MITIGATION OF VOLTAGE SAGS IN THE DISTRIBUTION SYSTEM WITH DYNAMIC VOLTAGE RESTORER

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Abstract
Dynamic Voltage Restorer (DVR) is a custom power device that is used to improve voltage sags or swells in electrical distribution system. The components of the DVR consist of injection transformers, voltage source inverter (VSI), passive filters and energy storage. The main function of the DVR is used to inject three phase voltage in series and in synchronism with the grid voltages in order to compensate voltage disturbances. This article deals with mitigation of voltage sags caused by three-phase short circuit. Dynamic voltage restorer is modelled in MATLAB/Simulink.

Keywords
Dynamic voltage restorer, voltage sags/swells, injection transformer, distribution system

1 INTRODUCTION

Power quality problems encompass a wide range of disturbances such as voltage sags or swells, flicker, harmonics, distortion, impulse transient and interruptions. Voltage sags or voltage swells are the most severe disturbances. To solve this problems, there are used the custom power devices. One of those devices is the dynamic voltage restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution systems. Advantages of DVR are lower cost, smaller size, and fast dynamic response to the disturbance.

DVR injects a dynamically controlled voltage V_{DVR} in series to the bus voltage by injection transformer. In structure of this device are three single – phase injection transformers connected to the three – phase converter with energy storage and control system. Any differential voltage caused by transient disturbances will be compensated by an equivalent voltage generated by the converter and injected through the injection transformers. It used to generate a voltage vector through the voltage sag, eventually trough the power failure in distribution system. Power scheme is showed in figure 1.

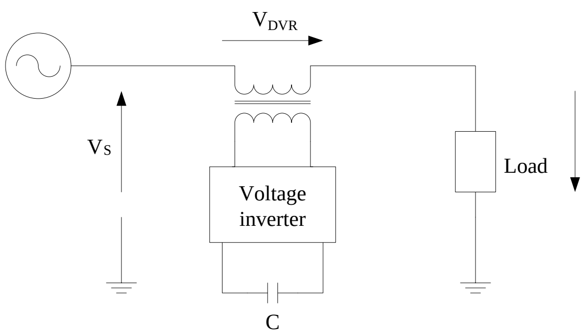

Fig.1 Power scheme of DVR

1.1 The basic elements of a DVR

The DVR system consists of two important components: a power circuit and a control unit. A power circuit of DVR basically consists of a voltage source converter, a series connected injection transformer, an inverter output passive filter, and an energy storage device that is connected to the dc link. The basic elements of power circuit are:

- Voltage source converter – a VSC is a power electronic system consist of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DVR application, the VSC is used to replace the supply voltage or to generate the part of the supply voltage which us missing. In our DVR model is used a insulated gate bipolar transistors (IGBT).
- Injection transformer – the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment. It connects the DVR to the

distribution system and transforms the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.

- Passive filter – basically, filter consists of inductor (L) and capacitor (C). In DVR, filter is used to convert the inverted PWM waveform into a sinusoidal waveform. This can be achieved by eliminating the unwanted harmonic components generated by the VSC. The passive filters can be placed at the high voltage side or at the low voltage side. If the filter is installed at the low voltage side it has the advantage of being closer to the harmonic source.
- DC link and energy storage – The DVR needs real power for compensation purposes during voltage disturbances in the distribution system. In this case the real power of the DVR must be supplied by the energy storage. The energy storage such as battery is responsible to supply energy storage in DC form. A DC link voltage is used by the VSC to synthesize an AC voltage into the grid and during a majority of voltage dips active power injection is necessary to restore the supply voltages.

In DVR the control circuit is used to derive the parameters like magnitude, frequency, phase shift, etc. of the control signal that has to be injected by the DVR. Based on the control signal, the injected voltage is generated by the switches in the power circuit. The control mechanism of the general configuration typically consists of hardware with programmable logic. All protective functions of the DVR should be implemented in the software.

Figure 2 shows all of these basic elements of dynamic voltage restorer.

