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Mitigation Of Voltage Disturbances By Converter Based DVR

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Abstract- **An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor. Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min.**

Voltage sag remains a serious power-quality (PQ) problem by being the most common and causing more economic losses. The dynamic voltage restorer (DVR) is a definitive solution to address the voltage-related PQ problems. Conventional topologies operate with a dc link, which makes them bulkier and costlier; it also imposes limits on the compensation capability of the DVR. Topologies with the same functionality, operating without the dc link by utilizing a direct ac–ac converter, are preferable over the conventional ones. Since no storage device is employed, these topologies require improved information on instantaneous voltages at the point of common coupling and need flexible control schemes depending on these voltages. Therefore, a control scheme for DVR topologies with an ac–ac converter, based on the characterization of voltage sags is proposed in this paper to mitigate voltage sags with phase jump.

The main objective of this project is, the control scheme is tested on an inter phase ac–ac converter topology to validate its efficacy based on characterization of voltage sags and to mitigate the voltage sags. Detailed simulations to support the same have been carried out in MATLAB, and the results show the effectiveness of proposed method.

Index Terms— **Dynamic Voltage Restorer (DVR); Instantaneous Symmetrical Component Theory; Phase Jump; Voltage Sag;**

I. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all.

The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

However, the development in the DVR topologies, with direct converters, is not matched with that of the control algorithms. Most of them are controlled either by instantaneous comparison of the voltage at the PCC with a unit reference vector or simple feed forward control to adjust the duty cycle. Since these topologies eliminate the dc link, the compensation depends directly on the voltage at the PCC, and each type of unbalance in the voltage at PCC imposes a limit on the compensation capability distinctly. Therefore, in this paper, a control scheme based on characterization of voltage sag is proposed for the topologies. Characterization of voltage sags has not received due attention, though more developments have come with mitigation of voltage sags. The applications of classification and characterization of voltage sag have been limited to assessing the performance of various systems under sag and to present statistics. This paper demonstrates that characterizing can aid in efficient compensation. It helps in knowing the compensation capability of the topologies, since they are dependent on the input voltage waveforms. Insight on this capability helps in a flexible operation between the compensation schemes, that is, pre-sag and in-phase compensation.

II. POWER QUALITY PROBLEMS

The electric power network has undergone several modifications from the time of its invention. The modern electric power network has many challenges that should be met in order to deliver qualitative power in a reliable manner. There are many factors both internal and external that affect the quality and quantity of power that is being delivered. This chapter discusses the different power quality problems, their causes and consequences.

There are many reasons by which the power quality is affected. The occurrence of such problems in the power system network is almost indispensable. Therefore, to maintain the quality of power care must be taken that suitable devices are kept in operation to prevent the consequences of these problems. Here an overview of different power quality problems with their causes and consequences is presented.

A. Interruptions:

It is the failure in the continuity of supply for a period of time. Here the supply signal (voltage or current) may be close to zero. This is defined by IEC (International Electro technical Committee) as “lower than 1% of the declared value” and by the IEEE (IEEE Std. 1159:1995) as “lower than 10%”. Based on the time period of the interruption, these are classified into two types. They are,

i) Short Interruption: If the duration for which the interruption occurs is of few mille seconds then it is called as short interruption.

Causes: The causes of these interruptions are,

- Opening of an Automatic Re-closure.
- Lightening stroke or Insulation Flash over.

Consequences:

- The data storage system gets affected.
- There may be malfunction of sensitive devices like- PLC’s, ASD’s

ii) Long Interruptions: If the duration for which the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as long interruption. The voltage signal during this type of interruption is shown in Fig.1.

Causes: The causes of these interruptions are-

- Faults in power system network.
- Human error.
- Improper functioning of protective equipment.

Consequences: This type of interruption leads to the stoppage of power completely for a period of time until the fault is cleared.

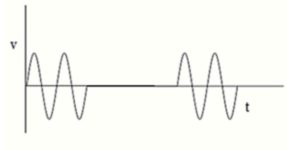

Fig.1 Voltage Signal with Long Interruption

B. Waveform Distortion:

The power system network tries to generate and transmit sinusoidal voltage and current signals. But the sinusoidal nature is not maintained and distortions occur in the signal. The cause of waveform distortions are-

- **DC Offset:** The DC voltage which is present in the signal is known as DC offset. Due to the presence of DC offset, the signal shifts by certain level from its actual reference level.
- **Harmonics:** These are voltage and current signals at frequencies which are integral multiples of the fundamental frequency. These are caused due to the presence of non-linear loads in the power system network.
- **Inter Harmonics:** These are the harmonics at frequencies which are not the integral multiples of fundamental frequency.
- **Notching:** This is a periodic disturbance caused by the transfer of current from one phase to another during the commutation of a power electronic device.
- **Noise:** This is caused by the presence of unwanted signals. Noise is caused due to interference with communication networks.

