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Simulation of Dynamic Voltage Restorer (DVR) for Voltage Sag Mitigation for Power Quality Improvisation

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Abstract—*Recent advances in drive technology have led to various electronic equipments being used with machines. These loads are very sensitive to changes in applied voltage and power quality. Hence it has become very much necessary to keep the voltage level of the system within permissible limits and maintain good power quality. A Dynamic voltage restorer (DVR) is a series injection type of device which helps to maintain voltage of the system nearly equal to its nominal value during the power quality disturbances. This paper discusses in brief the mathematical modelling, simulation and analysis done using MATLAB SIMULINK for DVR which is used to mitigate voltage sag simulated in the system. A Voltage Sag is a serious problem as it can interrupt a continuous process in an industry causing huge losses economically, here it is simulated by creating a shunt fault, which lowers the voltage to a level of 0.56 pu from 0.77 pu on the supply line after which the DVR begins compensation by comparing the error signals using sensing equipments, and eventually returns the system to its steady state value, which is 0.75 pu. The modelling of various parts of DVR such as Sensing equipment, Phase Locked Loop, PWM generator, Inverter and Injection transformer was done in SIMULINK. The error signal was optimized using Proportional Integral (PI) Controller before giving it to the PWM generator.*

Keywords*: DVR, Power quality, Sag.*

1. INTRODUCTION

Both Electric utilities and consumers are becoming very concerned about the quality of electric power. Now a days the word "Power Quality" has gained immense importance because of following reasons:

1. New control techniques are mostly microprocessor and power electronic device based which are very sensitive to power quality.

2. In order to increase efficiency of power system various equipments such as variable speed drives, shunt capacitors, etc. are used. This is cause of harmonic injections.

3. Increased awareness in consumers regarding quality of power being supplied.

4. Because of interconnected system, failure of any component has significant consequences.

Electrical power quality can be defined in several ways like from utility side, end user's side or manufacturer's side.

Utility may define reliability as power quality. Manufacturer may define it as a characteristic power supply that allows equipment to work properly. But ultimately power quality is consumer related issue. Therefore, it can be defined as: Any problem manifested in voltage, current and frequency deviations that result in failure or maloperation of consumer equipments.

Voltage Sag can be defined as a short duration reduction in RMS voltage caused by faults and starting of large loads like induction motors. Typical duration of voltage sag is 0.5 to 30 cycles.

There are four types of FACTS controllers [5]:

1. Series Controllers
2. Shunt Controllers
3. Combined series-series controller
4. Combined series-shunt controller

Out of above four types, Dynamic Voltage Restorer (DVR) is a series type controller. DVR is a device intended to protect sensitive loads from voltage sags/swells by connecting it at Point of Common Coupling (PCC). It acts as series voltage booster or static series compensators. It consist of a three phase Voltage Series Inverters (VSI) which will provide voltage vector corresponding to sag/swell magnitude. This voltage is added to source voltage during event of sag/swell and voltage is restored to nominal value.

2. LOCATION OF DVR

DVR can be inserted in primary distribution feeder. It is inserted in series with load as shown in Fig. (1). So, it changes

impedance. By controlling the change in impedance, load can be protected from voltage sags [3] [7].

DVR is inserted in low voltage (LV) side at PCC with following advantages:

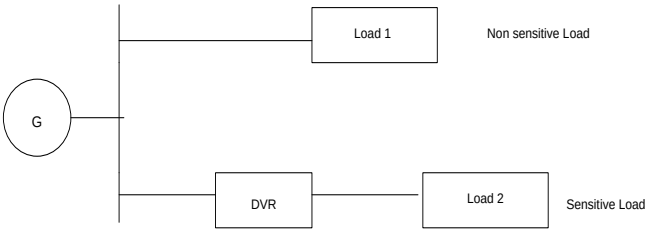

Fig. 1: Location of DVR

1. When DVR is connected to LV it can be accessed by both end users as well as utility.
2. DVR is easy to protect because of reduced short circuit levels after distribution transformer.

