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Mitigating Voltage Sags/Swells using Converter based Dynamic Voltage Restorer for Distribution Transformer

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Abstract**—** Power quality has become a major concern of the modern industries in the present era. Voltage sags/swells are considered as the most significant power quality problems because of increasing complexity in the power system. To overcome these problems, Custom Power Devices (CPD) is connected closer to the load end. One of those devices is Dynamic Voltage Restorer (DVR) which is a series connected most efficient and effective modern CPD used in power distribution network. The main function of the DVR is to monitor the load voltage constantly and if any sag or swell occurs, it can quickly mitigate by injecting the balance (or excess) voltage to the load voltage. The primary advantage of the DVR is keeping the users always on-line with high quality constant voltage to maintain the continuity of production.

Keywords: - Dynamic Voltage Restorer, Custom Power Device, Voltage Sag, Swell, Distribution Transform

I. INTRODUCTION

The voltage sag or swell which is usually encountered in distribution systems can be compensated by three-phase DVRs. In general, when the sag or swell in any phase is sought to be compensated by using the power from the other phases, extensive signal processing is required. This is mainly because of the phase shift and of the non-linear magnitude of the voltage available for compensation. In this work new control procedure is presented without involving intensive computations, which is mostly analog and which would take care of the phase shift and of the non-linear magnitude of the voltage available for compensation when the power is utilized from the other two phases [1]. In this paper, an application is discussed in which the sag is controlled by using the power from the same phase while the swell is brought down by using the power from the other two phases. However, the potential of the basic control procedure is not limited to the above strategy, but can be applied to a variety of other sag and swell mitigation schemes also. The emphasis is not to establish the superiority or otherwise of any of the arrangements of diverting power from any one phase to other phases for mitigating the sag or swell [2]. The core of the work deals with the simplicity of the new control procedure employed for such diversion of power. The feedforward nature of the control leads to stable operation. Its effectiveness has been demonstrated by simulations. The modern manufacturing and process equipment which operates at high efficiency require high quality power for the successful operation of their machines [3]. The failure of required quality power can cause complete shutdown of the industries which will make a major financial loss to the industry concerned.. In practice, power systems, especially the distribution system has numerous nonlinear loads which produce power quality problems such as voltage sag and swell, flicker, harmonics, distortion, impulse transient and interruptions [4]. Among these, two power quality problems such as voltage sag and swell have been identified a major concern to the customers .The voltage sag and swell have major impact on the performance of the microprocessor based loads as well as the sensitive loads [5]. Though there are many different methods to mitigate voltage sag and swell, but the use of a custom Power device is considered to be the most efficient method. The term custom power pertains to the use of power electronics controllers in a distribution system specially to deal with various power quality problems. Dynamic Voltage Restorer (DVR) is one of the most efficient and effective modern custom power device used in power distribution networks. DVR is series connected solid state device that injects voltage into the system in order to regulate the load side voltage [6]. It is normally installed in the distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sag and swell compensation, DVR can also have other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

II. POWER QUALITY

Over the last thirty years or so, the amount of equipment containing electronics has increased dramatically. Such equipment can both cause and be affected by electromagnetic disturbances. A disturbance that affects a process control computer in a large industrial complex could easily result in shutdown of the process. The lost production and product loss/recycling during start-up represent a large cost to the business. Similarly, a protection relay affected by a disturbance through conduction or radiation from nearby conductors could trip a feeder or substation, causing loss of supply to a large number of consumers. At the other end of the scale, a domestic user of a PC has to re-boot the PC due to a transient voltage dip, causing annoyance to that and other similarly affected users. Therefore, transporters and users of electrical energy have become much more interested in the nature and frequency of disturbances in the power supply. The topic has become known by the title of Power Quality. The main reasons for concern with power quality (PQ) are as following [7]:

- End user devices become more sensitive to PQ due to many Microprocessor based controls.
- Complexity of industrial processes: the re-startup is very costly.
- Large computer systems in many businesses facilities
- Power electronics equipment used for enhancing system Stability, operation and efficiency. They are major source of bad PQ and are vulnerable to bad PQ as well.
- Deregulation of the power industry
- Complex interconnection of systems, which results in more
- Severe consequences if any one component fails.
- Continuous development of high performance equipment: Such equipment is more susceptible to power disturbances.

