SIMULATION STUDIES FOR VOLTAGE SAG BY USING DYNAMIC VOLTAGE RESTORER

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Abstract- Voltage sag is the most severe type of power quality problem faced by many customers. Therefore, in this paper voltage sag will be discussed as it is posed as one of the main focus in recent industries. The emphasis will be on power quality problem of voltage sags. Dynamic voltage restorer (DVR) is the selected mitigation device and the feedback control system is discussed in this paper. The results are obtained from simulation work by using MATLAB SIMULINK. The sequences of power injection and the impact of types of power on the cost of the dynamic voltage restorer are explained in the content. This paper also explains the process of detecting to injection of the magnitude of power to compensate the voltage sag.

Keywords- Dynamic Voltage Restorer, Power Quality Problem, Simulink.

I. INTRODUCTION

Power quality represents the "health" of an electrical power supply from the source to the load end. With an unstable power supply, the electrical load or machineries may malfunction else if under long term of power quality problem, the load or equipment might breakdown.

One of the power quality which is known as voltage sag has leads to nuisance tripping and malfunction of sensitive equipment in most industries. Therefore, voltage sag is one of the main power quality problems which lead to strong concern of most manufacturers. Voltage sag is defined as decrease in R.M.S voltage of 0.1 to 0.9P.U. at the power frequency for duration of 0.5 cycles (8.3ms) to 1 minute. Voltage sag has been accounted for the highest percentage of interruptions to equipment which is 31%.

Thus, dynamic voltage restorer (DVR) is installed as a mitigation device to mitigate the voltage dip in most manufacturing factories. DVR is a custom power device to maintain a good power quality in transmission system. In order to compensate the voltage sag in a quick response, DVR employs a series of voltage boost technology. In the event of fault in the network, ensuing voltage sag will last until protective devices acts to interrupt the flow of current. In this sense, voltage sag duration is determined by the setting of protective devices.

Voltage sag event occurs unpredictably due to external factors, thus the fault in transmission will consequently cause sensitive equipment used in industrial plant, such as process controllers, variable speed drives, computers, PLC and robotics to fail. This occurrence will lead to tremendous economic and financial losses up to millions of dollars due to a single sag event. The main purpose of installing dynamic voltage restorer is that it can prevent a downtime of manufacturing process thus reducing the loss of capital.

A voltage dip may happen due to the high draw of current at load side. This situation happens very often due to the starting of motor, lightning and different faults which leads to significant losses to automated processing industry.

For example, a starting up of a direct on line motor, the draw of current might spike up to 2.5 times of its steady state current. Even though voltage dip may occur due to a particular transmission line, the voltage at nearby interconnected transmission line will be affected as well.

Thus, causing power quality problem to load that are connected at another end.

Custom Power Devices are the commonly used to mitigate these power quality problems. Since the demand for reliable, "healthy" and high quality power and the increasing number of loads which leads to distortion, this has increased the awareness of power quality by clients and end users.

This equipment incorporates electronic switching devices and controllers. Dynamic Voltage Restorer is one for the mitigation devices which mitigates voltage sag / swells at critical load.

II. DYNAMIC VOLTAGE RESTORER

A simple configuration of a dynamic voltage restorer working in a feedback control system is shown in Fig. 1 below.

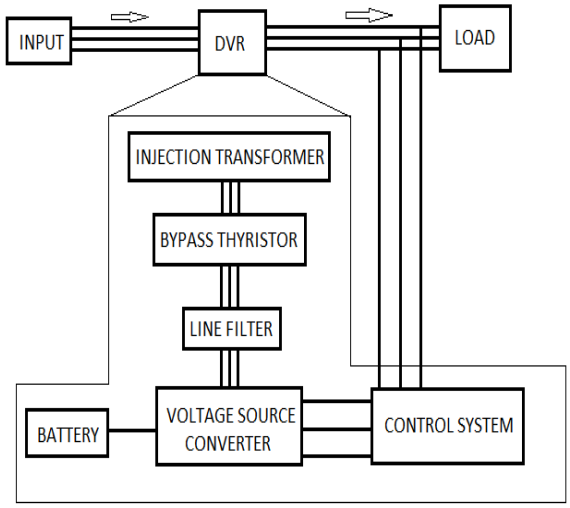


Fig. 1 Configuration of a DVR is transmission system

Inside a dynamic voltage restorer, it consists of battery bank, DC link, line filter, converter, bypass switch and an injection transformer. Besides, the control system of this dynamic voltage restorer consists of Pulse Width Modulator (PWM), IGBT, and inverter.