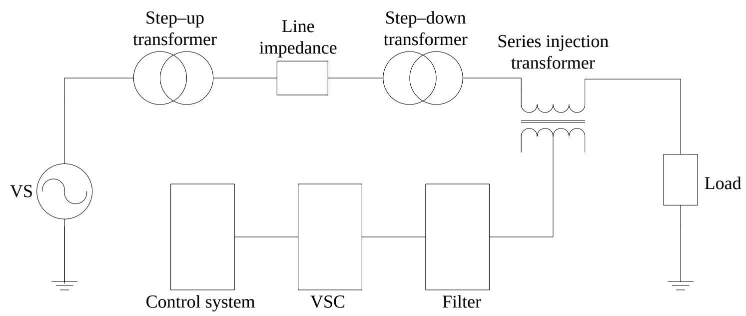

Fig.2 Circuit model of dynamic voltage restore

2 VOLTAGE INJECTION METHODS OF DVR

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as DVR power ratings, various conditions of load and different types of voltage sags. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude. Therefore the control strategies depend upon the type of load characteristics.

For the correction voltage dips has been proposed several methods of compensation: pre – sag compensation method, in – phase compensation method and voltage tolerance method with minimum energy injection. Control methods must accept restrictions of DVR based on operating principle: nominal value of the inverter, transformer and energy storage. Another constraint is the minimalization of active power supplied of DVR.

2.1 Pre – sag compensation method

Most non – linear loads, such as thyristor controlled load using the phase angle of supply voltage as reference data for phase control are sensitive for the changes in phase angle. The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so that the load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation method. In this method the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions.

Pre – sag compensation method is showed in figure 3.

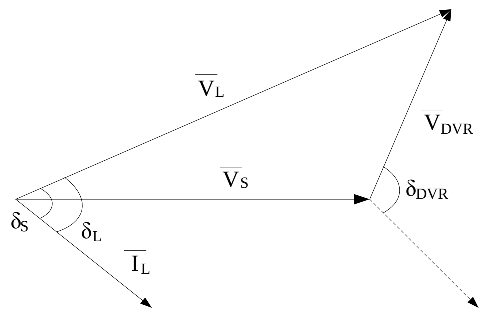

Fig.3 Pre – sag compensation method

2.2 In - phase compensation method

This is the most straight forward method. In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied.

Phasor diagram of this case is shown in figure 4, where I_L is load current and δ is the phase shift of current and load voltage. The voltage V_{DVR} is such that the voltage V_L is the unit, 1 pu.

$$V_{DVR} = 1 - V_S \tag{1}$$

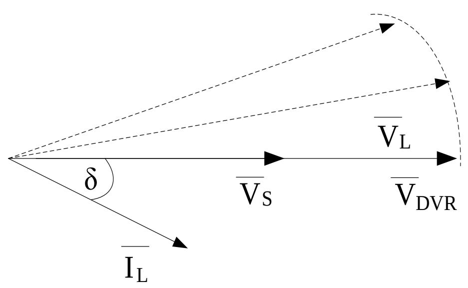

Fig.4 In – phase compensation method

The advantage of this method is that the size of the injected voltage is minimal. Therefore the apparent power of the DVR is minimized for load current and voltage sag. If the size of voltage of source is not correct, DVR generates he same voltage as the voltage sag in phase with voltage of source through the transformer. Some part of V_{DVR} is in phase with a load current I_L, DVR must generate an active power to je system.

The energy passing through the transformer for voltage disturbances can be calculated by (2) as (Δt – time to failure):

$$\Delta W_{DVR} = 3.(V_S - V_{SAG}).I_S.\cos\varphi.\Delta t \tag{2}$$

The DC capacitor discharge circuit can provide energy according to (3):

$$\Delta W_{DC} = \frac{1}{2}.C.\left(V_{DC\max}{}^2 - V_{DC\min}{}^2\right) \tag{3}$$

The principle of energy balance shows the following result (for assuming no losses in inverter):

$$\Delta t = \frac{C.\left(V_{DC\max}{}^2 - V_{DC\min}{}^2\right)}{6.(V_S - V_{SAG}).I_S.\cos\varphi} \tag{4}$$

2.3 Minimal energy control compensation method

If for a given load voltage phasor V_{DVR} is perpendicular to the load current I_L then for the restore voltage using DVR should not be injected active power. Figure 5 shows the phasor diagram for minimal energy control compensation method.

