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Design and Modelling of Dynamic Voltage Restorer to mitigate Voltage Sag in an Interconnected IEEE-test system

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Abstract: The boundaries are set for quality of electrical power that is being supplied to all the electrical power equipment to function properly. If these equipment are exposed to any of the power quality problems then the malfunctioning of the equipment will occur. Different loads will respond differently depending upon the type, duration and severity of the quality problem occurring in the system. Because of this reason the need of study of power quality disturbances is currently under the study of researchers. Different types of power quality problems occur in the electrical power system that depend upon the frequency and magnitude of the voltage. The most common type of voltage magnitude quality problem that occurs in the distribution network is voltage sag. Voltage sag will cause in increase in current and that will eventually damage the load side. In case of sensitive loads the voltage sag mitigation can be done with the help of a Dynamic Voltage Restorer. This research will focus on the Voltage sag mitigation technique in an interconnected system for a sensitive load with the help of a Dynamic Voltage Restorer (DVR). This technique can be used to mitigate the most dangerous Power Quality problems in different sensitive parts of the Power system.

Key words: DVR, Power Quality, Voltage Sag.

I. INTRODUCTION

Electrical Energy is the easiest energy to transform to any other form of energy. It is also the fastest and easily controllable form of energy. In the recent years all the company that distribute electrical power are facing the issues of power quality being bad [1]. The most worrying problem nowadays for any electrical company is to distribute effectively and efficiently the electrical power in the network. Power quality is becoming a major concerns for different industrial loads, especially sensitive in nature[2]-[3]. Because of the increase in nonlinear loads and increasing demand in electronic equipment quality of power is being distorted and has to be monitored continually to mitigate these issues. Because of the disturbances in electrical energy it will be causing damage to the equipment, data and all the interconnected systems [5].

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In electrical power system the very last part is distribution system, which gets electrical power from transmission system and feds it to the consumers. After secondary Transmission system, Primary Distribution network starts. For the purpose of distribution step down transformers are used to step down the high transmission line voltages to certain acceptable limits to provide electrical supply to primary and secondary distribution. For the purpose of distribution step down transformers are used to step down the high transmission line voltages to certain acceptable limits to provide electrical supply to primary and secondary distribution [7].A radial system is the mostly used system in the world, it is also the cheapest system of all. Its draw back might be that if any fault occurs anywhere the whole system will be affected.An interconnected system actually consist of a lot of loops connecting different loads with a number of sources together. Its highest advantage is the load can be supplied power from different sources at any time.The mitigation of a voltage quality problem like a Voltage sag with the help of a DVR, in an interconnected system is offered in this research work.

II. A DYNAMIC VOLTAGE RESTORER

Quality of electrical power can be defined by the quality of sinusoidal wave of electrical current and voltage [10]. Any kind of a deviation in these two parameters can disturb the quality of the power being consumed by the loads. It has major impacts on the economy of the industries. It is a concern of the utility companies to provide as pure sinusoidal wave as possible to the consumers. With the quality of power consumed the reliability, control and safety of the electrical power system can be ensured. If the value of the voltage is below 90 % or above 10% of the nominal value of the voltage for longer than 10ms and less than 1 minute then it is called Voltage Sag. The European standard name for this problem is “Voltage Dip”, and US standard uses the term “Voltage Sag” [11].For the purpose on mitigation of voltage sag in case of very sensitive loads, custom power device Dynamic Voltage Restorer is used. It is the most effective and efficient method of mitigating the voltage sag in any distribution network.

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A DVR consist of Power electronic devices and is always connected in series with the system[14]. The main purpose of a DVR is to inject Voltages to a very sensitive load in distribution network.

[8]There are three main modes of operations of a DVR connected to a network:

a) *Mode of protection:*

If the system faces any kind of a short circuit situation, because of high currents the DVR can be damaged, so bypass switches are used for the purpose of protection of DVR. As shown in figure 1, the two switches SW_2 and SW_3 become open in order to protect the DVR from the very high Inrush currents being produced. And Switch SW_1 becomes on.