a) Energy storage
It acts a large size rechargeable battery which able to charge during standby mode and supply real power during compensation mode. When reactive power is insufficient to mitigate the sag voltage, real power from this battery is essential.

b) Voltage Source Inverter(VSI)
VSI is used to convert the DC active power supply from battery into AC output waveform. When the voltage is in AC wave, it will flow into three phase injection transformer.

c) Injection transformer
Three single phase transformer is connected into the transmission system. When the VSI has converted the DC source into AC output, the voltage is step up by injection transformer and injected into the transmission system.

d) Passive Filters
Filters out the harmonics generated due to the switching of voltage source inverter. Thus, the product of a smoother waveform is used for injection purpose and not damaging the load.

III. POWER INJECTION SEQUENCE

The sequence of power injection of DVR starts with injection of reactive power. When the reactive power injection is unable to mitigate the voltage sag into the desired threshold voltage, then active power injection will be triggered. The sequence flow of power is shown in Fig. 2.

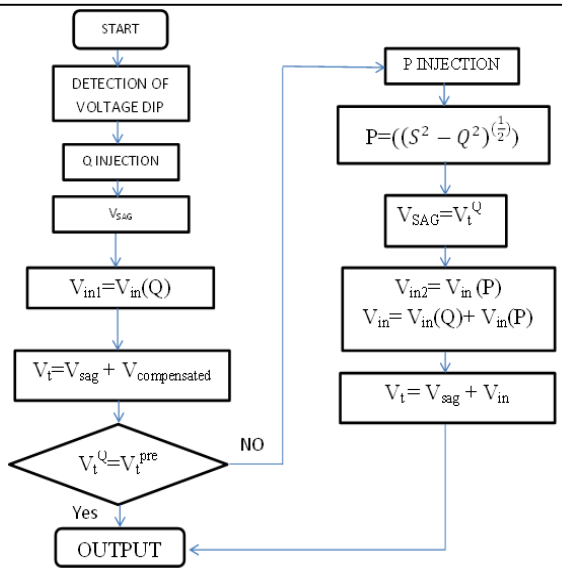


Fig. 2 Sequence of power injection in DVR

The reason for injecting reactive power first before active power is to mitigate as much power to the desired voltage with power without any cost. Active power is consider as power with cost as active power requires a storage device. The capacity of the storage device is proportional to the cost. Therefore, the main thing of having reactive power to be injected first is to reduce the cost of DVR.

With the reason discussed, it is logical to look at the flow of power in the sequence shown in Fig. 2. First, when the system detects a power quality of voltage sag, reactive power will automatically injects into the system. When a arithmetic operation is carried out, the deduction of voltage sag after injection of reactive power and nominal voltage will determine the amount of voltage required to be injected by active power. The signal will trigger and remaining magnitude of voltage injection to allow the voltage to be above threshold voltage can be injected.

IV. CONTROL STRATEGIES

The Table 1 below shows the description of different types of control strategies. Each method has their own characteristics which suits different demand by end users.

Table 1. Types and descriptions of control strategies

Method	Description
Pre-sag compensation	-Tracks the supply voltage continuously. -Compensate both phase angle and amplitude of voltage
In-phase compensation	- Inject voltage in the same phase with supply side voltage -Angles between the supply side voltage and load voltage

	are different. -Practical to loads which are insensitive to phase angle jump
In-phase advanced compensation	-Minimize active power spent by minimizing the power angle between sag voltage and load current. -Uses only reactive power, thus only suitable for limited range of sags
Minimum energy injection	- DVR voltage is controlled in such a way that the load current is in phase with the grid voltage after the sag. -Shallow voltage sag, sag is compensated with pure reactive power

The table 2 below shows the characteristics of three different transistors. Bipolar junction transistors (BJT), metal oxide semiconductor field effect transistor (MOSFET) and insulated gate bipolar transistors (IGBT) are commonly used as electronic switches. The justification of selection of IGBT is discussed as well.