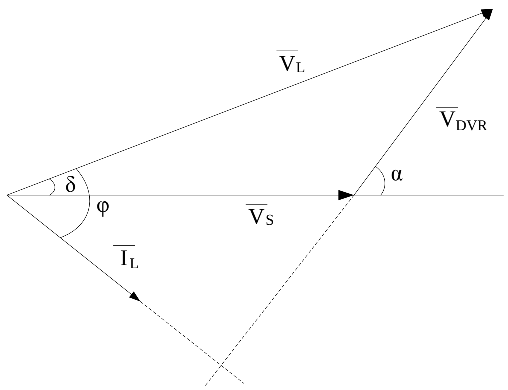

Fig.5 Minimal energy control compensation method

In this case calculate the angles α and δ as

$$\alpha = \frac{\pi}{2} - \varphi + \delta \qquad (5)$$

$$\delta = \varphi - \cos^{-1} \frac{V_L . \cos\varphi}{V_S} \qquad (6)$$

If the supply voltage parameters satisfy this condition (7), then the permissible value of δ is:

$$V_L . \cos\varphi < V_S \qquad (7)$$

Inequality (7) means that the level of voltage sag is only shallow. Therefore the injected active power of DVR is zero and the optimal value α is obtained from equation (5). If the inequality (7) satisfied, then the level of voltage sag deeper and injected active power is not zero.

3 MODELLING DVR AND SIMULATION VOLTAGE SAGS

Figure 6 shows the model of dynamic voltage restorer created in MATLAB/Simulink. The model is composed by three – phase source, transmission line through the two winding step – up transformer, transmission line feed distribution system through two winding step – down transformer. The DVR is simulated to be in operation only for the duration of the fault. Time duration of the fault was 250 ms.

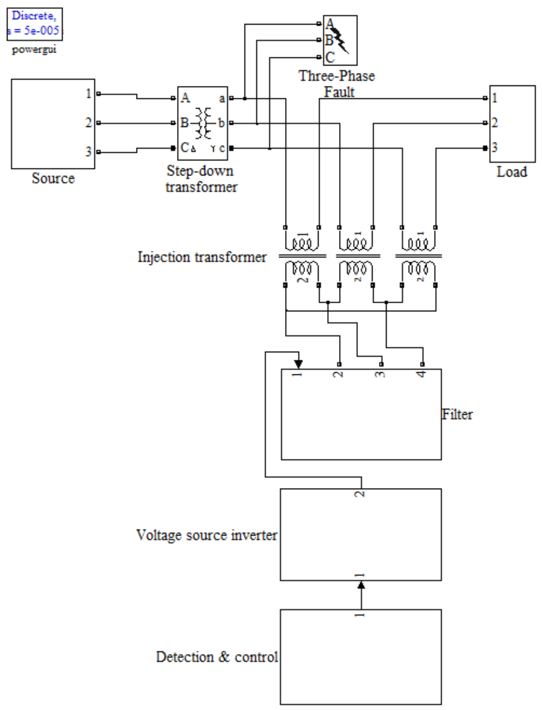

Fig.6 Circuit model of dynamic voltage restorer in Matlab Simulink

The simulation was done with three – phase fault in time simulation 500 ms lasted up to 750 ms. Results are showed in next figures.