III. POWER QUALITY DISTURBANCES

Power quality disturbances can be summarized as follows

Voltage sag

Voltage sag is defined as the reduction of R.M.S voltage to a value between 10-90% and lasting for duration of half a cycle to one minute. Voltage sags are mostly caused by system faults and starting of induction motor of large rating. It may be also caused by switching operations associated with a temporary disconnection of supply, the flow of heavy current associated with the starting of a large electric motors or the flow of fault currents or the transfer of load from one power source to another. These events may emanate from customers' systems or from the public supply network. The main cause of momentary voltage dips is probably the lightning strike. Each of these cases may cause sag with a special characteristics (magnitude and duration). Figure 1 shows a waveform depicting voltage sags.

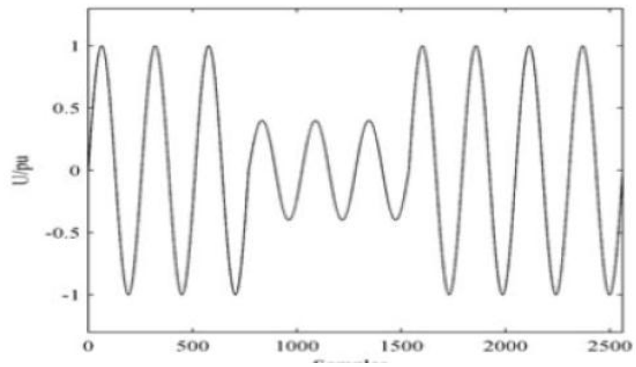

Figure 1: Voltage sag waveform

Voltage swell

Voltage Swell is defined as an increase in R.M.S voltage between 110 % to 180% at the power frequency for durations from 0.5 cycles to 1 min. They appear on the switching off of a large load; energizing a capacitor bank; or voltage increase of the unfaulted phases during a single line-to ground fault. Figure 2 shows a waveform of voltage swell.

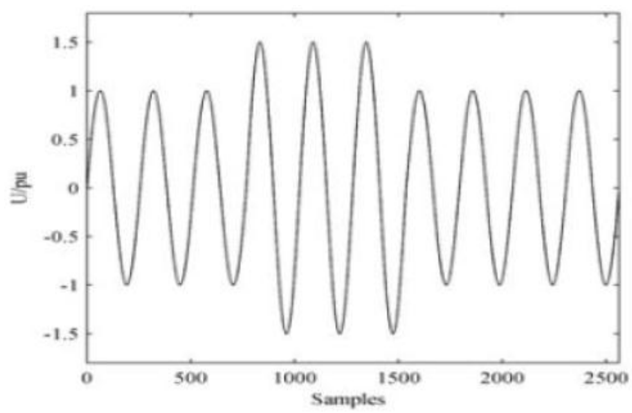

Figure 2: Voltage swell waveform

IV. STRUCTURE OF DVR

DVR is a series connected device located between sensitive load and grid in system. It detects both voltage sag/swell problems and injects controlled voltage to system. Additionally, it can be used for harmonics compensation and transient reduction in voltage and fault current limitations in available literature. To perform these processes, DVR injects a controlled voltage in series with the supply voltage in phase via injection transformer to restore the power quality.

It can be divided into four categories: inverter, DC-link capacitor, filter and injection transformer. An inverter system is used to convert dc storage into ac form. Passive filter is responsible for eliminating the unwanted harmonic components generated in inverter.

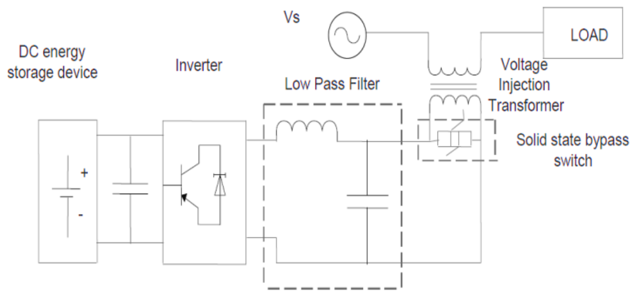

Figure 3: Basic structure of a conventional DVR

In this way, it converts inverter PWM output to sinusoidal waveform. Another component, energy storage unit such as batteries, super capacitors, SMES etc. is used to provide energy requirement in DC form. Lastly, transformer injects controlled voltage and provides isolation between load and the system.