C. Frequency Variations:

The electric power network is designed to operate at a specified value (50 Hz) of frequency. The frequency of the framework is identified with the rotational rate of the generators in the system. The frequency variations are caused if there is any imbalance in the supply and demand. Large variations in the frequency are caused due to the failure of a generator or sudden switching of loads.

D.Transients:

The transients are the momentary changes in voltage and current signals in the power system over a short period of time. These transients are categorized into two types impulsive, oscillatory. The impulsive transients are unidirectional whereas the oscillatory transients have swings with rapid change of polarity.

Causes:

There are many causes due to which transients are produced in the power system. They are-

- Arcing between the contacts of the switches
- Sudden switching of loads
- Poor or loose connections
- Lightening strokes

Consequences:

- Electronics devices are affected and show wrong results
- Motors run with higher temperature
- Failure of ballasts in the fluorescent lights
- Reduce the efficiency and lifetime of equipment

E.Voltage Sag:

The voltage sag is defined as the dip in the voltage level by 10% to 90% for a period of half cycle or more. The voltage signal with sag in shown in Fig. 2.

Causes:

The causes of voltage sag are-

- Starting of an electric motor, which draws more current
- Faults in the power system
- Sudden increase in the load connected to the system

Consequences:

- Failure of contactors and switchgear
- Malfunction of Adjustable Speed Drives (ASD's)

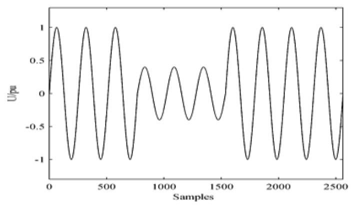

Fig.2 Voltage Sag

F. Voltage Swell:

Voltage swell is defined as the rise in the voltage beyond the normal value by 10% to 80% for a period of half cycle or more. The voltage signal with swell in shown in Fig.3.

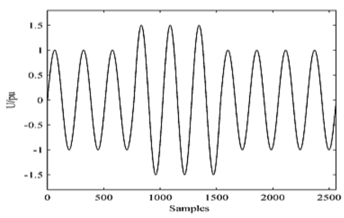

Fig.3 Voltage Swell

Causes:

- De-energization of large load
- Energization of a capacitor bank
- Abrupt interruption of current
- Change in ground reference on ungrounded phases

Consequences:

- Electronic parts get damaged due to over voltage
- Insulation breakdown
- Overheating

G. Voltage Unbalance:

The unbalance in the voltage is defined as the situation where the magnitudes and phase angles between the voltage signals of different phases are not equal.

Causes:

- Presence of large single-phase loads
- Faults arising in the system

Consequences:

- Presence of harmonics
- Reduced efficiency of the system
- Increased power losses
- Reduce the life time of the equipment

H. Voltage Fluctuation:

These are a series of a random voltage changes that exist within the specified voltage ranges. Fig.4 shows the voltage fluctuations that occur in a power system.

Causes:

These are caused by the

- Frequency start/ stop of electric ballasts
- Oscillating loads
- Electric arc furnaces

Consequences:

- Flickering of lights
- Unsteadiness in the visuals

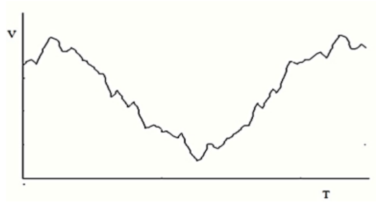

Fig.4 Voltage Fluctuation

III. PROPOSED SYSTEM

A Dynamic Voltage Restorer is a power electronic converter based gadget intended to ensure the discriminating burdens from all supply-side unsettling influences other than deficiencies. It is connected in arrangement with the distribution feeder for the most part at the purpose of regular coupling.

