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Abstract

Recently, Dynamic Voltage Restorer (DVR) has become a popular power electronic device as a protection for sensitive loads from voltage sag. Voltage sag widely known as one of the major problem in power quality, it is defined as a short reduction of voltage from the nominal. DVR is a custom power device for voltage sag mitigation which works when the fault occurs in power distribution system. In this paper, the effect of the DVR location is investigated at the low and medium voltage of the distribution system with different loads. To verify the performance of the DVR in mitigating the voltage sag, the system is simulated using PSCAD/EMTDC software. Results show the effect of DVR location in maintaining the voltage sag.

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The Effect of DVR Location for Enhancing Voltage Sag

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Abstract—Recently, Dynamic Voltage Restorer (DVR) has become a popular power electronic device as a protection for sensitive loads from voltage sag. Voltage sag widely known as one of the major problem in power quality, it is defined as a short reduction of voltage from the nominal. DVR is a custom power device for voltage sag mitigation which works when the fault occurs in power distribution system. In this paper, the effect of the DVR location is investigated at the low and medium voltage of the distribution system with different loads. To verify the performance of the DVR in mitigating the voltage sag, the system is simulated using PSCAD/EMTDC software. Results show the effect of DVR location in maintaining the voltage sag.

I. INTRODUCTION

Power quality is very important issue recently due to the impact on electricity suppliers, equipment manufacture and customers. Power quality is described as the variation of voltage, current and frequency in a power system. It refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location in the power system [1]. Nowadays, there are so many industries using high technology for manufacturing and process unit. This technology requires high quality and high reliability of power supply. The industries like semiconductor, computer, and the equipments of manufacturing unit are very sensitive to the changes of quality in power supply [2]. This power quality is essential for proper operation of industrial processes which involve a good protection to the system for being well and progress for long usage. Power quality problems such as voltage sag, swell, harmonic distortion, unbalance, transient and flicker may have impact on customer devices which will cause malfunctions and lost of production [3].

Voltage sag is a short duration of RMS voltage reduction in the range of 0.1 - 0.9 p.u which is caused by a fault on the power system or starting of large loads such as motor. Some of the equipments trip when the RMS voltage drops below 90% for longer than one or two cycles. A normal duration of sag according to the standard is 10ms to 1 minute and considered as the most serious problem of power quality [4, 5]. Sag could be balanced or unbalanced depending on the type of fault and could have unpredictable magnitudes depending on the distance from the fault and the transformer connection. In power distribution system, voltage sag becomes most common power disturbance which certainly affect the industrial and large commercial customers such as the damage of the sensitive equipments and lost of daily production and finances [3]. Every consumer is subjected to a voltage sag occurrence since faults cannot be totally

avoided. In fact, the greatest losses will fall upon customers having sensitive equipment as PLCs (programmable logic controllers) and ASDs (adjustable speed drives) [6].

Many techniques are used to mitigate voltage sag and swells, but the use of a custom power device is considered to be the most efficient method. Like Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, especially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply [3]. DVR has been used to compensate the voltage sag in [2, 7, 8 & 9]. The DVR with Uninterruptible Power Supply (UPS) was proposed for sag reduction [10]. Adaptive Neural Network with Dynamic Voltage Restorer was applied to solve sag's problem [11]. A new device which is named Inter-line Dynamic Voltage Restorer is discussed in [12]. This device consists of two conventional DVRs which are installed in two different distribution feeders and the DC link capacitor. DVR which is installed in LV feeder operates in voltage sag compensation mode. A novel control technique minimizes the energy flow from DC link capacitor to this feeder. The DVR, which is installed in MV feeder, controls the voltage of DC link capacitor.

DVR is a series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder. Its primary function is to rapidly boost up the load-side voltage in the event of a disturbance in order to avoid any power disruption to that load. There are various circuit topologies and control schemes that can be used to implement a DVR. In addition to voltage sags and swells compensation, DVR can also added other features such as: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations [3]. The basic operating principle behind the DVR is that the DVR injects the difference between the pre-sag and the sag voltage, by supplying the real power requirement from the energy storage device together with the reactive power. The maximum injection capability of the DVR is limited by the ratings of the DC energy storage and the voltage injection transformer ratio [8]. In the case of three single-phase DVRs the magnitude of the injected voltage can be controlled individually. The injected voltages are made synchronized (i.e. same frequency and the phase angle) with the network voltages [7].

