Removal of Voltage Sag using Dynamic Voltage Restorer (DVR)

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Abstract - Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that can cause failure or a miss-operation of equipment. With power quality problem utility distribution networks, industrial loads, sensitive loads etc. are suffered. Power quality problem dealt here is Voltage Sag. To overcome the problem related to power quality, custom power devices are introduced. A number of power quality solutions are provided by custom power devices. At present a wide range of very flexible controllers, which capitalize on newly available power electronics components, are introduce for custom power applications. Power system capability can be increased by the use of Flexible AC Transmission System devices (FACTS) in transmission systems experiencing high power flows. The Dynamic Voltage Restorer (DVR) is the key series compensation devices that open up new opportunities to control the power on transmission systems in order to enhance their utilization, increase power transfer capability and to improve voltage profile. The fast response of this device makes it the efficient solution for improving power quality in distribution systems.

Keywords – **Voltage Sag, Power Quality**, FACTS device, DVR, Voltage Profile, Series Compensation, IEEE

INTRODUCTION

Power Quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life expectancy. IEEE Standard (IEEE1100) defines Power Quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment". If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. Power quality problems include a wide range of disturbance such as Voltage Sag, Voltage Swell, Frequency Disturbances, Harmonic Distortion, Impulse Transients, Electro Magnetic Interference and Electro Static Discharge. One of the most common power frequency disturbances is Voltage Sag. Voltage Sag is defined as a short reduction in voltage magnitude for duration of time, and it is the most important and commonly occurring Power Quality issue. The definition to characterize Voltage Sag in terms of duration and magnitude vary according to the authority. IEEE standard (IEEE1159, 1995) defines Voltage Sag as a decrease of RMS voltage from 0.1 to 0.9 per unit (p.u.), for duration of 0.5 cycles to 1 minute. Voltage Sags are mostly caused by system fault and last for duration ranging from 3 cycles to 30 cycles depending on the fault clearing time. Voltage Sag is caused by Short Circuit fault on the system, Transformer energizing, heavy load switching, motor starting, customer load addition, large load addition in utility service area etc
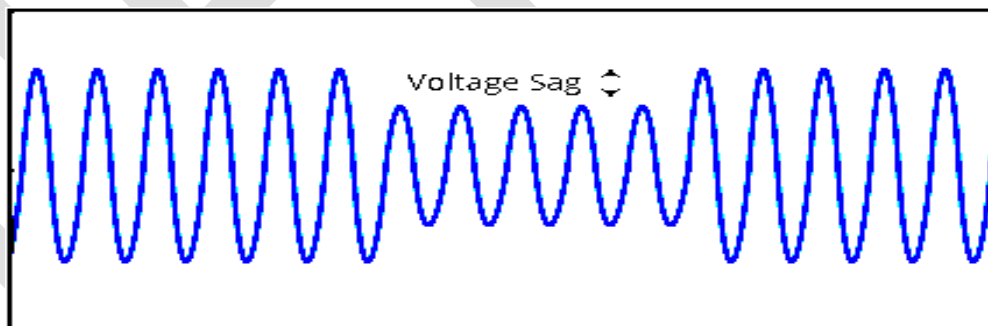
Principle of DVR (Dynamic Voltage Restorer)

DVR (Dynamic Voltage Restorer) is a static VAR device. It has wide applications in a variety of transmission and distribution systems. It is a series Compensation device, which protects sensitive electric load from Power Quality problems such as Voltage Sags, Voltage Swells, Voltage and Frequency unbalances and Harmonics distortion with the help of power electronic devices which are used in Voltage Source Converters (VSC). The first DVR was installed on 12.47 KV system located in Anderson, South Carolina, North America in 1996. DVR is small in size and it is a better power effective device as compared to other FACTs devices like DSTATCOM, SSSC and UPFC. DVR is the most effective and efficient custom power device because it has certain advantages like lower cost, smaller size and its fast response towards the disturbances. The capability of injection voltage by DVR system is 50% of nominal voltage. This allows DVRs to successfully provide protection against sags to 50% for durations of up to 0.1 seconds. Furthermore, most Voltage Sags rarely reach less than 50%.The Dynamic Voltage Restorer is also used to mitigate the damaging effects of Voltage Swells, voltage unbalance and other waveform distortions. DVR Works to mitigate any supply voltage disturbance, especially Voltage