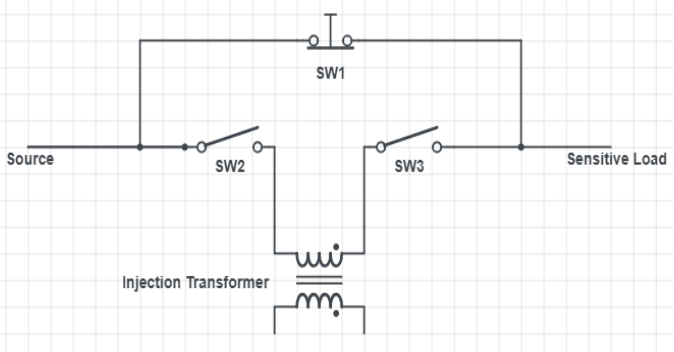

Fig.1: Mode of Protection

b) *Stand-by Mode of a DVR:*

In case of normal operation of the system, the LV side of the transformer is shorted so that the normal currents flow towards the load as shown in figure 2. In this stand-by mode of operation of DVR, full load currents will pass through Primary of transformer to the load.

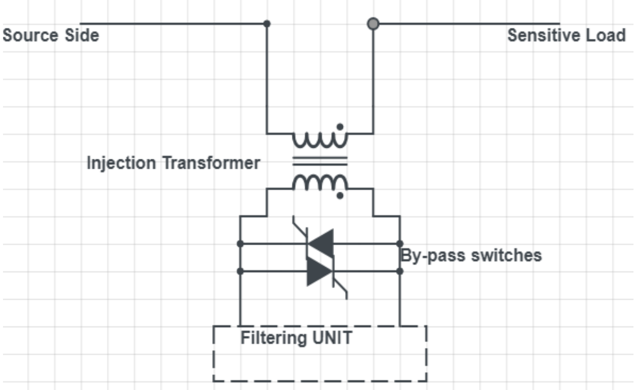

Fig.2: Mode of No Operation/Stand-by Mode

c) *Mode of injection*

In this mode DVR acts, in case of any sag is present in the system, to feed the desired amount of voltages with the help of booster transformer. Once the detection of any disturbance occurs the DVR acts and with the help of Power electronic devices it feds the voltages to the system.

The main purpose of a DVR is to sense the disturbance in the voltages and with the help of a controller it injects an exact amount of voltagesthat have dropped across a sensitive load.

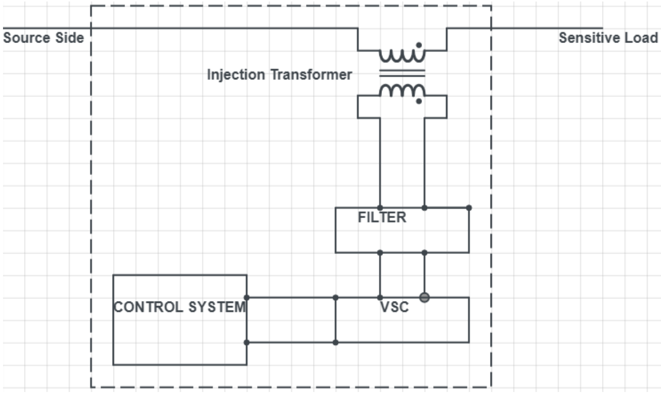

Fig.3: Basic structure of a DVR

This is done with the help of an energy source, a controller and an injection transformer connected in series with the load. Basic structure of a DVR is shown in Figure 3.

III. MODELLING OF IEEE-TEST SYSTEM

For the purpose of this research work a Ring main network is designed using MATLAB/Simulink. The data for thispurpose is taken from a test system of IEEE. [11] The IEEE 9 bus system is used to determine the values of generating units, transformers, transmission lines, distributed parameters and loads.

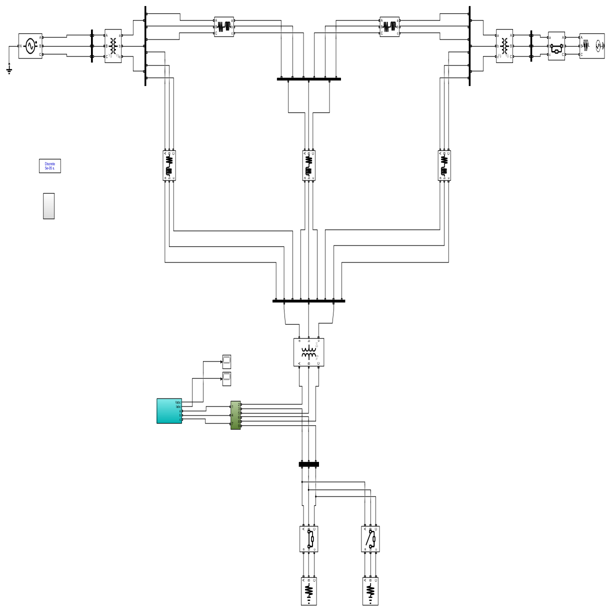

Fig.4: An interconnected network modelled in Simulink.