3. COMPONENTS OF DVR

DVR consists of following components shown in Fig. (3) [1] [3] [7]:

1. Energy Storage Unit:
   DVR injects voltage in the circuit during sag event. For this, energy is necessary. There are two configurations of DVR:
   i. Rectifier supported DVR: in this type of DVR, directly supply voltage is given to rectifier. This type is without internal storage.
   ii. Capacitor Supported DVR: in this type, VSI is given DC supply by using capacitors. This is having internal energy storage
2. Inverter circuit: it is mostly a voltage source inverter. It consists of switches which are fired using sinusoidal pulse width modulation technique and energy storage device. This can generate voltage at any required frequency, magnitude and phase angle.
   It uses mainly four switching devices: Metal oxide semiconductor field effect transistor (MOSFET), Gate turn-off thyristor (GTO), Insulated Gate Bipolar Transistor (IGBT), and Integrated gate commutated thyristor (IGCT).

   VSI used should be able to handle both voltage sag as well as swells. Cascading of VSIs in series can eliminate need of injection transformer.
3. Control unit:
   This ensures the proper operation of DVR unit. Magnitude of load voltage and reference voltage is compared and generates error signal if there is any difference. This error signal acts as actuating quantity for driving PI controller. Output voltage of this controller controls PWM pulses of the inverter. This is shown in Fig. (2).

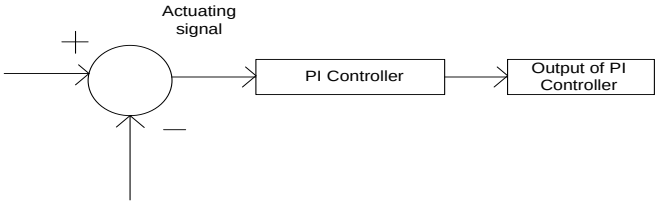

Fig. 2: Schematic of PI Controller

4. Filter

Filter is used to reduce harmonics generated because of use of switching devices in inverter. It is normally a LC filter. Value of Inductor (L) is calculated on basis of current ripple. Normally ripple current is chosen as 10-15% of rated current. Capacitance C of filter can be calculated on the basis of amount of reactive power supplied by capacitor at fundamental frequency.as follows:

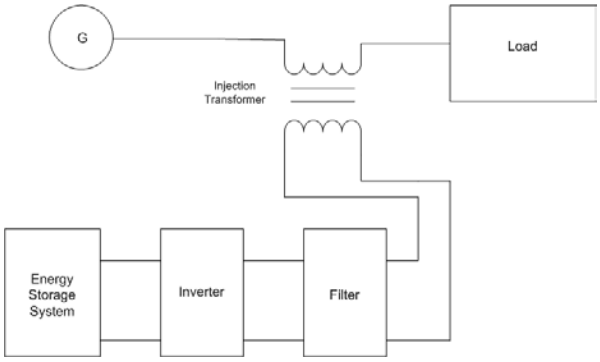

Fig. 3: Components of DVR

$$\Delta I_L = \frac{V_{dc}}{8*L*f_s}$$

Where,

ΔI_L : Ripple in rated current

V_{dc} : DC input to the inverter

f_s : switching frequency of Inverter

$$C = \frac{15\%\, P_{rated}}{3*2*\pi*f*V_{rated}^2}$$

Where,

P_{rated} : Rated load power

V_{rated} : Rated load voltage

f: Supply frequency

5. Series Injection Transformer

This is used in circuit for isolation purpose. It isolates control circuit of DVR from high voltage distribution network. It allows to design DVR for low voltage level. The high voltage

side of the injection transformer is connected in series to the distribution line, while the low voltage side is connected to the DVR power circuit.

For a three-phase DVR, three single-phase or three-phase voltage injection transformers can be connected to the distribution line, and for single phase DVR one single-phase transformer is connected. For the three-phase DVR the three single phase transformers can be connected either in delta/open or star/open configuration. Here delta connection is used to eliminate zero sequence components.

