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Review of Dynamic Voltage Restorer (DVR) Using Various Control Topologies

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ABSTRACT
The main problems with the quality of electricity are voltage fluctuations like the voltage drop and swell, which impact the reliability of electrical networks. The use of dynamic voltage restorer and thus secure sensitive loads are an effective solution to minimize this voltage sag or swell. The base structure of the DVR is created using an inverter, DC connecting condenser and injection transformer. Inverters are used to compensate for the voltage drop / swell and other problems including flickering, current harmonic interference in system. DVR inverter's various property includes voltage levels, unbalanced power compensation requirements and/or dc link voltage requirements. This paper aims to analyze the number of phases, scale, voltage and structure of different inverters and controller topologies. In addition, in this analysis are presented each of the properties of inverters, controllers and compensation.

Key words: Control topologies, DC link voltage, DVR, Voltage fluctuation, Voltage sag/swell.

1. INTRODUCTION
The changing utility climate will continue to demand financial and market forces that the power system is run more optimally and profitably in terms of generation, transmission and distribution. More than ever, the safe and efficient operation of electricity networks is crucial to advanced technology [1]. More flexibility in the use and management of existing transmission system capital is evident, so that organizational trust and financial productivity can be achieved [2-3].Tthe use of advanced control technology would allow the current power system to be improved. Power-electronic equipment (FACTS) offers validated technical solutions to meet the new operational problems that have been presented today [4-5]. Unlike the development of new transmission lines, the FACTS strategy provides companies with limited investment in infrastructure, environmental impacts and distribution times for efficient transmission systems. In addition the electrical transmission network infrastructure has been upgraded, predominantly by new transmission lines, 37 substations and related equipment. However, the past ten years have shown that the authorization, development and construction of new transmission lines are highly complex, expensive, time-consuming and contentious. As economic alternatives to new transmission line building, FACTS technologies offer innovative solutions. Power system engineering and T&D societies are now well aware of the potential benefits of FACTS equipment. As for facts equipment, a range of systems worldwide have used the voltage-based converter (VSC) technology, using self-driven thyristors/transistor systems [6-7]. The biggest power quality concerns are called voltage sag and swell in electrical systems. For short voltage between 0.1 pu and 0.9 pu, the voltage sag is defined as a decrease in the RMS value. For RMS voltage the voltage ripple is raised by more than 1.1 pu. Many custom power devices such as the Uninterrupted Power Supply (UPS), the Dynamic Voltage Restorer (DVR) and the Static Sequence Compensator (STATCOM) have been built to solve such problems [8-10]. The availability of efficient, quick-switching and high speed computing components, and new controls have opened the way for wide-ranging use of custom power devices based on voltage source converters. Dynamic voltage restorer is a series of connected devices designed to reduce voltage and swell.

Sag and swell terms are given as voltage magnitude - total 9.0, total magnitude – total 1.1 swell for PU. The basic structure of the traditional DVR is an inverter, a direct-stream (dc) link condenser, a filter and an injection transformer. In order to compensate for the voltage swell, this inverter generates regulated AC voltage in phase through injection transformers [11-13]. This paper is intended to provide a complete review of various topologies used in DVR on utilities ' systems by inverters, controllers and compensations. General block diagram of the DVR system is shown in figure 1.

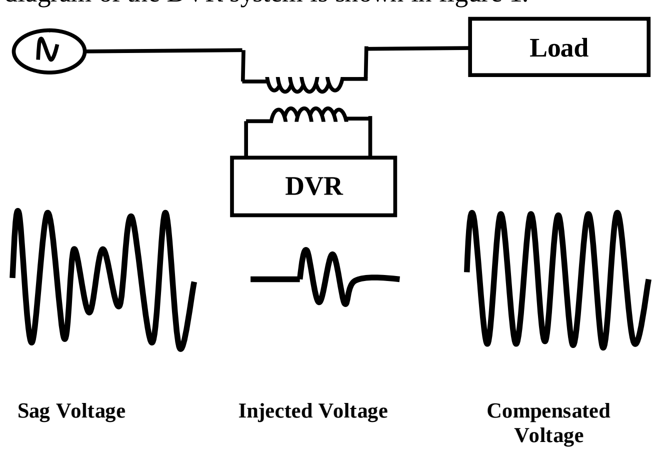

Figure 1: Single Phase and Three Phase Inverter in DVR Setup

2. CONVERTER TOPOLOGIES

This paper is aimed at providing an extensive review of various inverter topologies on the utilities in DVR [7]. The first type of converter is called as a power rating of DC-AC converters. The second type is known in five topologies as AC-AC converters [14]. The description of converter topologies used in DVR for the compensation of voltage disturbances is shown in figure 2.