There are two generating units consisting of Swing Bus. After generating units two three phase transformers are connected to feed the transmission network. And then primary and secondary distribution networks are connected with the transmission lines. The DVR is connected in series with the primary distribution of a sensitive load. The figure for an interconnected network is shown in Figure 4.

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IV. MODELLING OF DVR FOR PROPOSED SYSTEM

A DVR mainly consist of following components:

a) Storage devices:

Storage devices in a DVR are used to supply the required amount of energy for the mitigation of voltage sag [9].These devices are connected to support the system for compensation of required voltages. These devices can be in the form of a DC link, Batteries, Capacitors or superconductive magnetic energy storage (SEMS).

b) Voltage source converter:

Voltage source converters are power electronic devices used to convert the form of electrical energy. After the energy is given by a storage device in the form of DC it is the function of the Voltage Source Converter to change that to sinusoidal wave and supply the desired voltages. As the Voltage source converter consist of power electronic devices, it has the capability to convert voltages at any desired frequency, magnitude and phase angle.[13]

A voltage source converter is actually a switching device with very fast switching speeds. For the purpose of this research Insulated Gate Bipolar Transistor (IGBT) type of converters are used to convert and control the amount of required voltages to feed the system. IGBTs are used because of their fast switching and very reliable performance for the applications of high power systems.

c) PWM based control system:

For the purpose of this research a PWM based control system is used to control the amount of voltages that are required to be fed to the system when the system faces the situation of a Voltage sag condition. The purpose of PWM controller is to measure the RMS value of voltage, the figure for the simulated PWM controller is shown on Figure 5.

Along with the PWM, a PI controller is also used whose purpose is to measure the amount of error generated between the reference voltages and the amount of voltages at any sensitive load side. Once the error is generated the PI controller process the error towards the PWM system so that required pulses are produced and sent to the voltage source converter. Because of the PWM system exact amount of voltages are converted and controlled to be sent to the sensitive load.[14]

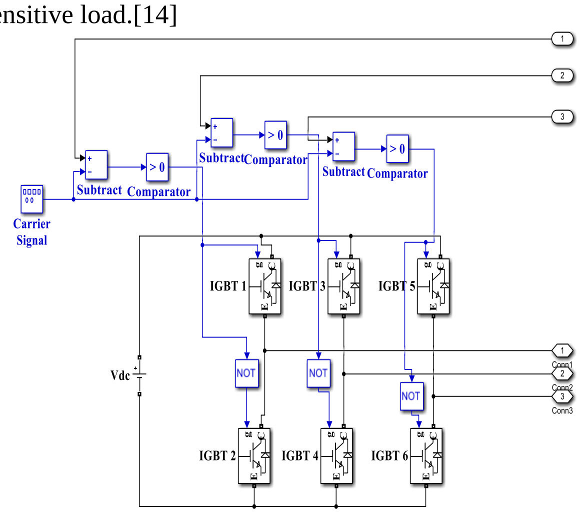

Fig.5: Model of PWM Controller

Because PWM system actually controls the firing angle of the IGBTs that are used to convert the amount electrical energy for the purpose of mitigation of the Voltage sag. The proper tuning of the PI controller is also required and done in the model of research to get good results. The diagram for the PI controller is shown in figure 6.

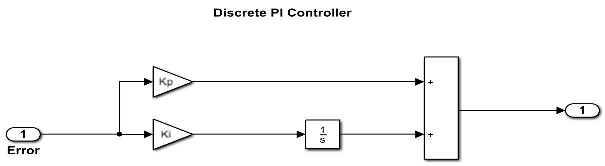

Fig.6: PI Controller Model

d) Harmonic filter

Because of the use of power electronic devices in the model of DVR, harmonics are produced which are not good for a sensitive load. Harmonics are suppressed by the use of passive filter so that the voltage generated by Voltage Source Converter are within permissible limits of harmonics.

e) Injection transformers

There are two main purposes to use a special purpose Injection or Booster transformer:

1. To connect the DVR to the distribution system and inject the amount of voltages transformed after the Voltage source converter has produced on the primary side.
2. To protect the DVR system by isolating it from the other parts of the DVR.

The injection transformer used in this model is shown in figure 7, and consists of 3 linear transformer connected to each phase to mitigate the voltage sag.

