Power Quality Improvement using Dynamic Voltage Restorer

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Abstract

Power Quality is an issue of chief concern for distribution system. Power quality problem comprises of variation in standard current, voltage or frequency which will result in failure of equipments at the user end causing havoc to system performance. The major problems of power quality consists of sags, swell, transient, and harmonic distortions out of which the sag and swell are predominantly found. To mitigate this problem custom power devices are utilized. Amongst all , Dynamic Voltage Restorer is one of the most capable and promising device at power distribution level for voltage sag mitigation owing to its dynamic response which is fast, smaller in size and low cost. In this paper simulation of DVR in MATLAB/SIMULINK comprising of PI controller and synchronous dq0 theory has been presented.The simulation results depict the effectiveness of dynamic response of DVR and successful mitigation of the voltage sag and swell.

Keywords: *Power Quality, Dynamic Voltage Restorer, Voltage sag, Voltage swell, PI controller.*

INTRODUCTION

The modern industrial devices used nowadays are based on electronic devices like variable speed drives, programmable PLC, and several other precision equipments in which disturbances such as voltage sag, swells, and harmonics occur frequently. Amongst all of them the voltage sag is considered to be the most common and severe one problem. As more and more sophisticated devices are being used due to advancement in technology, their dependency on quality of power is increasing. “Voltage sag is a decrease in the RMS value of voltage or current between 0.1 p.u and 0.9 p.u, at the power frequency and it is occurring for the duration ranging from 0.5 cycles to 1 minute”. “Voltage swell, in contrast, is a rapid increase in RMS value of voltage above the nominal value from 1.1 to 1.8 p.u and which can last for half a cycle to 1 minute.” The voltage sag may occur due to large starting current drawn during start of large induction motors, switching on heavy inductive loads, some kind of faults, etc. Switching off of the large loads, energizing the capacitor banks may cause voltage swell. The phenomena of Voltage sag occurs more frequently than voltage swell in the distribution power system. Sensitive electronic and electrical equipments may be forced to failure, complete shutdown or generation of a huge inrush current which may result in blowing of fuses and tripping of circuit breakers due to voltage sag and swell. The influence of voltage harmonics will cause serious problems in equipments connected to electrical supply systems. Voltage compensation and a solution to power quality problems can be achieved by usage of Custom power devices. Out of all the custom power devices, DVR is one of the most promising devices for voltage sag mitigation and mitigation of impact of voltage disturbances on sensitive loads.

This paper contains of five sections. Section II consists of overview of DVR, and its operating principle, basic equation and fundamental components of DVR. Section III describes about the control strategy used consisting of PI controller and dq0 theory. Section IV depicts the simulation, its parameters and the results. Finally based on above discussions section V gives concluding remarks for performance of DVR under sag and swell conditions.

DYNAMIC VOLTAGE RESTORER

The basic configuration structure of DVR is shown in Fig. 1 where DVR is connected in series with the main system with help of an injection transformer. Whenever there is occurrence of voltage sag in the system, DVR will inject a controlled voltage which is generated by Voltage source converter in series with the bus voltage by means of injection transformer for diminishing the sag [1]. DVR has three operating modes. In standby mode there is no voltage sag or swell occurrence and is the normal operating condition of the system. In this mode the injected voltage is very less to overcome the losses of injection transformer. In the Injection mode the DVR will operate under sag or swell conditions and inject the required voltage to diminish or mitigate the sag. When the current on load side will exceed a permissible limit, due to short circuit in the system or some fault, DVR operates in the protection mode and will isolate from the system using bypass switches.

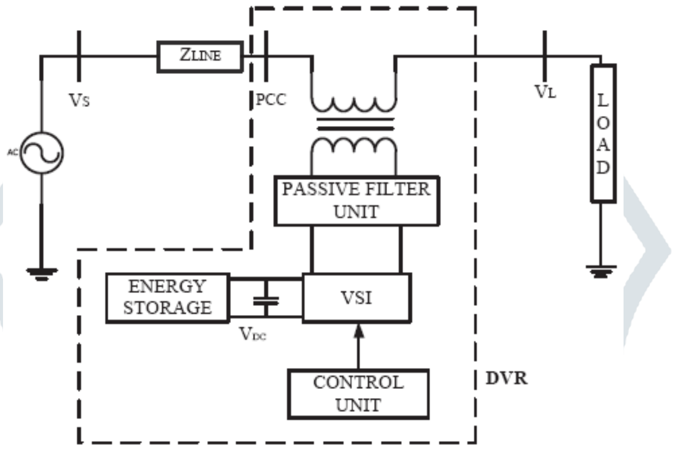

Fig. 1: Basic diagram of ASF

A. Operating Principle

The fundamental principle of DVR operation is that it will inject a voltage through injection transformer that is the difference between sagged voltage and pre-sag voltage. The maximum capability of DVR injection depends upon the injection transformer turns ratio and ratings of energy storage device.