Sag, by inserting a voltage with the required magnitude and phase shift in order to restore the load voltage to its rated value.
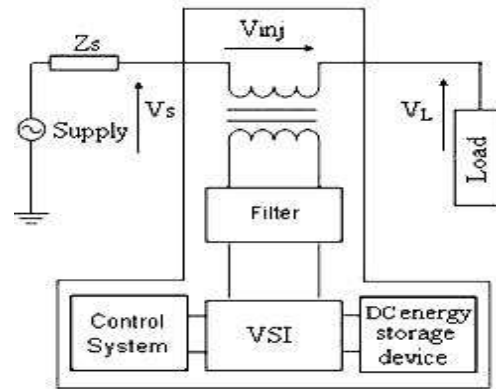

FIGURE 2 Basic component of Dynamic Voltage restorer

DVR consist of following components:

    A.   Voltage Source converter (VSC):

It is a power electronic system, which consists of switching devices and storage unit to generate sinusoidal voltage at any required frequency, magnitude, and phase angle. This could be a 3 phase–3 wire VSC or 3 phase–4 wire VSC. The latter permits the injection of zero–sequence voltages.

    B.   An Injection/Booster transformer:

In most DVR applications the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment. Three single phase transformers are connected in series with the distribution feeder to couple the VSC to the higher distribution voltage level.

    C.   Harmonic filter:

The filter is inserted to reduce the switching harmonics generated by the PWM VSC. The filters can be placed either on the high voltage side or the converter side of the boosting transformer. The advantages of the converter side filters are (a) the components are rated at lower voltage and (b) higher order harmonic currents do not flow through the transformer windings.

    D.   Storage Devices:

This is required to provide active power to the load during deep voltage sags. Lead–acid batteries, flywheel or Super Conducting Magnetic Energy Source (SMES) can be used as energy storage.

Simulation of Voltage Sag for RL Load

A Voltage Sag is defined as a momentary decrease in the root mean square (RMS) of Voltage ranging from 0.1-0.9 p.u., and a duration lasting for half a cycle to one minute. As shown in Figure 3.1, complete modal of DVR for removal of voltage sag is simulated and satisfactory results are achieved. In below simulation modal, Voltage Sag is generated with the help of three phase programmable voltage source which is shown in Figure 3.2. As explain, for removal of Voltage Sag basically following arrangement is required which are as follows:

1. Control strategy of DVR
2. Voltage source converter
3. Generation of gate pulse for VSC

In DVR modal, filter circuit is also used because when the DVR is suddenly inject the voltage to the transmission line of distribution system with the help of injecting transformer then some disturbances are occur which lead to spike in a load voltage. To reduce that spikes L-C filter circuit is used. Control strategy basically abc to dq0 transformation i.e., Clarke Park transformation and dq0 to abc transformation i.e., inverse Clarke Park transformation is used, which is shown in below Figure 3.3.

Simulation modal rating of DVR:

1. Supply Voltage = 3-Ø 1p.u. 50Hz
2. Voltage at Sag = 3-Ø 0.6p.u. 50Hz
3. Injected Voltage = 3-Ø 0.4p.u. 50Hz
4. R-L load:
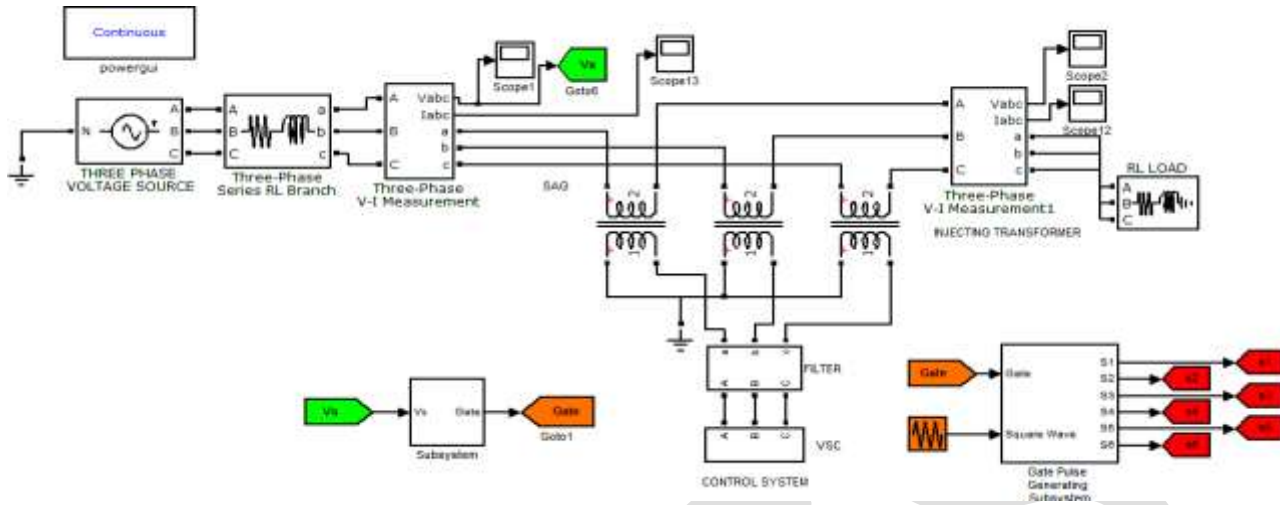   I.   P = 1KW
   II. Q_L = 1000VAR

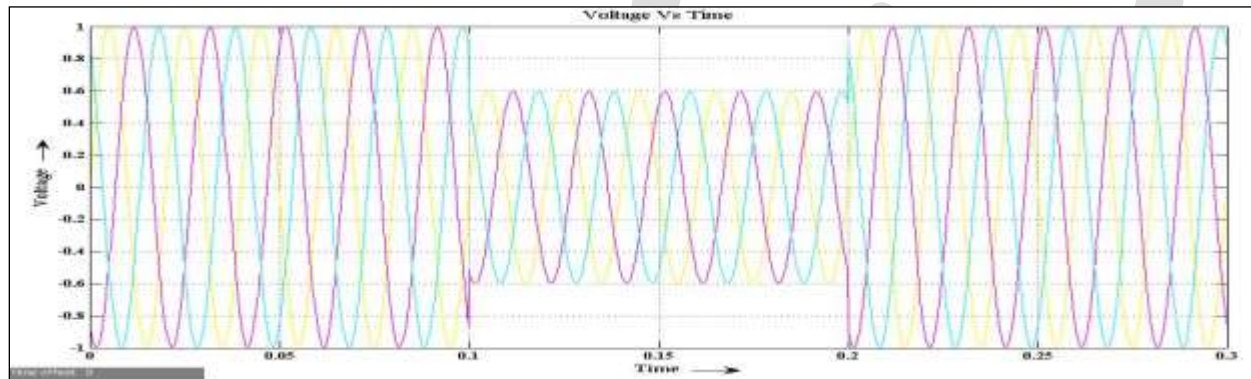FIGURE 3.1 Simulation modal of DVR for removal of Voltage Sag