4. OPERATING MODES OF DVR:

DVR is operated in three modes [3] [6]:

1. Protection mode

The DVR will be isolated from system if the system parameters exceeds limits. During short circuit event on load side S1 switch provides bypass path where S2 and S3are opened which isolates DVR. DVR is removed from circuit for two reasons one is to protect DVR and another is to avoid additional disturbances cause by DVR. Fig. (4) shows view of protection mode.

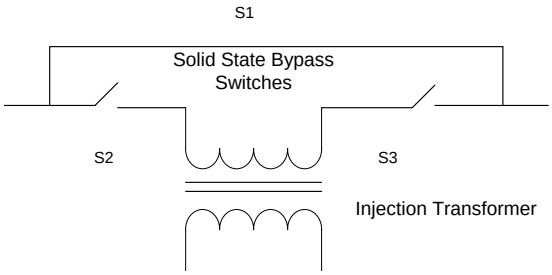

Fig. 4: View of Protection Mode

2. Standby mode

Standby mode refers to normal steady state operation. In this mode DVR is either short circuited or inject small voltage to compensate losses or voltage drop in transformer. But normally it is operated in short circuit mode. Fig. (5) shows view of standby mode

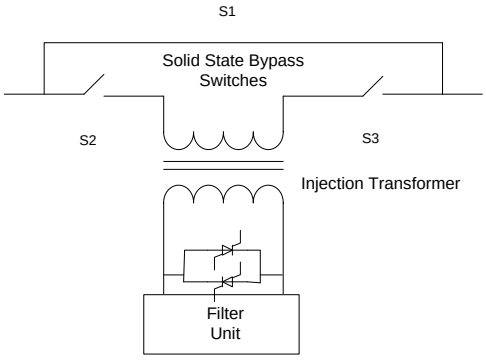

Fig. 5: View of Standby Mode

3. Injection mode: this mode is mode where DVR is performing its basic function. As soon as sag is detected DVR goes to injection mode and injects three

5. COMPENSATION STRATEGIES:

Compensation strategies used for DVR depends upon various factors like power rating of DVR, various load conditions, and different types of voltage sags. Some loads are sensitive to change in magnitude of voltage, some are sensitive to phase angle jumps whereas some are sensitive to both. So, it can be said that load characteristics is a deciding factor for choice of compensation technique used. There are three compensation or voltage injection techniques [3] [4] [6]:

1. Pre-sag compensation:

In this type of compensation, supply voltage is continuously tracked. If there is any disturbance in supply voltage, DVR injects voltage equal to disturbance value at PCC and load voltage is restored back to the previous value. In this method, compensation for both magnitude and phase is given. In this method injected active power cannot be controlled.

$$V_{DVR} = V_{prefault} - V_{sag}$$

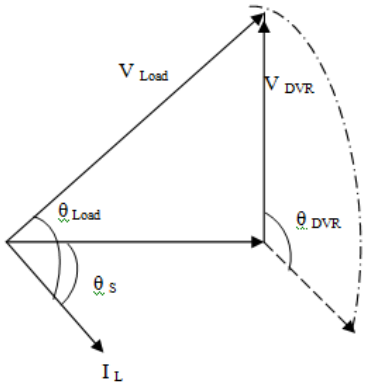

Fig. 6: Phasor Diagram for Pre-sag Compensation

2. In phase compensation

In this method, voltage injected by DVR is in phase with sag voltage. Phase angle of pre sag voltage and load voltage are different. But they have same magnitude which is important for maintaining power quality.

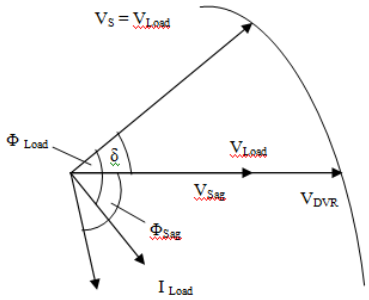

Fig. 7: Phasor Diagram for In-phase Compensation

3. Minimum energy injection

In this method of compensation active power supplied by network is maximized and reactive power is decreased by minimizing the active power and maximizing reactive power supplied by compensator. In this method apparent power is maintained constant.