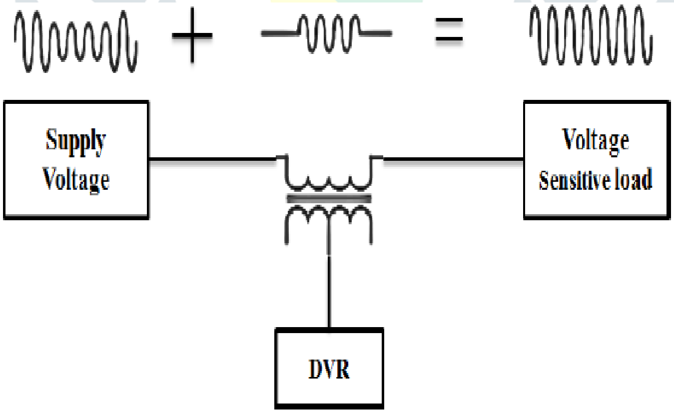

Fig. 2: Operation of DVR

B. Fundamental components of DVR

The DVR consists of following fundamental components:

1) **Injection Transformer:** The injection transformer fulfils the basic purpose of connecting the DVR to distribution feeder and injection of voltage as per the sag and swell detection by the control unit which is generated by the VSI. The performance of DVR is affected and dependent upon the rating of the injection transformer.

2) **Voltage Source Converter:** VSI is a device based on power electronics comprising of DC link energy storage device and is of two levels or can be multilevel. Its basic function is the conversion of DC voltage supplied by the DC link or energy storage device into AC voltage and this voltage will be fed by the injection transformer.

3) **Harmonic filter:** The VSI itself is a device based upon power electronics so it will generate harmonics during the switching action. So it is necessary to suppress out those harmonic which is obtained using the harmonic filter.

4) **DC energy storage:** The requirement of the real power for voltage compensation is fulfilled using the DC energy storage devices. Flywheels, batteries, (SMES), Ultra Capacitors can be used as an energy storage device.

5) **Control system:** The control system comprises of the control strategy used in the operation of DVR In the proposed paper the DVR based on PI controller along with dq0 theory is used.

C. Equations related to DVR

The equivalent circuit of DVR is shown in Fig.3. Whenever there is detection of any reduction in the supply voltage V_{source} from any of the set value, the DVR will inject a voltage, V_{DVR}, which is in series with the help of injection transformer such that the desired load voltage, V_{load} obtained at the load side.

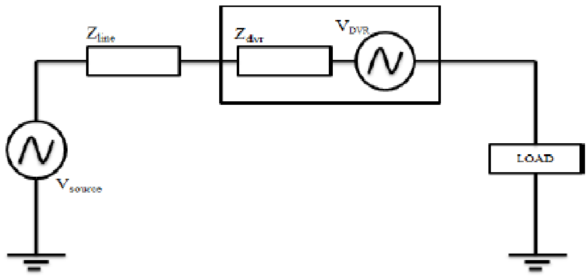

Fig. 3: Equivalent circuit of DVR

$V_{DVR} = V_{load} + Z_{line} I_{load} - V_{source}$

Where,
V_{load} = Desired load voltage
Z_{line} =Impedance of the line
I_{load} = load current
V_{source} = System voltage at time of any fault
V_{DVR} = voltage injected by DVR

D. Operating Modes of DVR

The DVR is designed to inject a dynamically controlled voltage. It has three operating modes of operation.