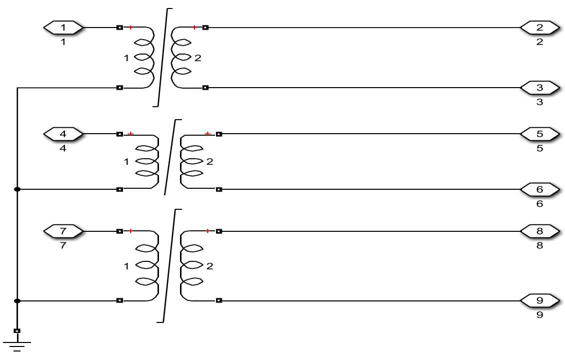

Fig.7: Three Injection Transformer

The complete proposed model of a DVR showing all the parts as discussed above with full details is shown in figure 8.

V.MATHEMATICAL EQUATIONS FOR DVR

An equivalent circuit of a DVR is shown in figure9, where Thievenin's Theorem is applied to find out the injected voltages of a DVR.Impedance Z_{TH} of the system will depend upon the fault in the system.

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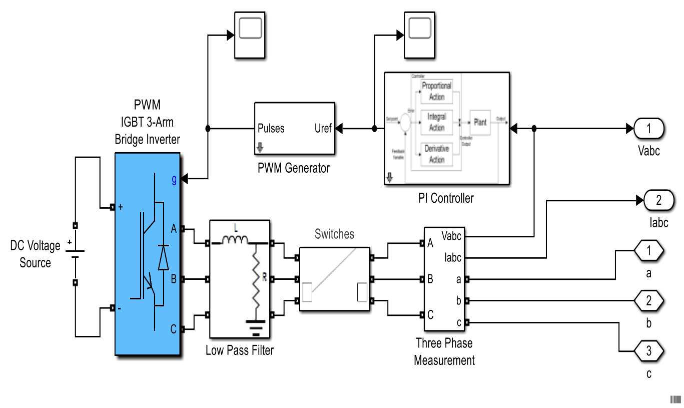

Fig.8: MATLAB/Simulink Model of DVR

When any fault occurs in the system, Voltages are reduced near the load and a voltage sag is produced. And the magnitude of the voltages (V_{TH}) drop, and the DVR injects the voltages V_{DVR} with the help of injection transformer to maintain the voltages (V_L)across the load.

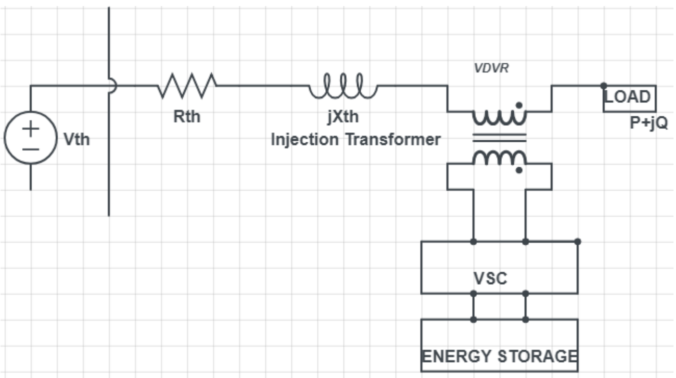

Fig.9: Equivalent Circuit of a DVR

The Voltages injected by DVR can be expressed as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \qquad (1)$$

The current of the load is given by the equation,

$$I_L = \frac{P+jQ}{V} (2)$$

If the reference voltages are V_L, then

$$V_{DVR} < \alpha = V_L < 0 + Z_{TH} < (\beta - \theta) - V_{TH} < \gamma$$

Where α, β, γ are the angles of V_{DVR}, Z_{TH} andV_{TH}respectively. And θ is the load angle and is given by the equation,

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) (3)$$

The complex that is injected by the DVR can be written as,

$$S_{DVR} = V_{DVR} I_L * \qquad (4)$$

VI. RESULTS

The system that is discussed in the modelling part is given a three phase electrical fault in one part of the system. This creates a sag after 0.1sec in the nominal voltages of the system. At this time the DVR in the system is not connected to see the behavior of voltages and its impacts on the load. The wave from for simulated results of Voltage sag in the system is shown in figure 10.

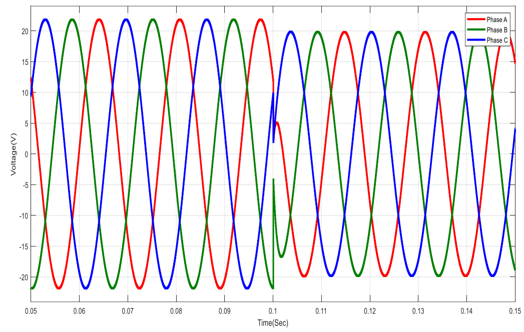

Fig.10: Waveform of Voltage Sag at Load.