Table 2. Choices of power electronic switches

	BJT	MOSFET	IGBT
Voltage rating	High <1kV	High<1kV	Very High>1kV
Current rating	High<500A	Low<200A	High >500A
Input drive	Current	Voltage	Voltage
Input impedance	Low	High	High
Output impedance	Low	Medium	Low
Switching speed	Slow	Fast	Medium
Cost	Low	Medium	High

The table 3 below shows the characteristics of feed-forward and feedback control system that can be implemented in the system. From general speculation, feedback and feed-forward system are categorized as shown in the table 2. However, in this paper, these two systems with different characteristics are brought out for simulation to show the difference in results.

Table 3. Characteristics of feed-forward and feedback control system

	Feed-forward Control	Feedback Control
Response time	Fast	Medium
Stationary error	Can be low with compensation	Can be eliminated
Transient overshoot	Difficult to control	Controllable
Stability	Stable	Unstable
Compensation of DVR causing harmonics	Hard to control	Can be reduced
Compensation of background harmonics	Difficult	Possible
Compensation of non-symmetrical fault	Slow, possible	Good
Voltage distortions at nonlinear loads	High distortions	Can be reduced

V. SELECTION OF INJECTION METHOD

This section shows the selections of control strategy, control system and power electronic switches for voltage source inverter (VSI). Pre-sag compensation is the chosen control strategy because it does not just compensate the magnitude but phase angle too. This control strategy tracks the power in the transmission system continuously which provides a fast response time. Insulated Gate Bipolar Transistor (IGBT) is a power electronics used in the VSI for switching purpose. It acquires the advantage from both BJT and MOSFET, thus making it cost at a higher price. IGBT has it gate controlled by voltage like MOSFET and has the output characteristic of a BJT. IGBT is ideal for switching purpose since it has a low on state resistance, thus able to switch at high voltage without damage.

VI. METHODOLOGY

The injection of power by DVR is varied by the amplitude of voltage sag, angular change and location. In this project, the pre-sag voltage is 400V which is set to 1.0p.u. Fault voltage was injected at transmission towards load side. When the three phase fault voltage is injected, the voltage did not just show effect at load side, whereas the supply side has been affected as well.

Thus, when fault is detected, DVR must be able to inject sufficient voltage in a quick response to sustain the RMS value voltage in a range of 0.8 to 1.0p.u. In other words, DVR will only operate when the RMS value of voltage at transmission has dropped below 0.8p.u.

Fig. 3 and 4 provide the configuration of transmission circuit along with fault injection. It is used in the 3 phase fault simulation.

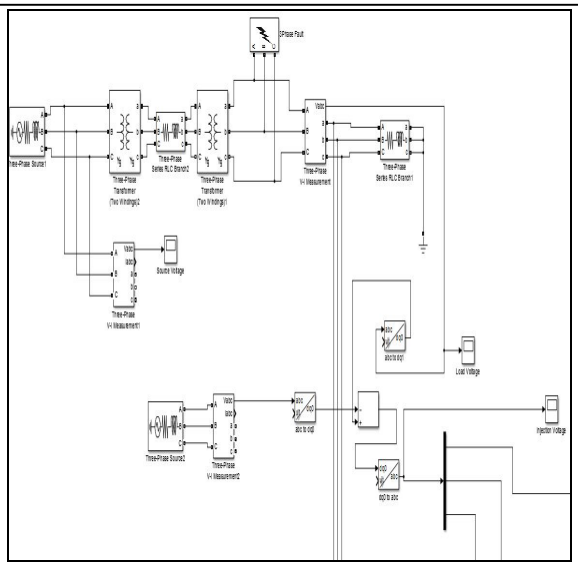


Fig. 3 The transmission system part (a)

