Voltage Sag Mitigation by Using Dynamic Voltage Restorer (DVR)

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Abstract – Due to increasing complexity in the today's power system, voltage sags and swells are now becoming one of the most critical power quality problems. Voltage sag is a short reduction voltage from nominal voltage, occurs in a short duration of time, they are bound to have a greater impact on the industrial customers. If the voltage sags exceed two to three cycles, then manufacturing systems making use of sensitive electronic equipment's are likely to be affected leading to major problems. It leads to wastage of financial losses and resources. This is possible only by ensuring that uninterrupted flow of power is maintained at proper voltage levels. Electrical power utilities are looking for solutions to ensure high quality power supply to their customers, a lot of solutions have been developed, but this project tends look at the solving the problems by using custom power devices such as "Series active power filter (SAPF)". This work describes the techniques of correcting the supply voltage sag and voltage in a distributed system. Among these, the distribution static compensator and the series active power filter (SAPF) are most effective devices based on the VSC principle. The series active power filter (SAPF) injects a voltage in series with the system voltage to correct the voltage sag and swell. Comprehensive results are presented to assess the performance of each device as a custom power solution.

Keywords: *Dynamic Voltage Restorer, Power Quality, Voltage Sag, DC Energy Storage*

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I. INTRODUCTION

Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged, we would say that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, during normal usage, we would suspect that the Power quality is poor. There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side and other from utility side. First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filters. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Series active power filters operates as a controllable voltage source. [2] Both schemes are implemented preferable with voltage source PWM inverters with a dc bus having a reactive element such as a battery. One of the most common power Quality problems today is voltage dips. Voltage sag is a short duration time (10 ms to 1 minute) Event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two Parameters, depth/magnitude and duration. The voltage sag magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half cycle to 1 min.

A. Conventional system configuration of DVR

Dynamic Voltage Restorer is a device designed for maintain a constant RMS voltage value across a sensitive load. The DVR considered consists of: [4]

1. An injection / series transformer
2. A Voltage Source Converter (VSC),
3. An energy storage and
4. A control system/Compensator,

As shown in Figure.1

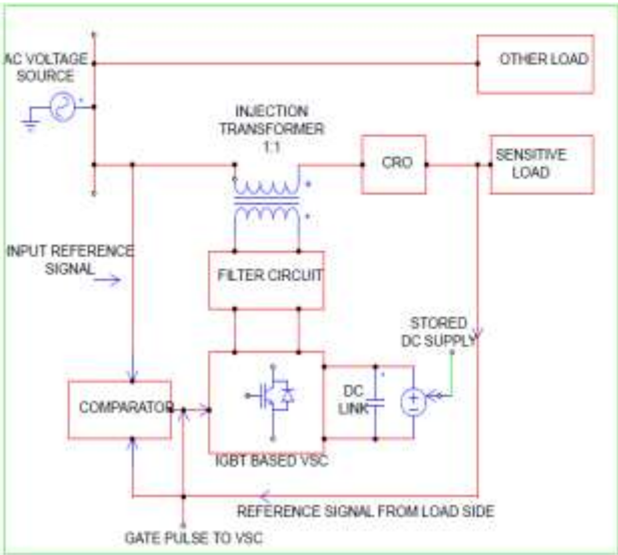

Figure 1: Dynamic Voltage Restorer (DVR) schematic diagram

The main function of a DVR is the protection of sensitive loads from voltage sags/swells coming from the power network. Therefore as shown in Figure.1, the DVR is located on approach of sensitive loads. If a fault occurs on other lines, DVR inserts series voltage and compensates load voltage to pre fault value.
The momentary amplitudes of the three injected phase voltages are controlled to eliminate any detrimental effects of a line fault. This means that any differential voltages caused by transient disturbances in the line will be compensated by an equivalent voltage generated by the VSC and injected on the medium voltage level through the injection transformer. [1]
The DVR works independently of the type of fault or any event that happens in the system, provided that the whole system remains connected to the supply.
The DVR has two modes of operation which are: **standby mode** and **boost mode.** In standby mode, the booster transformer's low voltage winding is shorted through the converter. The DVR will be most of the time in this mode. In boost mode, the DVR is injecting a compensation voltage through the booster transformer.