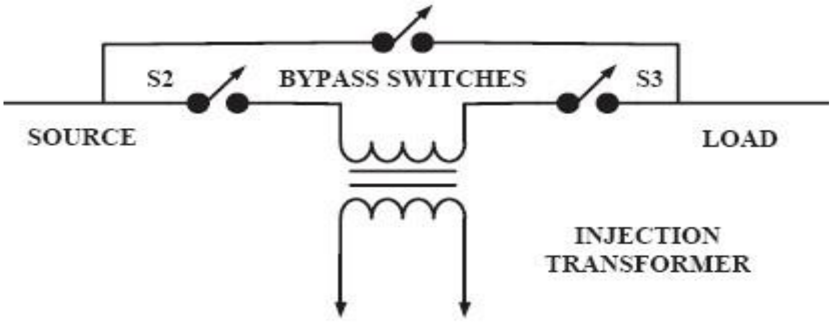

Fig. 4: DVR operating modes

1) Standby mode: This is the normal operating condition. Under this circumstance the DVR will inject no voltage or very less voltage for compensation of the voltage drops on transformer reactance or losses.

2) Injection mode: This mode will be operates when the sag or swell is detected. The switches S2 and S3 will be closed and the voltage will be injected through the injection transformer and the voltage compensation will take.

3) Protection mode: Whenever the phenomena of short circuit or heavy fault current takes place then it is necessary to protect the DVR against it. So the switches S2 and S3 will get open and bypass switch will be closed, hence bypassing the DVR and providing protection to it.

CONTROL STRATEGY

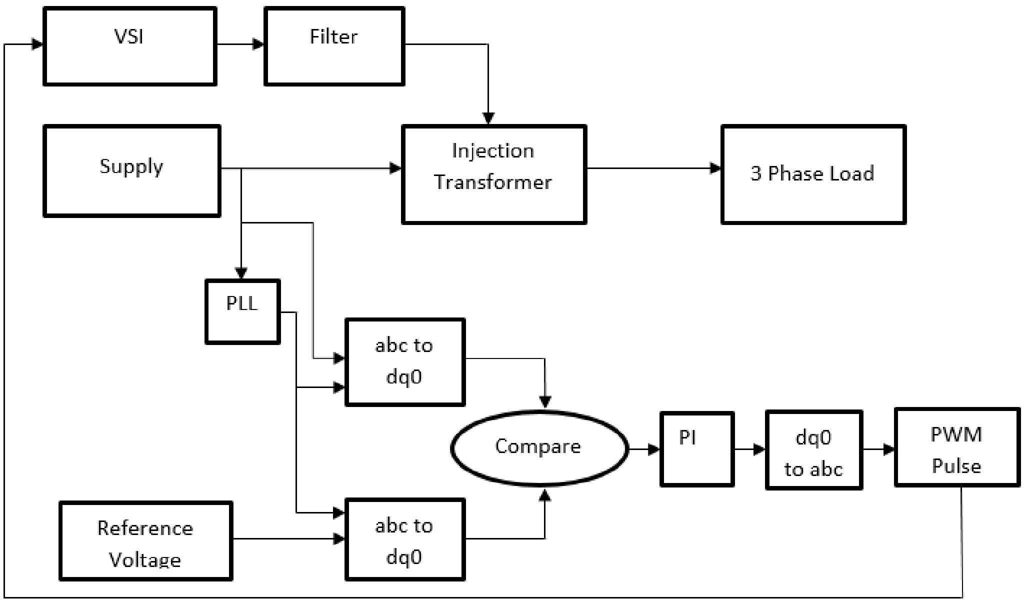

Fig. 5: DVR control strategy

The control strategy used here utilizes PI controller and dq0 theory. To figure out whether sag or swell occurs in the source voltage, is done by comparison of the load voltage and reference load voltage. This difference is the essential amount of load voltage to be injected by DVR. The load voltage and the reference voltage are first of all converted from abc reference frame to dq0 reference.

The difference of this is given to the PI controller. The PI controller identifies the error signal and tries to reduce the error to zero. The output of PI controller is used as a control signal that generates a commutation sequence pattern for power switches of VSI using SPWM technique.

SIMULATION AND RESULTS

The simulation of DVR has been performed in MATLAB/SIMULINK to check out the performance under different sag and swell conditions of DVR. The fig. 5 represents the simulation model.