FIGURE 3.2 Wave form of Voltage Sag

As shown in above figure voltage sag is generated by the using of programmable voltage source. As shown, voltage sag is taking place in between 0.1sec to 0.2sec. At the time of voltage sag period, the voltage is reducing to 0.6 p.u.
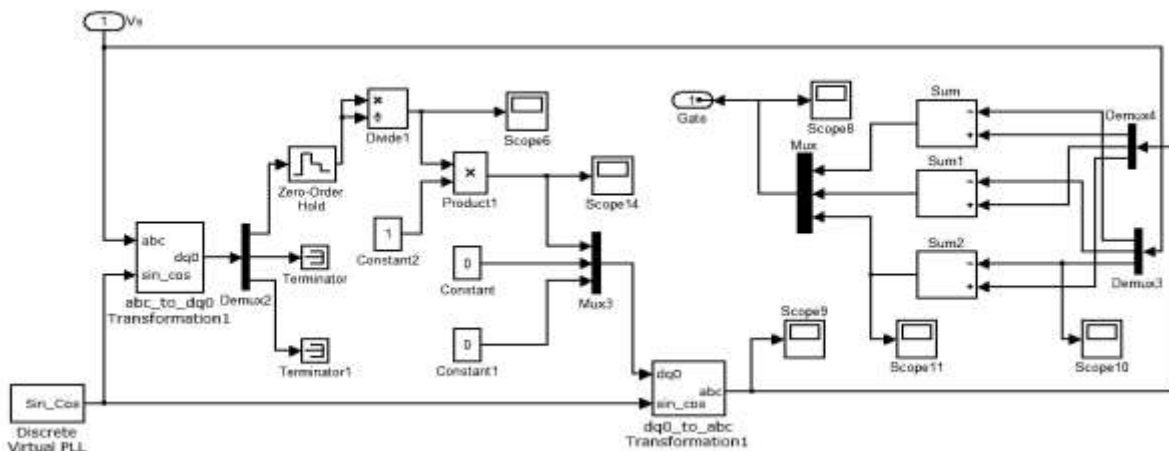

Figure 3.3 Control strategy of DVR

As discussed, firstly supply voltage (including voltage sag) is convert from abc to dq0 with the help abc to dq0 transformation. Here reference sine wave, which is vectorized inputs in terms sine wave is provided for abc to dq0 transformation. After this transformation zero order hold is used to hold at Voltage Sag in the waveform of one axis either it is direct axis or quadrature axis. After the zero order hold reference, voltage signal will multiply and divided by itself due to that 1p.u. signal will be generated in direct axis or quadrature axis. That 1p.u. signal will compare with the constant 1 with the help of product block to generate 1p.u. signal in

either direct or quadrature axis. To generate 1p.u. in AC system dq0 to abc transformation is performed. In this transformation two inputs are taken from zero i.e. terminator signal and remaining one input is taken from above generated 1p.u.

Here dq0 to abc transformation is done with the help of dq0 to abc transformation in which stationary frame is converted into rotatory frame. Due to that sine wave with the magnitude 1p.u. is generated is three phase system. This 1p.u. reference sine wave is compared with the supply voltage due to that error is generated, which is required to be injected in the system. Magnitude of error in p.u. will be injected to the system with the help of injecting transformer.
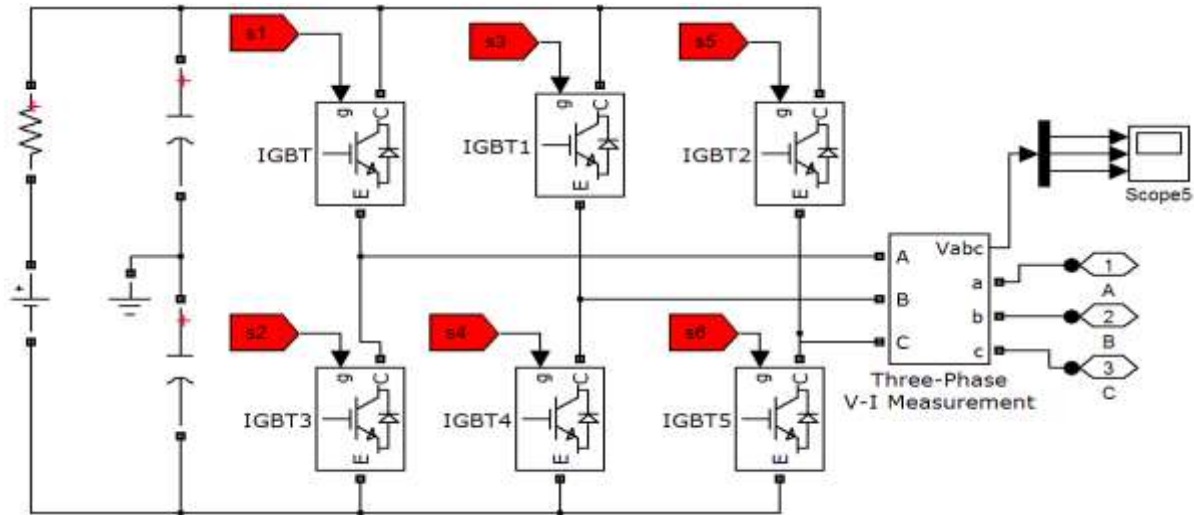