II. CONTROL ALGORITHM

The phase lock loop (PLL) circuit is used to generate a unit sinusoidal wave in phase with mains voltage. Figure 2 Flow chart of feed-back control technique for SAPF based on dqo transformation for voltage sag detection. The detection is carried out in each of the three phases. The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va, Vb, Vc).The voltage sags is detected when the supply drops below 90% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches. (IGBT's)

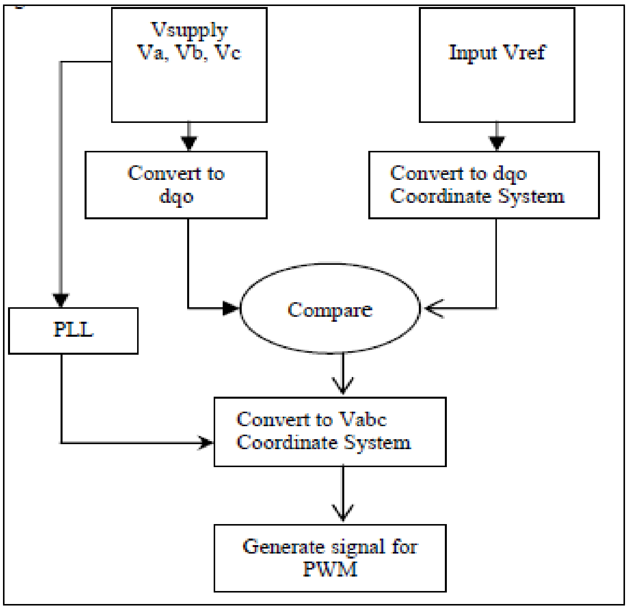

Figure 2: Flow chart of control technique for DVR based on dqo transformation

The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The sequence of the operation of control unit is starting with sag detection. When the sag occurred in the system installed with SAPF, it will detect the sag. Then, the actual signal (sag) and reference signal will convert into dq0 form. After comparing both of the signals, the error signal in dq0 form will produce. This signal will convert back into Vabc form. Because of inverter need pulse signal to operate, the Vabc signal in sinusoidal form will convert into pulse signal via PWM control. This pulse will send to the inverter which is in power unit. Thus, power unit will settle the rest of the operation.[5]

Following figure 4: In this case only voltage sag is generated with the introduction sudden load at bus B2 due to operation of circuit breaker.

III. MATLAB SIMULATION

A. Voltage Source Inverter

Three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable.

Applications require sinusoidal voltage waveforms. (E.g. ASDs, UPSs, FACTS, VAR compensators) Arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators).

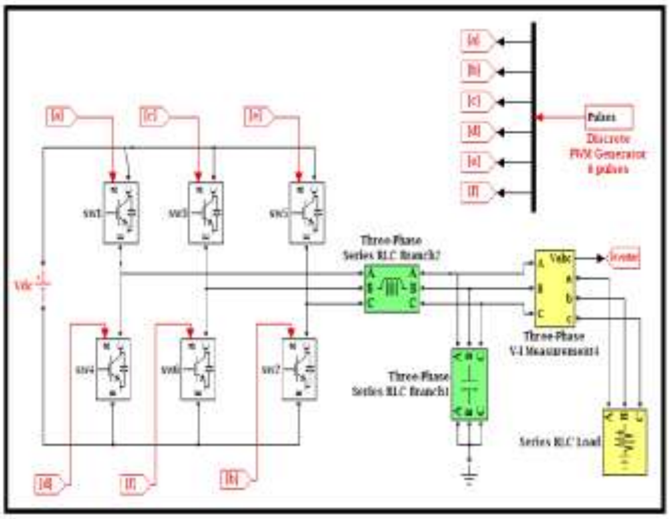

Figure 3: Simulated model of three phase inverter

IGBT is used for switching purpose, the IGBT combines in it all the advantages of BJT and MOSFET. The IGBT is a minority carrier device with high input impedance & large bipolar current carrying capability.[6]