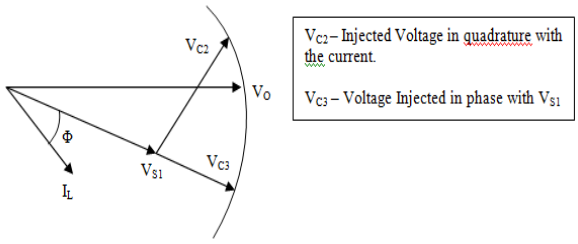

Fig. 8: Phasor Diagram for Minimum Energy Injection

6. SAG DETECTION TECHNIQUES

Sag detection techniques should detect occurrence of sag, start and end instant of sag, depth and phase shift of sag. Common techniques are as follows [3]:

1. Peak value method:

This is the simplest method. Peak of system voltage is monitored and compared with reference value. If there is any difference more than 10% of specified value, inverter is switched in.

2. Root mean square (RMS) method:

In this method, RMS value of system voltage is monitored. Start point of sag is when value of voltage falls below 0.9 pu.

3. Fourier Transform (FT):

The FT is achieved by orthogonal decomposition of power signal. Applying FT to each supply phase, magnitude and phase of every frequency components of power system signal can be obtained. Drawback of this method is it uses an averaging technique so needs a cycle to return information about sag depth and phase.

4. Space vector:

Three phase voltages are transformed onto two dimensional voltage V_{dq} which corresponds to magnitude and angle. Any change in value of d and/or q gives occurrence of event. Comparison of disturbance with reference gives amount of disturbance in d-q frame which is transformed back to abc frame. It does not have any time delay.

7. CONTROL TECHNIQUES

For controlling of injected voltage of DVR there are two types of controller which are employed in practice [3] [7]:

1. Linear controller:

Three types of linear controllers can be used.

The feedforward voltage controller is normally a choice for DVR. It is simple and fast. System voltage is monitored and compared with reference voltage continuously and difference in voltage is supplied by DVR. Disadvantage of this is high steady state error.

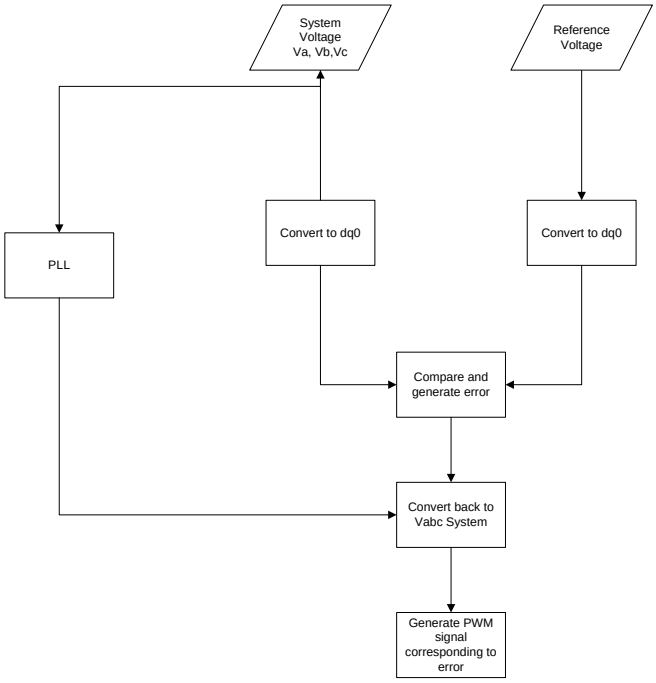

Fig. 9: Flowchart for feedforward controller

In feedback controller, difference between system voltage and reference voltage is injected by DVR in feedback loop at supply bus. This method is accurate but is very complex and time delayed.