This paper investigates the effect of DVR location in mitigating the voltage sag of distribution system. Three phase short circuit is applied in different locations to evaluate the response of DVR placement at the MV and LV system. The paper is organized as such that, the problem formulation is given in section 2. Section 3 illustrates the system used for this study and discusses the methodology of simulation using PSCAD/EMTDC software. Simulation results and conclusion are provided in sections 4 and 5 respectively.

II. PROBLEM FORMULATION

A typical DVR topology connected system circuit is shown in Fig.1 where the DVR consist of essentially series connected injection transformer, a voltage source inverter (VSI), filter and energy storage device connected to the link. The power system upstream to the DVR is represented by an equivalent voltage source and source impedance. Loads connected downstream are thus protected from the point of common coupling PCC voltage sag [13].

The series injected voltage of DVR shown in Fig.1 [14] is:

$$V_{dvr} < \alpha = V_l < 0 - V_{pcc} < -\delta \quad (1)$$

Where α and δ are the angle of V_{dvr} and V_{pcc} respectively with the load voltage V_l as the reference. The Complex power injection of DVR is then:

$$S_{dvr} = V_{dvr} < \alpha \times I_l < \phi \quad (2)$$

Here $I_l < \phi$ is the load current with:

$$I_l = \left(\frac{P_l + jQ_l}{V_l} \right)^*, \quad \phi = \tan^{-1} \left(\frac{Q_l}{P_l} \right) \quad (3)$$

III. CASE STUDY

The DVR structure depicted in Fig. 2 and the power systems shown in Fig. 3 & 4 have been implemented in PSCAD/EMTDC. Fig. 3 shows the location of the DVR at MV system and Fig. 4 shows the intended location for the LV-DVR is in a three wire LV-system with 420 V line voltages. The system parameters and constant value are listed in Table I. Test system is comprised of a source which feeds three different loads: 1) a squirrel-cage induction machine, nonlinear load which consists of an uncontrolled three-phase rectifier with an inductive-resistive load, and three-phase sensitive load which consists of a star made up of a resistance connected in series with an inductance in each phase [8]. A number of simulations have been performed during normal operation and during abnormal conditions such as three phase short circuits with differing load situations. Both the steady state effect of the DVR in standby mode and the dynamic sag protection active modes are investigated. The three phase short circuits (symmetrical) are injected into the MV system when the DVR is located at the MV system and the same fault was applied into the LV system when the DVR is located at the LV system. A fault level of approximately 0.125 kA on the LV system (0.04 kA on the MV system) was achieved during the fault tests, with a voltage sag of 0.72 p.u. The generation of a voltage sag in a strong 7.5 kV distribution system is not a trivial task, and can require a sag deep enough to significant currents

to create satisfactorily test the DVR. Therefore, to maximize the sag depth, the sensitive load was connected to the weakest distribution system and the fault position was placed just upstream of the DVR protecting this load.

Figure 1. DVR circuit topology (single phase representation)

Figure 2. The structure of DVR

TABLE I
THE PARAMETERS OF THE DVR

System parameters	Values
Base MVA Rating Transformer	1MVA
DVR supply voltage for LV level	420V
DVR supply voltage for MV level	2kV
High Pass Filter Resistance	10 Ω
High Pass Filter Inductance	0.00164H
High Pass Filter Capacitance	5.66 μ F
Capacitor	4000 μ F
Sensitive Load Resistance	56.25 Ω
Sensitive Load Inductance	0.13H