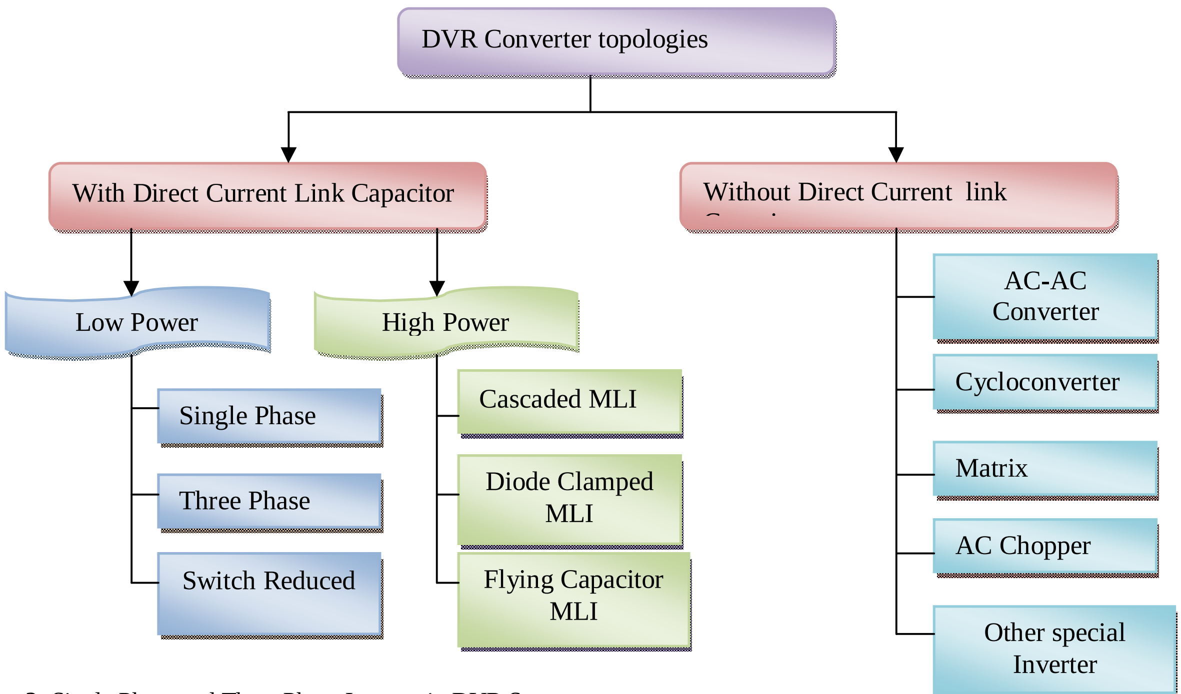

Figure 2: Single Phase and Three Phase Inverter in DVR Setup

2.1 With DC Link Capacitor

A. Low Power Inverter based DVRs

The most common topology to achieve single phase output voltage is the single phase DVR inverter system. Low power inverter based DVR system consist of consists of four power semiconductor switches and diodes. In three phase inverter circuit consist of 12 power switches and diodes to produce three phase voltages in DVR is shown in figure 3. The DVR based on the single phase inverter is favored most of the time in DVR topologies due to its unequaled and balanced voltage sag / swell offset.

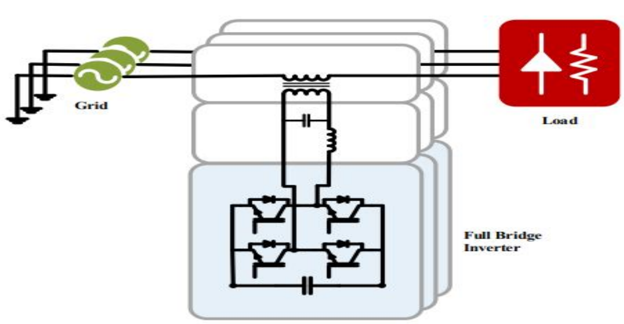

Figure 3: Single Phase and Three Phase Inverter in DVR Setup

B. High Power Inverter based DVRs

Instead of these inverters, multilevel inverters allow high voltage, as shown in figure 4. More power capacity and lower switching power losses, less THD are the advantages of the multilevel inverter. Multi-level inverters implementing DVR are the most common topologies:

1) *Diode Clamped Multilevel Inverter (DCMLI)*
2) *Cascade Multilevel Inverter (CMLI)*
3) *Flying Capacitors Multilevel Inverter (FCMLI)*

. Different H-bridge inverters and high voltage DC sources are required for cascades. Cascade Multilevel Inverters use H-bridge n-number to generate the level of voltage ($2n-1$) at output phase voltage. A DCMLI consists of capacitors ($n-1$), switching devices $2n-1$ and $n-1*n-2$ clamping devices for the processing of the phase output voltage at the n-level. An inverter n-level flying condenser uses DC connectors ($n-1$) and storage capacitors ($n-1*n-2/2$) per phase. Hence, the FCMLI needs large DC capacitor with increased the voltage levels.