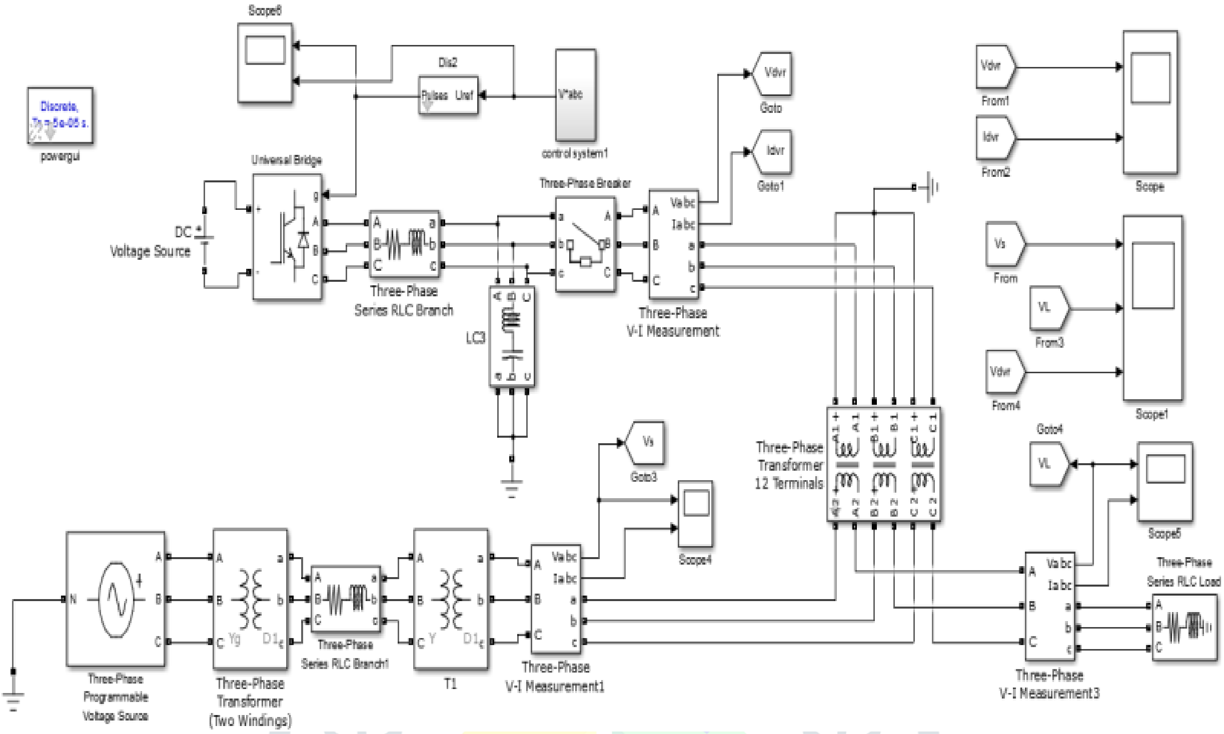

Fig. 6 : DVR Simulink model

Table 1: Simulation parameters

Three phase source	13 kV, 50 Hz
Transmission line parameters	R= 0.01 ohm, L= 0.005 H
Step up transformer	100 MVA, 13/115 kV
Step down transformer	100 MVA, 115/0.415 kV
Injection transformer ratio	1:1
Inverter	IGBT based, 3 arms, 6 pulse
DC battery	240 V
Filter	L=1 mH, C=500 μF
Switching frequency	1080 Hz
Load	P=3 kW, Q= 1 kVAR

The system data information used in simulink model is stated in table 1 above. The performance of DVR is checked at different sag and swells conditions. The following table 2 depicts the different sag and swells conditions with respective time in seconds. In the simulation we check the performance of DVR for all these sag and swell conditions.

Table 2: Voltage sag swell conditions

Time (seconds)	Source Voltage (p.u.)
0	1.0
0.2	0.8
0.3	0.6
0.5	1.0
0.6	1.2
0.8	1.3
0.9	1.0

Whenever there is no voltage sag or the voltage injected by DVR is very less to compensate voltage drop on transformer or loss. When there is sag the DVR voltage injection is in phase with supply voltage while at the time of swell it will be 180 degree out of phase as of supply voltage At time 0.2 sec the voltage sag is there of 0.8 p.u. At time 0.3 sec the sag increases and the voltage falls down to 0.6 p.u. This situation prevails upto 0.5 sec. At 0.5 sec, the voltage regains to 1 p.u. Now the voltage swell takes place at time 0.6 sec and voltage increases to 1.2 p.u. The swell increases at 0.8 sec worsening the voltage to 1.3 p.u. At 0.9 sec onwards the voltage 1 p.u is reached. The DVR will operate under all these conditions.