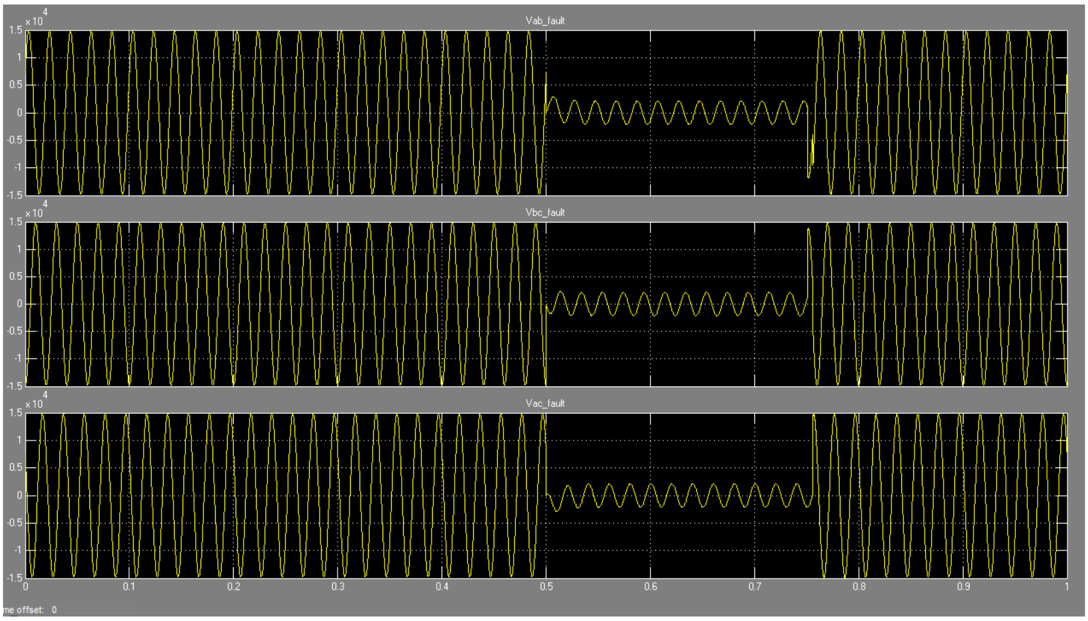

Fig.7 Phase – phase voltages for three – phase fault (a,b,c)

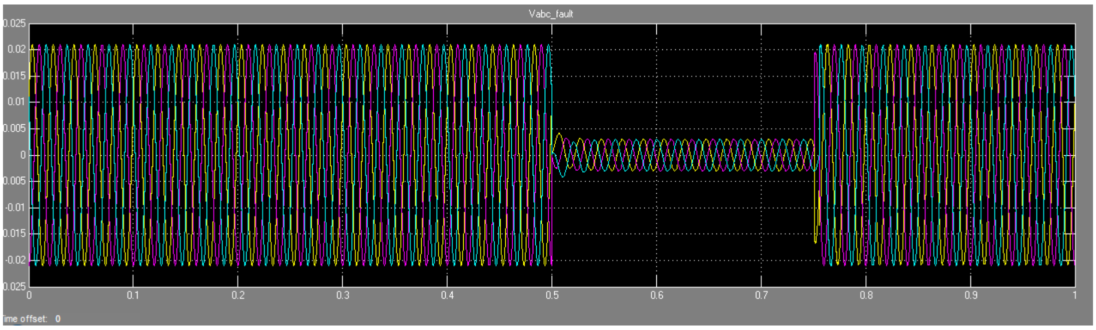

Fig.8 Three - phase voltage for three – phase fault (a,b,c)