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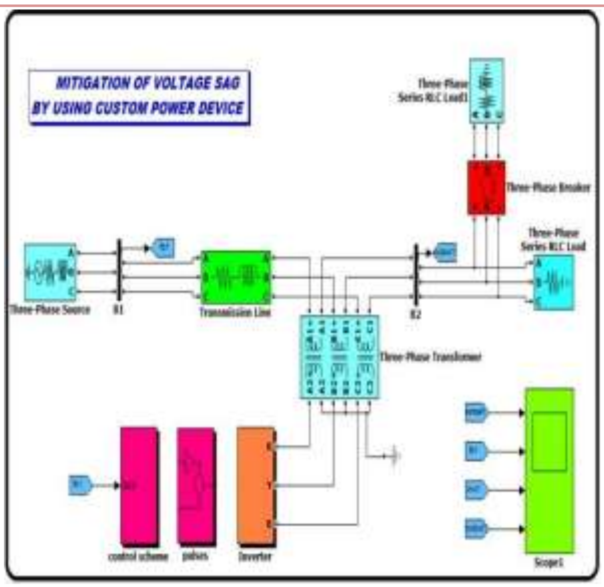

Figure 4: System when increased load on bus B2

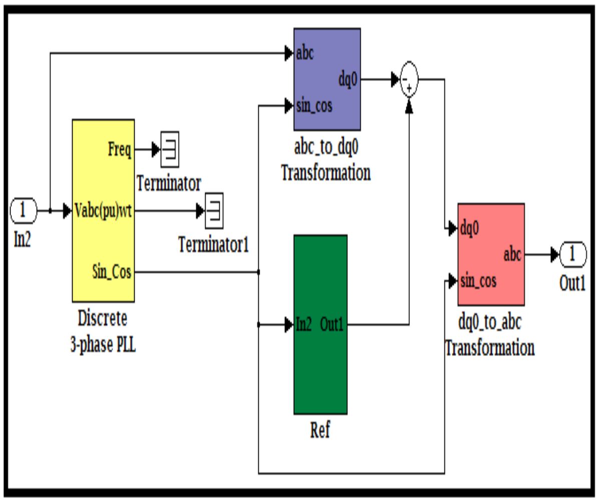

Figure 5: Simulation of feed-back control strategy

The basic functions of a controller in a SAPF are the detection of voltage sag/swell, distortion, and harmonic events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells. The d-q-o transformation or Park‘s transformation is used to control of SAPF. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from a-b-c reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored. The detection is carried out in each of the three phases.[5]
The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va,Vb,Vc).The voltage sags is detected when the supply drops below the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value.
The error signal is used as a modulation signal that allows to generate a commutation pattern for the power switches (IGBT‘s) constituting the voltage source converter. The IGBT conduction pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The PLL circuit used to generate a unit sinusoidal wave in phase with mains voltage.

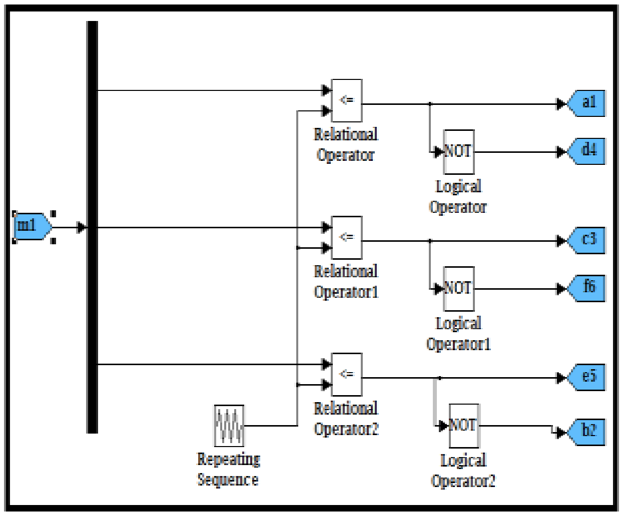

Figure 6: Simulated model of PWM control of Inverter

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off time periods of the IGBT’s. This is the most efficient method of controlling the output voltage and this method is termed as Pulse-Width Modulation (PWM) Control. The advantages possessed by PWM techniques are as under:

1] The output voltage control with this method can be obtained without any additional components.