Figure 3.4 Voltage Source Converter Subsystem

Voltage source converter is made up of combination of six IGBTs. Here separate gate signal is provided for generation of voltage in p.u. which is required to be injected. Three arm of voltage source converter consisting of two IGBTs each. Each IGBT is operated for 60° of conduction period. Two IGBTs in one arm cannot be operated simultaneously. Here gate signal is provided by comparison of two signals one is error signal which is generated in the control strategy of DVR and other one triangular or carrier signal. Here comparison is performed with the help of Boolean expression. According to this comparison gate pulse is generated in square wave which is given to the irrespective IGBTs. Comparison is made in between carrier signal which is in triangular form and modulating signals (error signal) which in sinusoidal form. Hence this voltage source converter is also known as sinusoidal pulse width inverter (SPWM).
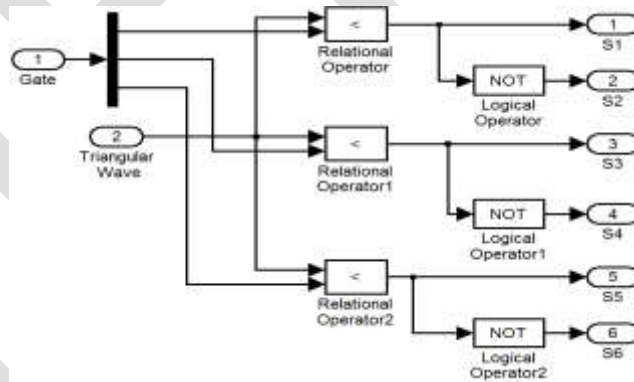

FIGURE 3.5 Gate pulse Controller

Gate pulse controlling mechanism is shown in above Figure 3.5. This gate pulse is fed to the irrespective IGBTs of voltage source converter. Due to that voltage source converter will generate error voltage in p.u. System, which is required to be injected in the system with the help of injecting transformer. After injection operation Voltage Sag will be mitigated.
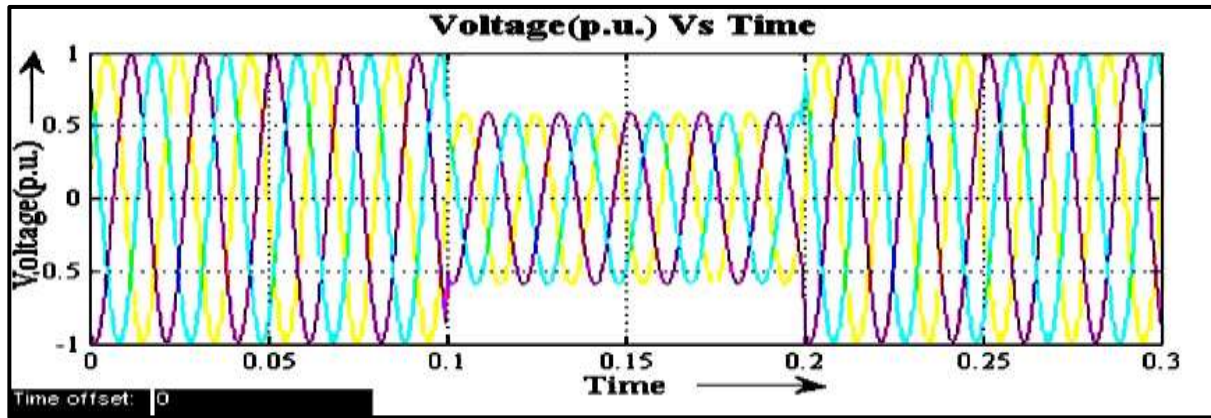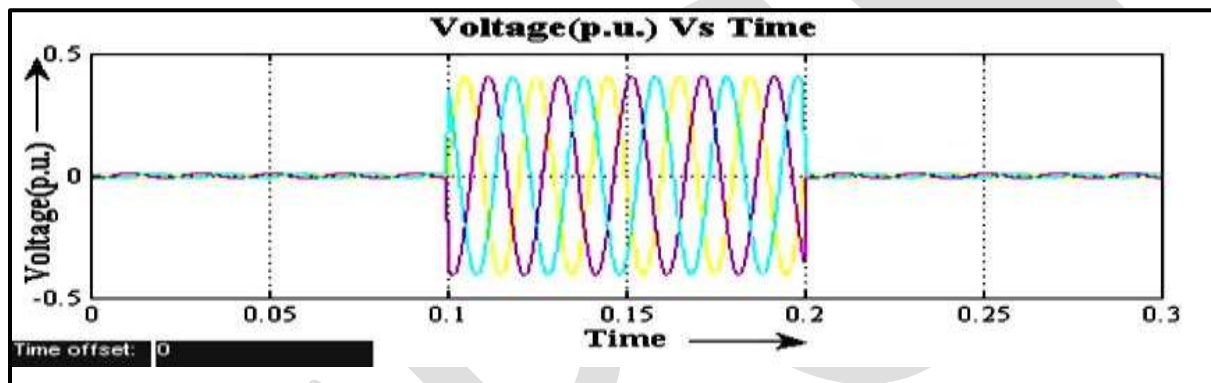
FIGURE 3.6 Voltage Sag for 0.1 sec to 0.2 sec