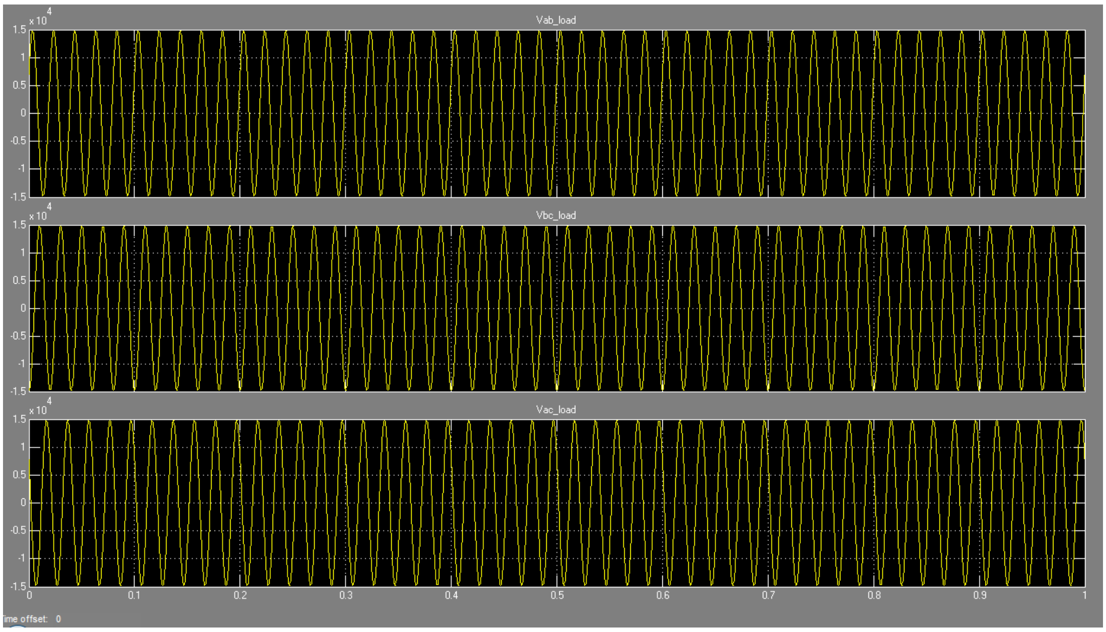

Fig.9 Phase – phase voltages at load point with injective voltage

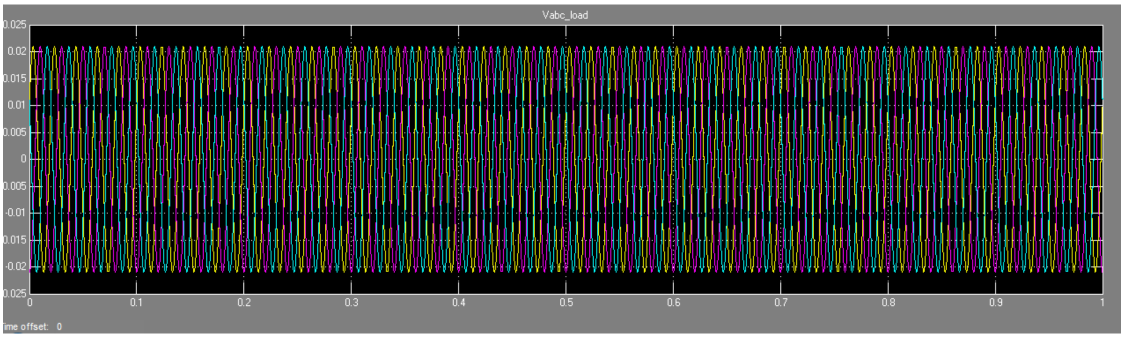

Fig.10 Three – phase voltage at load point with injective voltage

4 CONCLUSION

In this article, dynamic voltage restorer is proposed for mitigating the problem of voltage sags in simple distribution network. This problem was simulated using MATLAB. A DVR is connected to a system through a series transformer. In – phase compensation method is used. DVR handles unbalanced situations without any difficulties and injects the appropriate voltage component to correct rapidly any deviation in the supply voltage to keep the load voltage constant at the nominal value. The proposed PWM control scheme using PI controller is efficient in providing the voltage sag compensation. DVR was used to mitigate voltage sag caused three – phase fault.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

[1] BOONCHIAM, P., MITHULANANTAN, H., 2006. Understanding of Dynamic Voltage Restorers through MATLAB Simulation. Thammasat Int. J. Sc. Tech., 11(3), July-Sept. 2 p.

[2] NIELSEN, J., G., NEWMAN, M., NIELSEN, H., BLAAJBERG, F. 2004. Control and testing of a dynamic voltage restorer (DVR) at medium voltage level. IEEE Trans. Power Electron. 19(3): 806 May.

[3] NIELSEN, J., G. Design and Control of a dynamic voltage restorer. Denmark: Aalborg University, Institute of Energy Technology. 2002. 21 p.

[4] TIWARI, H. P., GUPTA, S.,K. Dynamic voltage restorer based on load condition. International Journal Innovation. Management and Technology, 2010, Vol.1.No.1, ISSN: 2010-0248

[5] DOBRUCKÝ, B., ŠUL, R., ŠPÁNIK, P. Zabezpečenie napájania kontinuálnych procesov s využitím zariadení FACTS. Žilina: Žilinská univerzita v Žiline, 2010. 2 s.

[6] NIJHAWAN, P. Power quality improvement of distribution networks using dynamic voltage restorer. Patiala: Electrical and Instrumentation Engineering Department, 2011. 22, 23, 24 p.

[7] OMAR, R., RAHIM, N.A., SULAIMAN, M. Dynamic voltage restorer applications for power quality improvement in electrical distribution system: An owerview. Australian Journal of Basic and Applied Sciences, 5(12): 379-396, 2011. 24 p.