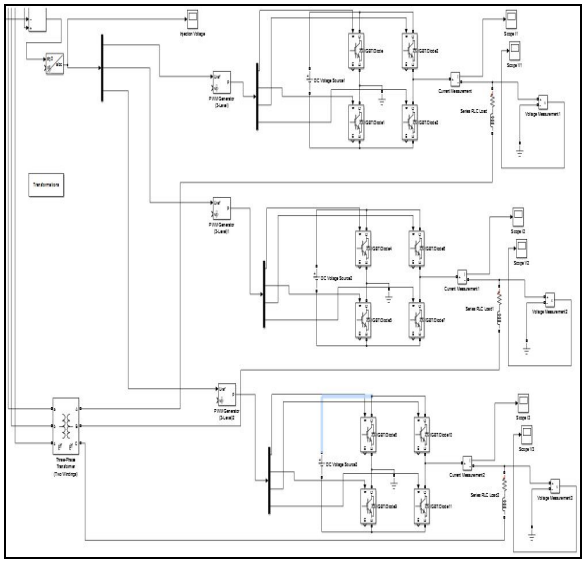


Fig. 4 The transmission system part (b)

VII. SIMULATION RESULTS

When fault voltages are injected into the system, the voltage are shown in figures below. In Fig. 5 the load voltage has shown voltage sag of 0.5p.u. The duration of voltage sag is 0.11 seconds.

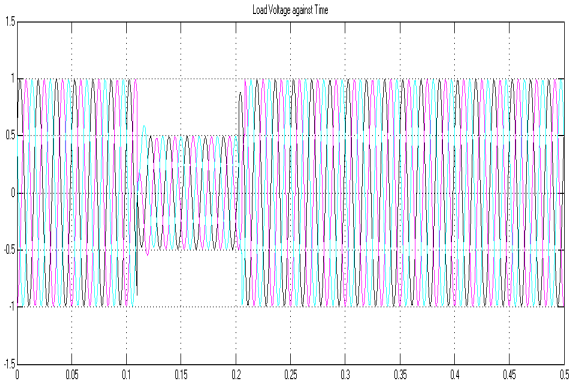


Fig. 5 Supply side Voltage

The voltage sag at load side has shown effect on the supply side voltage. This has proved that when an event of voltage sag occurs at a point of common coupling, the load connected to the bus will be affected as well.

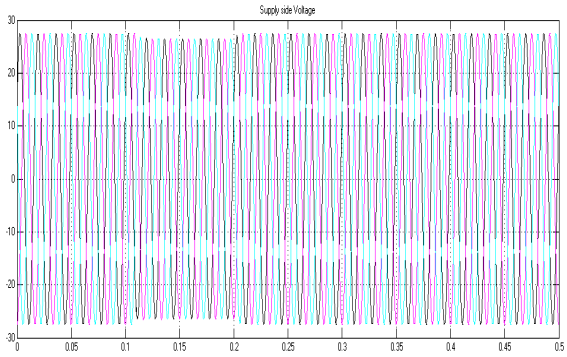


Fig. 6 Supply Voltage

As mentioned in the flow chart shown in Fig. 2, it was determined that after the voltage was supplied the reactive power, the remaining power is required to be supplied by active power. Therefore in Fig. 7, the voltage shown was the output of voltage required to be injected by DVR.

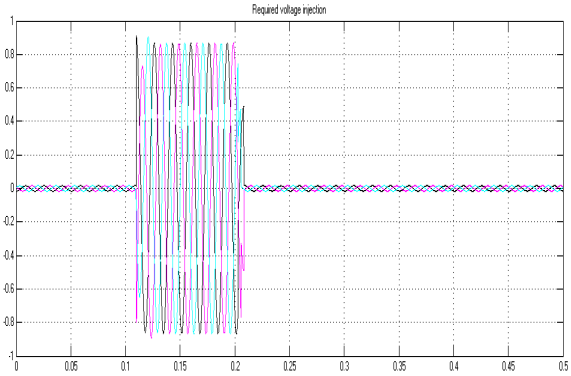


Fig. 7 Voltage required for Injection

The voltage required for injection is sent to VSI to be triggered and to transformer for step up purpose and inject into the system. Fig. 8 to Fig. 9 showed the current and voltage of each inverter in the VSI during triggering mode.