2] With the method, lower order harmonics can be eliminated or minimized along with its output voltage control.

The main disadvantage of this method is that IGBT’s are expensive as they must possess low turn-on and turn-off times. PWM inverters are quite simple in industrial applications. PWM techniques are characterized by constant amplitude pulses.
The width of these pulses is however modulated to obtain inverter output voltage control.The different PWM techniques are as under:
(a) Single-pulse modulation
(b) Multiple pulse modulation

(c) Sinusoidal pulse width modulation (Carrier based Pulse Width Modulation
Technique)
Here we have used Sinusoidal Pulse Width Modulation.

IV. SYSTEM UNDER STUDY

Table 1: shows the parameters of system under consideration

PARAMETERS	SPECIFICATION
Source voltage	440 volt (1PU)
Frequency	50 Hz
Transmission line parameter	R=0.1 ohm L=0.5 mh
Injection transformer ratio	1:1
3 Phase load	P=1000 watt Q=25000 watt
DC link	250 volt

V. MODE OF OPERATION

1. STANDBY MODE: (Vinj= 0)
When there is no fault in system, difference between reference and feedback signal is zero.

2. INJECTION MODE: (Vinj>0)
In this mode the device is injecting a compensating voltage through the injection transformer due to the detection of a disturbance in the supply voltage

VI. SIMULATION RESULT

Table 2: Shows simulation result when increased load (sudden) on bus B2 with system specification mentioned bellow.

System Voltage	Voltage sag	Injected voltage	Mitigated voltage
440 volts (1PU)	0.30 PU	0.30	1 PU

From figure 4: it shows that when sudden load increase on bus B2, Voltage sag occurred at that bus. Sudden load on Bus B2 is increased with the help of Circuit breaker. The operating time of Circuit breaker is assumed to be 0.2 to 0.3 sec. Therefore Voltage sag is occurred within the period of 0.2 to 0.3 sec. In order to mitigate this Voltage sag it is necessary to add the missing Voltage within required time. Following results shows that when 0.30 pu Voltage sag occurred at Bus B2, inverter generate 0.30 pu Voltage and gives input to injecting transformer. As injecting transformer having 1:1 turn ratio therefore it add 0.30 pu voltage in series with system voltage. Due to injection of this voltage, voltage sag completely mitigated.

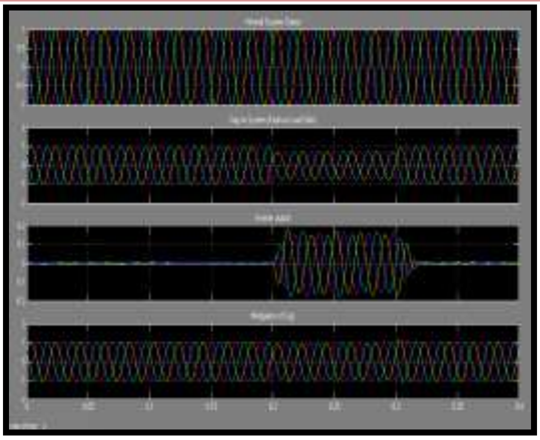

Figure 7: Simulation for mitigation of voltage sag when increased load on bus B2

VII. CONCLUSIONS

Paper gives brief idea about dynamic voltage restorer circuit connected to sensitive load. Showing MATLAB simulation circuit for three phase voltage source converter and dq0 control technic has been proposed in this paper. Simulation results show an effective mitigation of voltage sag. These results show that employed control strategy has an excellent capability of voltage restoration, within specified time frame for smooth,dynamic and clean power flow to load.
A feedback control strategy to mitigate power quality problem like voltage sags, with the help of in-phase series injection technique.

VIII. REFERENCES

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