The basic function of DVR is to compensate the voltage sag/swell by transfer the voltage from DC side of the inverter to the injected transformer after the filter. The compensation capacity of a particular DVR depends on the maximum voltage injection capability and the active power that can be supplied by the DVR. When DVR's voltage disturbances occurs active power or energy should be injected from DVR to the distribution system. A DC system which is connected to the inverter input contains a large capacitor for storage. It provides reactive power to the load during faulty conditions. Therefore, there is a minimum voltage required below which the inverter of the DVR cannot generate the require voltage thus, size and rating of capacitor is very important DVR power circuit. The DC capacitor value for a three phase system can be derived. The most important advantage of these capacitors is the capability to supply high current pulses repeatedly for hundreds of thousands of cycles.

COMPONENTS OF DVR

The main components of DVR are energy storage unit, converter circuit, filter unit and series injection transformer. The components are described with more details on the following.

Inverters

The common inverter connection methods for three phase DVRs are 3 phase Graetz bridge inverter, Neutral Point Clamp inverter.

Voltage Source Inverter

Generally Pulse-Width Modulated Voltage Source Inverter (PWM VSI) is used. The most common inverter topologies are the two- or three-level three-phase converter where the dc-side capacitor(s) is connected alternately to all ac phases. The inverter configuration, switching and output waveforms for the fundamental switching are shown in Figure 4.

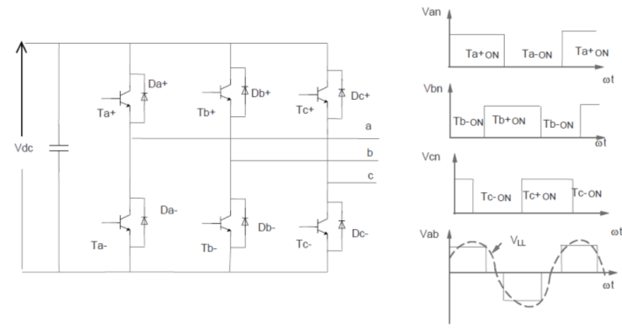

Figure 4: Three phase Inverter and its switching arrangement

This is referred to as two-level since the phase output voltage waveform consists of two output levels; +Vd and 0 Volts The basic function of the VSI is to convert the DC voltage supplied by the energy storage device into an AC voltage. In the DVR power circuit step up voltage injection transformer is used. Thus a VSI with a low voltage rating is sufficient. In three phase inverter each leg is switched according to the PWM technique used. In the case of fundamental switching is used then the switches are ON for a period of 180o with a duty ratio of 50%. The purpose of the capacitor is to absorb harmonic ripple and hence, it has a relatively small energy storage requirement, particularly when operating in balanced conditions. The size of this capacitor has to be increased, if needed, to provide voltage support in unbalanced conditions. Also, since the capacitor is shared between the three phases, sag on only one phase may cause a distortion in the injected current waveforms on the other phases.

H Bridge Inverter

Another popular converter topology is the H-bridge cascade inverter. A single phase of this converter and its switching arrangement is shown in Figure 5. For fundamental switching each switch is ON for a duty cycle of 50% .Converters with this topology are suitable in power systems applications due to their ability to synthesize waveforms with reduced lower order harmonics and to attain higher voltages with a limited maximum device rating. The principal of operation for this topology is that each capacitor can be connected by means of the insulated-gate bipolar transistor (IGBT) switches so that its voltage contributes positively or negatively or not at all to the output waveform. In the H bridge inverter, four switches are used. When it used for multilevel arrangement especially for high voltage application, it is commonly called as chain circuits.