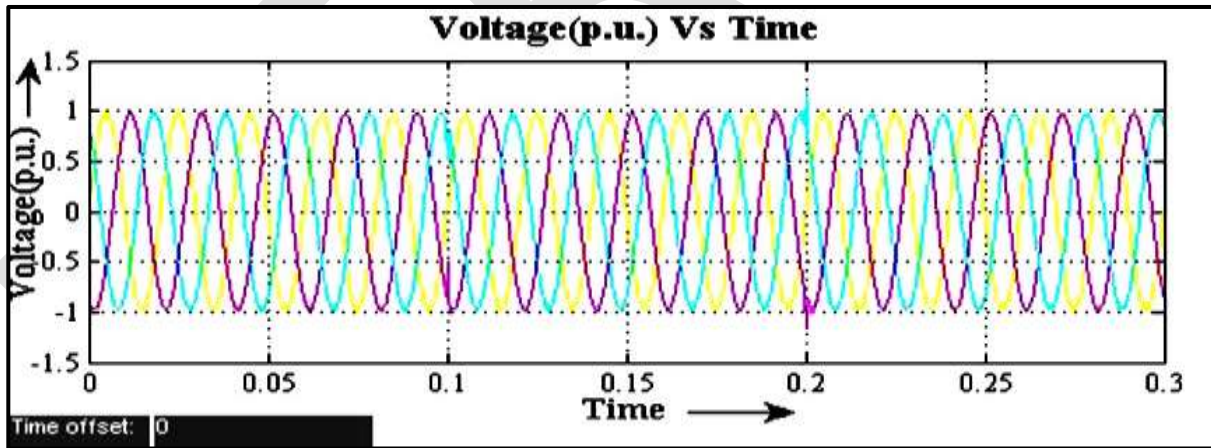FIGURE 3.7 Required Injected Voltage after Voltage Sag

FIGURE 3.8 Voltages after Removal of Voltage Sag

When Voltage Sag is taking place, supply voltage is affected as shown in above Figure 3.6 and magnitude of Voltage Sag is about 0.6p.u. for time period of about 0.1 to 0.2sec. In accordance with error signal and reference signal the require voltage which is to be injected in the system is taken from voltage source converter through injection transformer shown in above Figure 3.7 and Figure 3.8 shows voltage result after removal of voltage sag. This result is achieved by the above mention control strategy of DVR which shows smooth voltage profile of system.

CONCLUSION

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dq0 technique which is

detect error between source side of the DVR and its reference for Voltage Sags correction. The simulation result shows that the DVR performance is satisfactory for removal of voltage sags. From simulation results also show that the DVR compensates the voltage sags quickly and provides excellent voltage regulation. The DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct quickly any deviation in the supply voltage to keep the load voltage balanced and constant at the nominal value.

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