The Waveform of the value of voltage sag present in the load in shown in figure 11, that shows the amount of RMS voltages dropped across the load. This figure shows the amount of the voltages that across the sensitive load after the system has faced a three phase fault at 0.1sec.

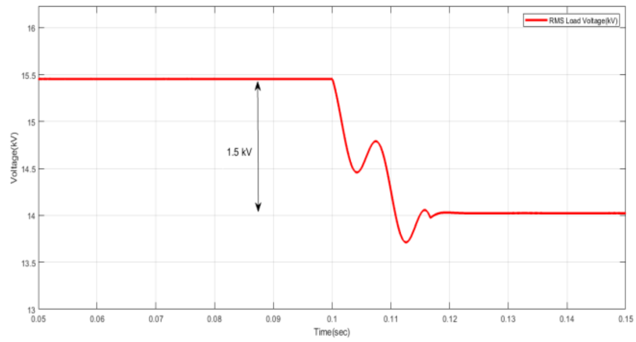

Fig.11: RMS value of voltage sag at load.

Once a sag is present in the proposed model, the DVR comes in action and mitigates is sag after 0.1sec. The waveform for the voltages across the load after the action of DVR is shown in figure 12. This figure shows that the DVR improves the voltages across the load after a fault has occurred at 0.1sec in the system.

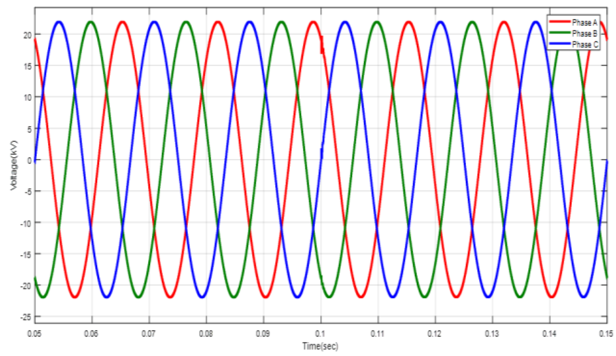

Fig.12: Waveform of Voltages at Load with DVR.

The RMS value of the voltages that are fed to the load is shown in figure 13. This figure shows that the DVR have injected voltages across the load, and there are only 0.02kv of voltage difference between nominal voltages of load and applied voltages by DVR after 0.1 seconds which is acceptable and doesn't come in category of Voltage sag.

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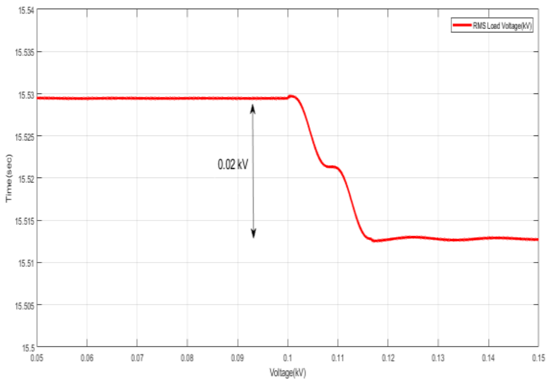

Fig.13: RMS value of voltages across load with DVR

The waveform for the injected voltages by DVR is shown in figure 14. The figure shows at the time of fault at 0.1 seconds the DVR acts and there is little notch in the voltages that might be because of the inrush current of injection transformers.

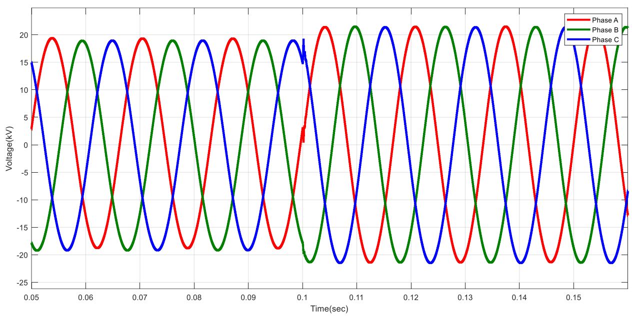

Fig.14: Injected three phase voltages by DVR.

VII. CONCLUSION

This research shows that in an interconnected system, a healthy part of the system is heavily affected by any abnormal condition on any other part of the system. If the load is of PQ type then a sag will cause an increase in current, which is very dangerous in case of any sensitive type of a load. By proper tuning the values of voltage converters the mitigation of the sag effective and accurate mitigation of Voltage sag issue is done.For the purpose of future research this research work will be extended for the work to be done on Phase angle jump and different techniques for mitigation method of Voltage sag by DVR. And extended IEEE system will be used to get real time large electrical networks.

VIII. ACKNOWLEDGMENT

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