the voltage level is boosted up to the few extend level.

VI. CONCLUSION

The DVR is considered to be the best choice to protect the industrial facilities from voltage sag. This paper aims to propose a PI controller for the DVR for voltage mitigation in the distribution utilities. The reference load terminal of the DVR has been extracted by obtaining the reference voltages. The performance of DVR has been observed to be satisfactory for various power quality problems like voltage sag, voltage swell in supply voltage. Moreover, it is able to provide self-supported dc bus of the DVR through power transfer from ac line at fundamental frequency. These results also shows that the DVR compensation is fast and the source voltage fault can be compensated by series voltage injection transformer and it can be examined through simulation using MATLAB software along with Simulink and power system block set toolboxes.

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