Multi loop controller is the third type of controller in which outer loop is of voltage and inner is of current. It is very complex and time delayed.

2. Non-linear Controllers:

As DVR is a nonlinear device, these type of controllers are more suitable for DVR.

Artificial Neural Network (ANN) has self-learning capability which gives improved precision. It has adaptive capacity.

Fuzzy Logic (FL) controllers are used when exact mathematical modeling of system is not possible. This reduces transient overshoot of PWM considerably.

Space Vector Pulse Width Modulation (SVPWM) is method which monitors space vector of inverter. This improves performance at low switching frequency.

This system consist of a voltage source, a three phase transformer and a 3-phase lagging load of 20 MW. Voltage sag was created by creating fault for 0.2 – 0.3 seconds with fault resistance of 100 Ω and ground resistance of 10 Ω. Fig. 5 shows the voltage waveform during three phase fault.

Function of DVR is to inject power to compensate for this sag. The simulation parameters are given below.

8. SIMULATION AND SIMULATION RESULTS:

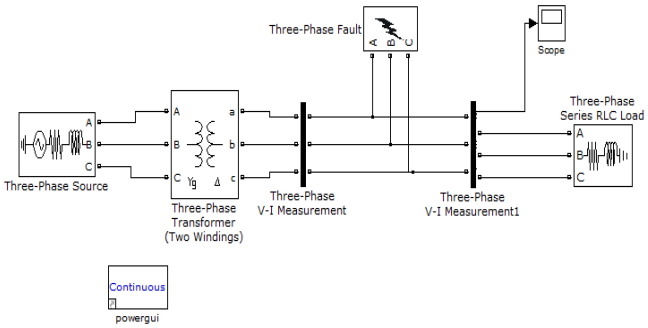

Fig. 10: Simulation circuit for voltage sag without DVR

Table 1: System Details

Sr. No.	System Quantities	Values
1.	Source	3 –phase, 11 KV, 50 Hz
2.	Inverter Parameters	IGBT based, 6 pulse, carrier frequency=1000 Hz
3.	PI Controller	Kp=2, Ki=.2
4.	RL load	Active Power=20MW, Inductive reactive Power=15 MW
5.	Filter	L=8.25mH, C=0.182µH

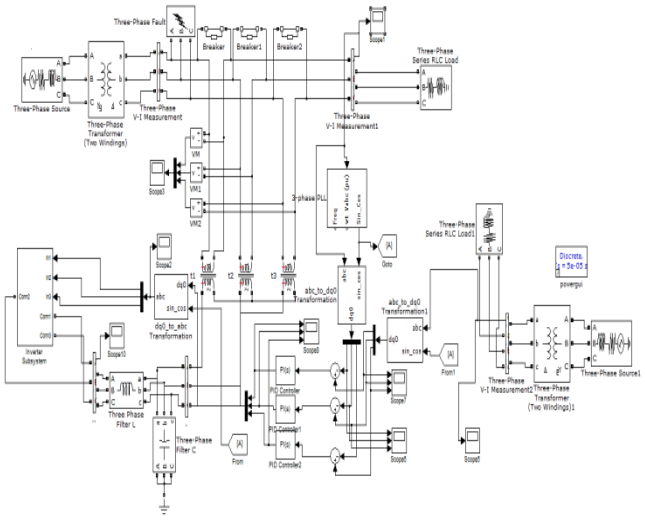

Fig. 11: Test model of DVR

Simulation time for model is taken as 0.5 seconds. In the beginning simulation was done without creating any fault on the network. Fig. (12) shows the voltage waveform on the laod side without fault in per unit on the base of 132 KV. Y axis shows the magnitude and X axis shows simulation time.