Figure 3. DVR located at the MV system

Figure 4. DVR located at the LV system

IV. SIMULATION RESULT AND DISCUSSION

To verify the efficiency of the DVR, the simulation is carried out and the results are analyzed for different voltage sag and load conditions as discussed in section 3 and briefly given in this section. The obtained results of the voltage sag by locating the DVR at MV and LV system are illustrated in Table II and graphically shown in Figs 5, 6, 7 & 8. Figs.5 & 6 shows the voltage sag before and after the mitigation when sensitive loads are connected to the same circuit. From Fig.5, it is noted that the voltage drops about 0.2 pu. Here, the duration of the fault is 0.2 second and the percentage of sag is about 20% which means that the system needs 20% of the voltage from the DVR to be injected into the system. After the mitigation as seen in Fig. 6, the sag has been mitigated and the voltage increased until 1 pu. This indicates the effectiveness of the DVR in mitigating the voltage sag. As for the location of the DVR at the LV system, Figs 7, 8 show the voltage sag before and after mitigation respectively. It is seen from these figures that the voltage drops about 0.2 pu and after the mitigation, the voltage increases until 0.91 pu.

TABLE II
THE SAG MITIGATION WHEN DVR LOCATED AT MV AND LV SYSTEM
CONNECTED TO DIFFERENT LOADS

DVR Location	Voltage sag before mitigation (p.u)		Voltage sag after mitigation (p.u)	
	Sensitive Loads	Nonsensitive loads	Sensitive loads	Nonsensitive loads
MV System	0.799116	0.799116	0.999512	0.999462
LV System	0.729725	0.780244	0.915387	0.975536

Figure 5. Voltage sag before mitigation when the DVR located at MV system

Figure 6. Voltage sag after mitigation when the DVR located at MV system

Figure 7. Voltage sag before mitigation when the DVR located at LV system

Figure 8. Voltage sag after mitigation when the DVR located at LV system

Referring to Table II, the results show that the DVR effectively mitigating the sag when DVR located at the MV system. Moreover, the sensitive loads are protected and the voltage increased during the sag up to 0.99 pu compare to the location of the DVR at the LV system, in this location, the DVR could not protect the sensitive loads and the compensation of the sag is not more than 0.91 pu. Applying a DVR in the medium or low voltage distribution system would often be possible and a radial grid structure is the only type of system considered here. A main difference between a LV connection and a MV connection is the flow of zero sequence currents and the generation of zero sequence voltages. In the four wire system, the DVR must secure low impedance for zero sequence currents and the zero sequence must either flow in the power converter or in a delta winding of the injection transformer [15]. Furthermore, the current rating of the DVR is critical. It should be scaled according to the existing load and a future load increase. If the load consists of large loads with transient currents, the DVR must be rated to handle these higher currents or somehow bypass the current. During voltage sag, the voltage applied to the transformer changes abruptly and the transformer is magnetized according to the sag size. A transient DC-current can be detected and saturation effects in the transformer can even increase the inrush current. The DVR converter has to

supply the inrush current and must be rated to supply this current.

Inserting a large DVR at the MV-level will only increase the supply impedance for a LV load slightly. Assuming an infinite busbar at the 7.5kV level, the impedance for a LV load consists of the summation of impedances from the 7.5/2kV transformer, cables and overhead lines at the 2kV level, the 2/0.420kV distribution transformer and LV cables to the LV load. Protecting a large MV load close to the DVR, the increase in impedance experienced by the load can be significant. Insertion of DVR at LV-level is close to sensitive load. The increase in impedance by insertion of a small rated DVR can be significant for the load to be protected from voltage sag. Moreover, the costs per MVA to protect are expected to be lower if one large central DVR is located at the medium voltage level instead of decentralized low voltage units. On the other hand, the disadvantages with a LV location are that the impedance increase after the insertion of the DVR for the protected load can be large, which may influence the site short circuit level and protection. An increased load voltage distortion and load voltage variation can be expected, which may be caused by non-linear and time varying load currents.

V. CONCLUSION

The paper evaluates the effects of DVR location to mitigate the voltage sag using sensitive and nonsensitive loads. The highly developed graphical facilities available in PSCAD/EMTDC program have been used very effectively to carry out all aspects of the system implementation. In order to compensate voltage sag, it is possible to use DVR at MV or LV distribution system. The simulation results demonstrated the capability of DVR, this was confirmed by the results of which sample are given in this paper. Finally, DVR is an effective custom power device for voltage sags mitigation. The impact of voltage sags on sensitive equipment is severe when the DVR located at the MV system. Therefore, DVR is considered to be an efficient solution due to its relatively low cost and small size, also it has a fast dynamic response.

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