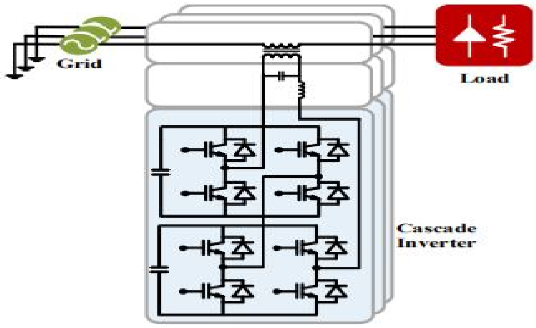

Figure 4: Multilevel inverter topologies in DVR

2.2 Without DC Link Capacitor

Figure 5 represents the AC-AC converters and it has recently been playing an important part in compensating voltage fluctuations in utilities rather than inverters. The direct AC / AC, cyclo-converters, Matrix converter and AC / AC converter DVRs are simply designed to complement the voltage disturbances such as tensile / swell voltage, harmonic and flickering, and do not involve the connection between power supplies.

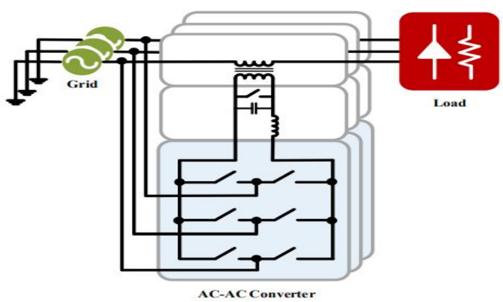

Figure 5: AC-AC converters in DVR

3. VOLTAGE COMPENSATION METHODS

The DVR compensate sag or swell by the supply voltage in series to keep the load side voltage to a desired voltage. A DVR is typically a power storage unit and an inverter that is connected to the grid via a series transformer. This inverter is intended to restore load voltage efficiency by using a regulated magnitude or phase angle voltage sequence. The DVR has two main control parts: the reference signal is recognized and this signal is determined. The grid voltage is calculated and evaluated in the detection portion of the DVR and based on the sag or swell method. The second part of the DVR is the recognition by the type of power storage device of the series injected voltage reference signals. Four basic voltage compensation methods are available. There are

1. In- phase voltage sag compensation
2. Pre-phase voltage sag compensation
3. Balanced voltage sag compensation
4. Unbalanced voltage sag compensation

A. In-Phase Voltage Sag Compensation

The main approach used the in-phase voltage compensation system in which the injected voltage (Vinj) is in any pre-fault state, in which the DVR is in a phase with the supply voltage (Vs). Figure 6 shows the phasor scheme of the process compensation method.

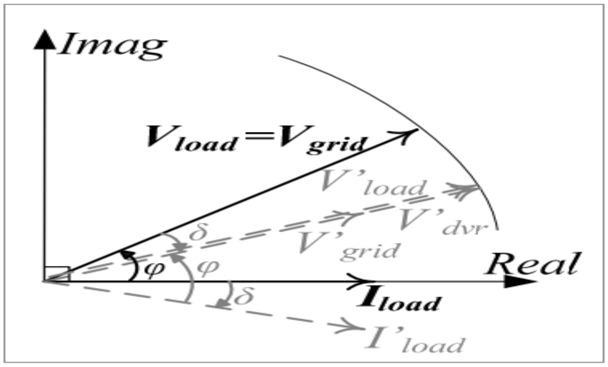

Figure 6: In-phase process of compensation phase diagram

A common method of voltage compensation is to restore the load side voltage (VL) to the pre-sag level and position. The voltage amplitude and the pre-sag step must be restored precisely and its phasor diagram is shown in figure 7.

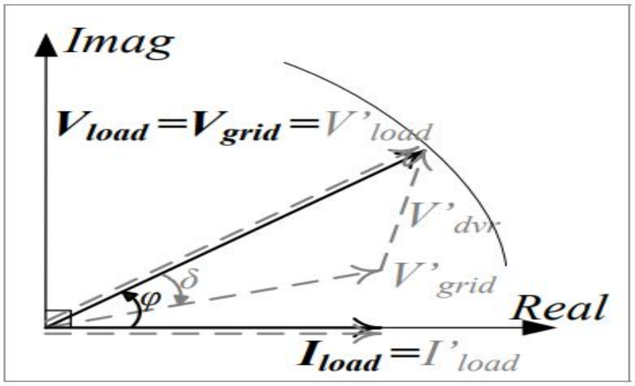

Figure 7: Phasor diagram of pre-phase compensation method

B. Balanced Voltage Sag Compensation

In this balanced voltage sag compensation, the shift for phase and amplitude of the grid voltage during the voltage sag during all three phases are equal. The voltage phasor in the balanced voltage slope demonstrates the energy controlled compensation strategy in figure 8.