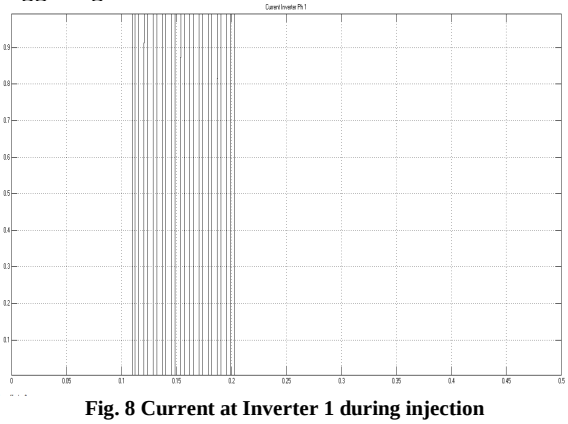


Fig. 8 Current at Inverter 1 during injection

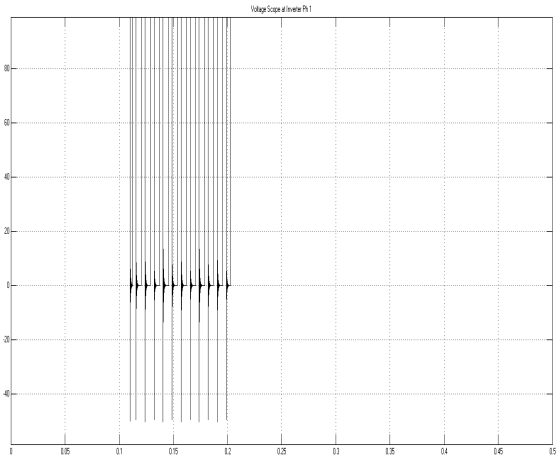


Fig. 9 Voltage at Inverter 1 during injection

Fig. 8 and 9 showed the current and voltage magnitude of inverter 1 during injection mode. Both are triggered at 110.05milisecond.

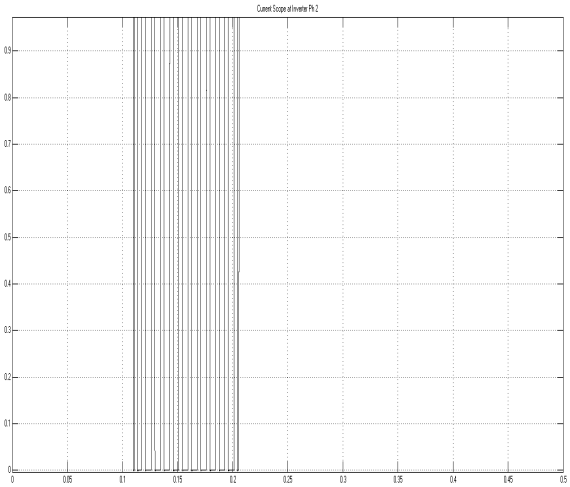


Fig. 10 Current at Inverter 2 during injection

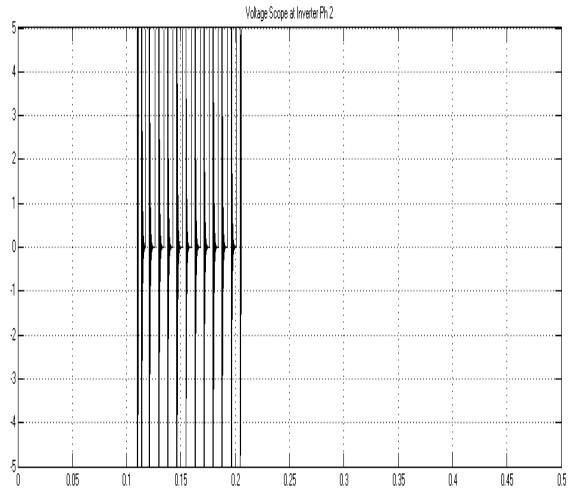


Fig. 11 Voltage at Inverter 2 during injection

Fig. 10 and 11 showed the current and voltage magnitude of inverter 2 during injection mode. Both are triggered at 110.023milisecond.