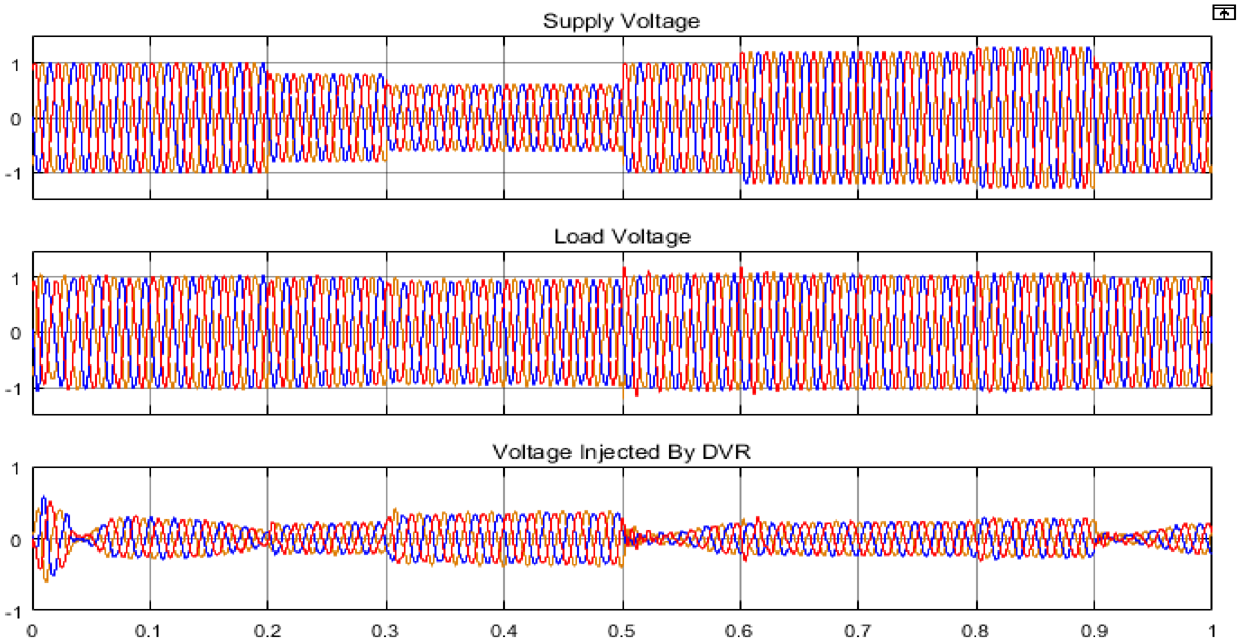

Fig. 7: Simulation results

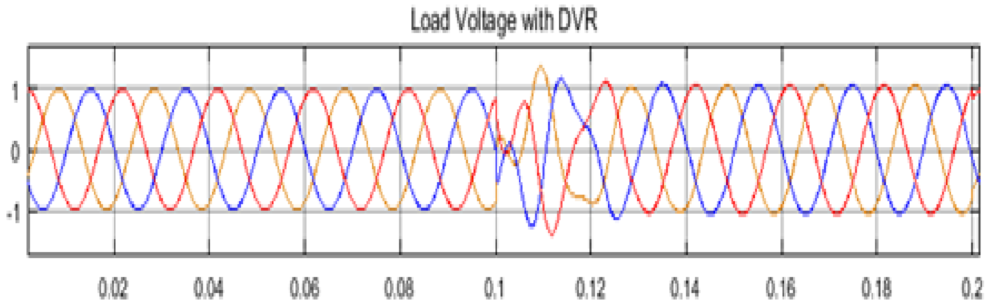

Fig. 8: Transient response of DVR

Fig. 7 shows the simulation results. Under all the given conditions of sag and swell we can get near about 1 p.u. with the help of DVR. Whenever there is no sag or swell i.e. under normal operating conditions the voltage injected is very less. During the occurrence of sag, the voltage injected by DVR increases. During the swell conditions the voltage injected by DVR is in phase opposition and hence compensating the load voltage. Hence the dynamic nature and effectiveness of working of DVR is depicted. Also from Fig. 8 we observe that the dynamic response of DVR is very fast and the transients die out within 2-3 cycles.

CONCLUSIONS

In this paper modeling and simulation of DVR based on PI controller and dq0 theory has been performed in MATLAB/SIMULINK. The simulation results show the effective nature and capability of DVR for successful sag and swell mitigation and provide excellent voltage regulation and power quality improvement.

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