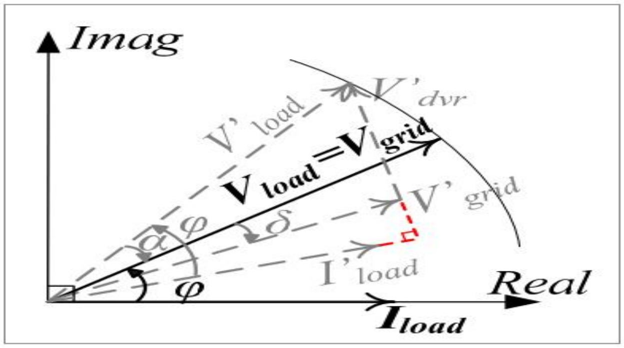

Figure 8: Diagram of balanced phase voltage sag compensation method

C. Unbalanced Voltage Sag Compensation

The amplitude and phase angle of the voltage and variance in the signals are not identical in this unbalanced voltage distorting process. The voltage phasor for unbalanced voltage sag are shown in figure 9. The applied voltage of the DVR series phasor is not perpendicular to the phasor.

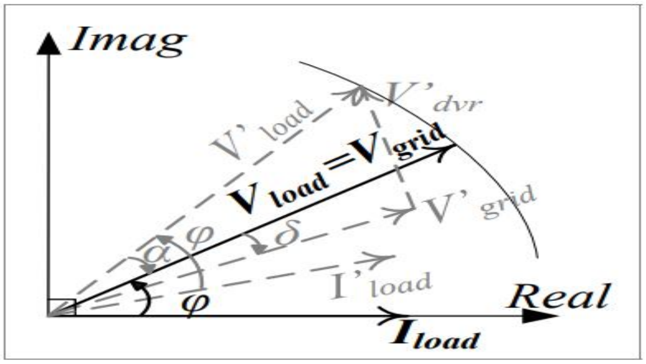

Figure 9: Phasor diagram of unbalanced balanced phase voltage sag compensation method

4. CONTROL UNIT

The DVR Series Converter allows actual and reactive power flow control on the transmission line simultaneously. For this, the voltage injected by the series converter is divided into two parts. The square injected portion regulating the transmission line's real power flow is one part of the injected voltage sequence. This strategy is close to a phase shifter. The in-phase function regulates the reactive power flow of the transmission line. There are various types of control method is used to control the DVR system. Some of the controllers are listed as following, PI, PID, Fuzzy, ANFIS, synchronous reference frame theory, sliding mode controller, model predictive controller [15], shunt active filter, P-Q theory based controller, artificial intelligence based control topologies, optimization based control methods like genetic algorithm, particle swarm optimization, cuckoo algorithm, bat algorithm, and so on. Generalized control topology block diagram is shown in figure 10. Using anyone of the control methods by compensates the voltage sag as well as swell that occur in the power system line.

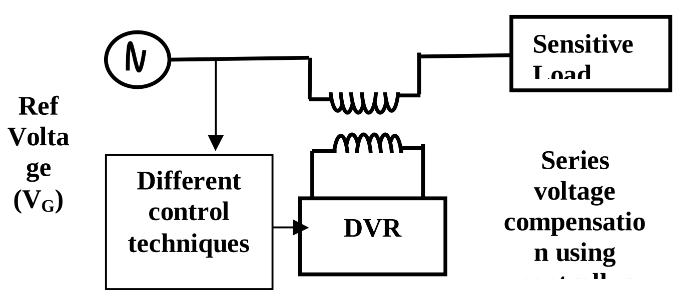

Figure 10: Block diagram of control topology

5. CONCLUSION

Inverter types and compensation of voltage sag that occurs in transmission line has been reviewed in this paper. Various control strategy of Z-source inverter based DVR topology is proposed. The high performance the of power quality issues is achieved by the proper utilization of converters, inverters and desired control strategies. Moreover the inverter's with control method is designed to have high gain, quick settling time, reduced power quality issues as voltage sag and swell, and less ripples. The inverter's selection is based on the less switch count, harmonics reduction and simple structure. This paper includes the advanced control technique based voltage compensation. The sliding mode observer based MRAS is also introduced during the external disturbance is more. The FOC and DTC schemes are compared and review is provided in this paper

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