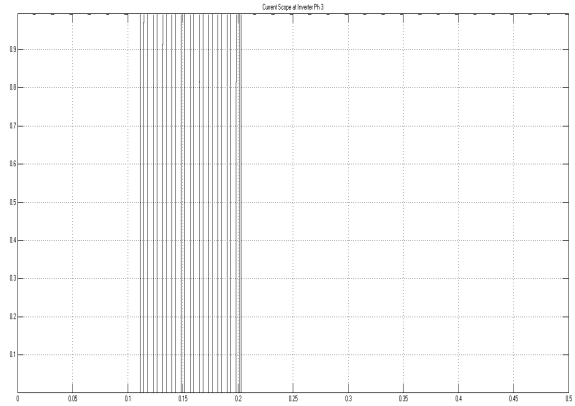


Fig. 12 Current at Inverter 3 during injection

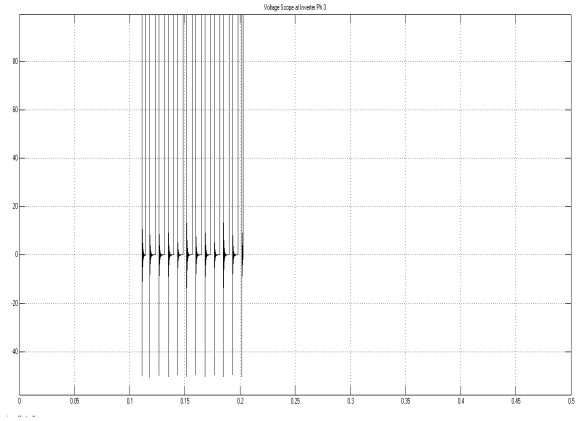


Fig. 13 Voltage at Inverter 3 during injection

Fig. 12 and 13 showed the current and voltage magnitude of inverter 2 during injection mode. Both are triggered at 110.066milisecond.

The inverter 1 is used to inject voltage for phase 1, while inverter 2 is used to inject voltage for phase 2 and inverter 3 is used to inject voltage for phase 3. The triggering time of inverter controls the phase of the voltage injection to sync with the transmission voltage. Thus, when the voltage is injected, the voltage shown in Fig. 14 below shows the voltage after the mitigation by DVR.

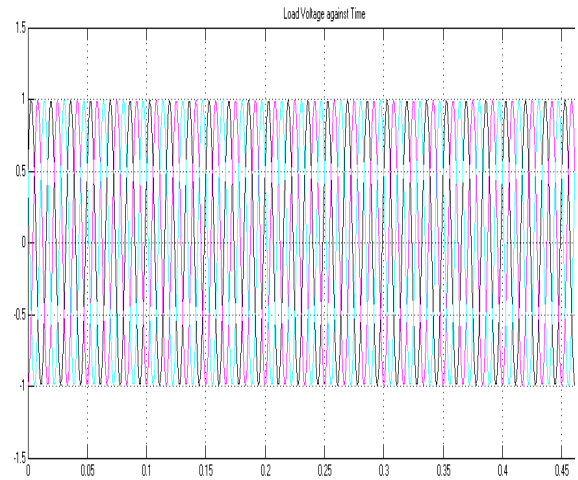


Fig. 14 Load voltages after compensation

CONCLUSION

Power quality problem that is focused is on voltage sag and the compensation method is by using a dynamic voltage restorer. This paper discussed about the selection of basic devices required in a dynamic voltage restorer and the sequence of power flow in DVR. The design and applications of DVR with presence of voltage sag is carried out by using a MATLAB Simulink. The results have proven that with the mitigation device, DVR, the output voltage has a better regulation.

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