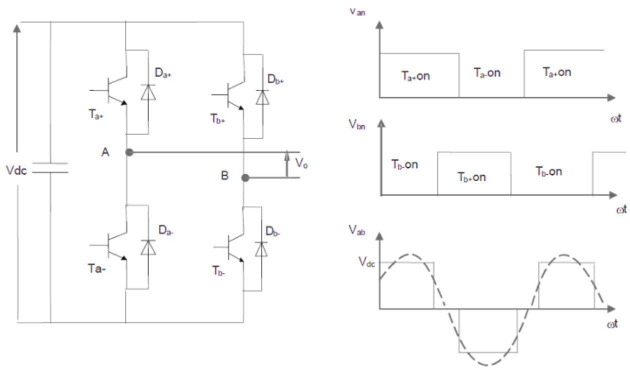

Figure 5: H-bridge inverter configuration and its switching arrangement

V. SIMULATION RESULT

First a case of symmetrical sag is simulated .A 30% voltage sag is imitated at t=1.5 ms and it is kept until t=2.0ms as shown in the Figure 6.and the corresponding input current is shown in the Figure 7. The Figure 8 show the voltage injected by the DVR show the load voltage with compensation and corresponding load current. As a result of DVR, the load voltage is kept constant throughout the simulation including the voltage sag period. Observe that during normal operation, the DVR is doing nothing. It quickly injects necessary voltage components to smooth the load voltage upon voltage sag.

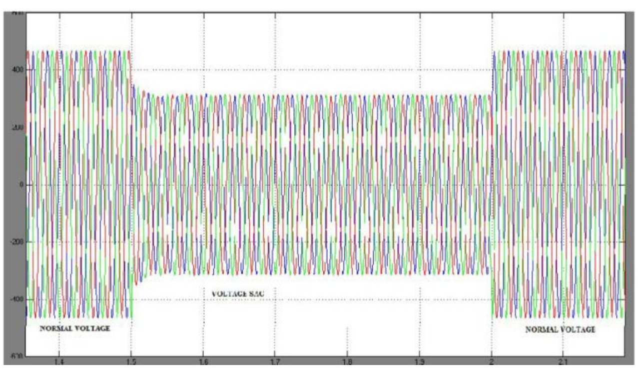

Figure 6: Supply Voltage during sag in VSI based DVR

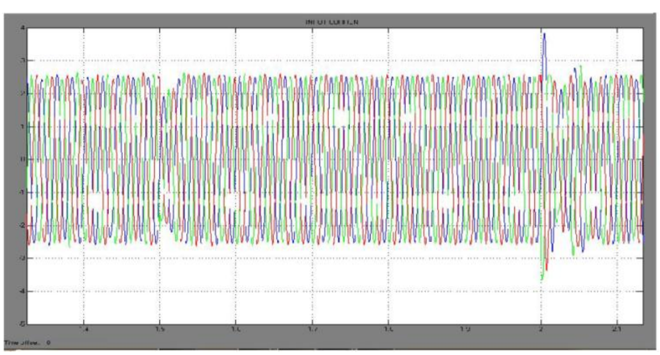

Figure 7: Supply current during sag in VSI based DVR

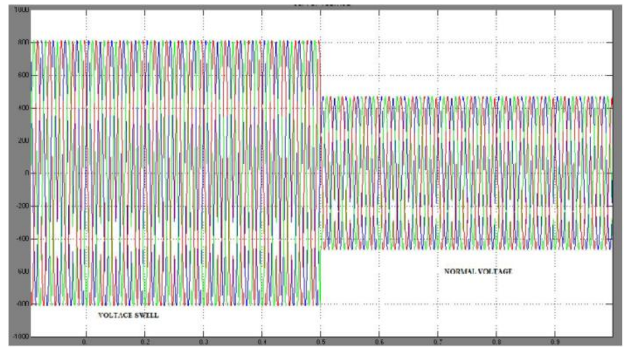

Figure 8: Supply Voltage during Swell in VSI based DVR

VI. CONCLUSION

Dynamic voltage restorers (DVR) are used to protect sensitive loads from the effects of voltage sags and voltage swells on the distribution feeder. The DVR is a cost – effective device which is placed in series with a sensitive load, must be able to respond quickly if end users of sensitive equipment are to experience voltage sags/swells. It is appropriate before choosing the rating of DVR components to determine a proper compensation strategy. The control algorithm based on in-phase injection method has been employed in the thesis. This method has ensured the minimum injected voltage magnitude and reduced active power injection especially for high power factor loads.

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