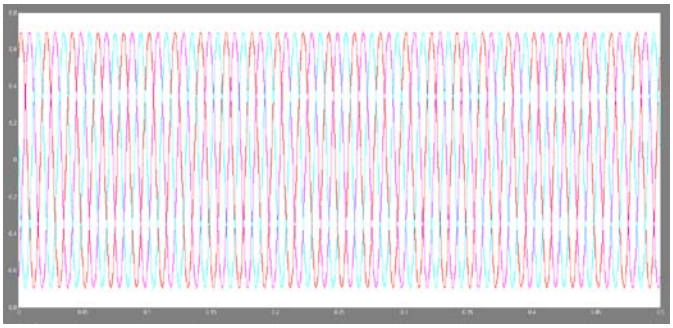

Fig. 12: Load voltage without Fault

Then second simulation is done by creating Triple line to ground fault on the system with fault resistance of 100 Ω from 0.2 to 0.3 seconds.Fig. (13) shows laod voltage waveform during fault. From this waveform we can observe large amount of voltage sag. Voltage drops to almost to 0.56 pu. This voltage dip is needed to be compensated by DVR.

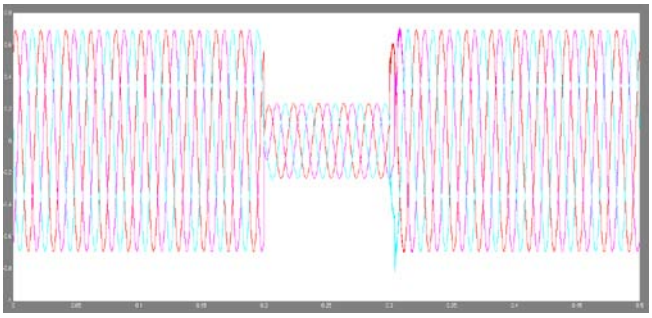

Fig. 13: Load voltage During Fault without DVR

Third simulation is carried out by connecting DVR for compensating the voltage sag occuring on the system mentioned above. The PWM pulses for VSI will be generated corresponding to the error signal shown in Fig. (14).

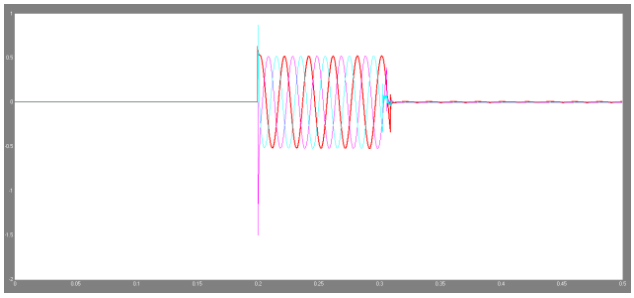

Fig. 14: Error voltage output from PI Controller

Fig. (15) shows the voltage side waveform after applying DVR compensation. From this waveform we can say that DVR restores the voltage value to 0.75 pu whereas actual value is 0.77 pu.

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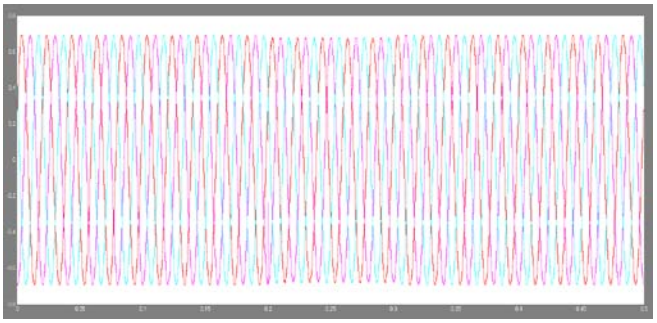

Fig. 15: Load voltage During Fault without DVR

9. CONCLUSION

In this paper modelling of DVR is done using MATLAB/ SIMULINK. This DVR consist of components like magnitude and phase detector, energy storage system, inverter, filter and series injection transformer. This DVR compensates for voltage sag occurring in the system during fault condition. In this paper control of DVR is done using PI Controller. From the detail analysis it can be seen that compensation achieved in case of three phase to ground fault is about 97%.

10. ACKNOWLEDGEMENTS

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