A. Basic Structure:

The DVR is a series connected power electronic device used to inject voltage of required magnitude and frequency. The basic structure of a DVR is shown in Fig.5. It contains the following components:

- Voltage Source Inverter (VSI)
- DC storage unit
- Filter circuit
- Series Transformer

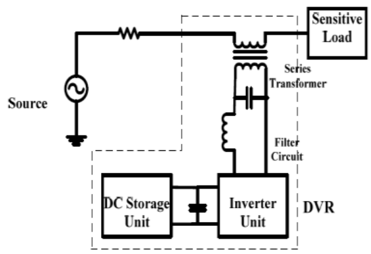

Fig.5 Basic Structure of DVR

The storage unit may consist of batteries, capacitors, flywheel, or super magnetic energy storage (SMES). For DVR with internal storage capacity, energy is taken from the faulted grid supply during the sag. This configuration is shown in Fig. 5. Here a rectifier is used to convert the AC voltage from the grid to DC voltage required by the VSI.

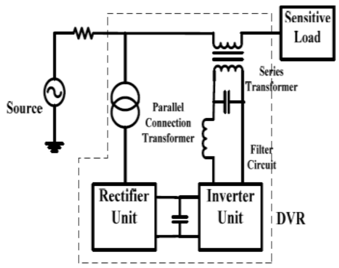

Fig.6 DVR without Internal Storage

The main operation of the DVR is to inject voltage of required magnitude and frequency when desired by the power system network. During the normal operation, the DVR will be in stand-by mode. During the disturbances in the system, the nominal or rated voltage is compared with the voltage variation and the DVR injects the difference voltage that is required by the load. Fig. 7 shows a schematic of a three-phase DVR connected to restore the voltage of a three-phase critical load. A three-phase supply is connected to a critical and sensitive load through a three-phase series injection transformer. A three-leg VSC with insulated-gate bipolar transistors (IGBTs) is used as a DVR, and a BESS is connected to its dc bus.

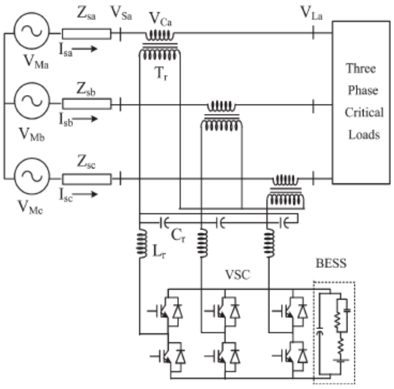

Fig.7. Schematic of the DVR-connected system.

The compensation for voltage sags using a DVR can be performed by injecting or absorbing the reactive power or the real power. When the injected voltage is in quadrature with the current at the fundamental frequency, the compensation is made by injecting reactive power and the DVR is with a self-supported dc bus. However, if the injected voltage is in phase with the current, DVR injects real power, and hence, a battery is required at the dc bus of the VSC. The control technique adopted should consider the limitations such as the voltage injection capability (converter and transformer rating) and optimization of the size of energy storage.

IV. SIMULATION RESULTS

To test the efficacy of the algorithm, two asymmetrical sags, and a symmetrical sag are simulated using MATLAB, and the results are shown in Figs.

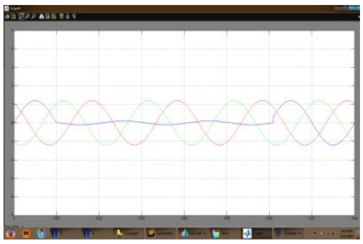

Fig 8 (a) Phase voltage at the PCC with sag

The calculated T_y value and the presence of the zero components (V_{a0}) suggest that it is type B_a sag. Since phase-a is affected, the phase sag supporter is activated.

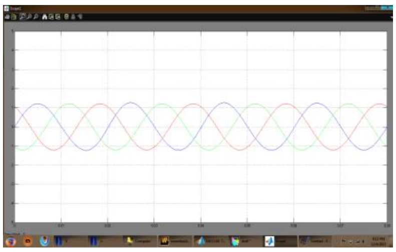

Fig 8 (b) Load voltage at pcc shows compensated voltage which is accompanied by an SF

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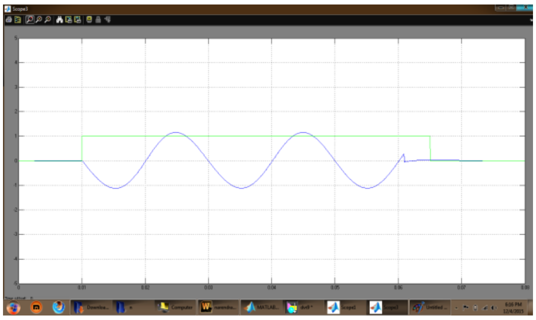

Fig 8 (c) Injected voltages with the sag flag (SF)

Injected voltage (v_{ia}), which is accompanied by an SF. The instant when the SF is high, the DVR is made operational. Here, the algorithm takes $1/8^{th}$ of a power cycle to detect and set the SF.

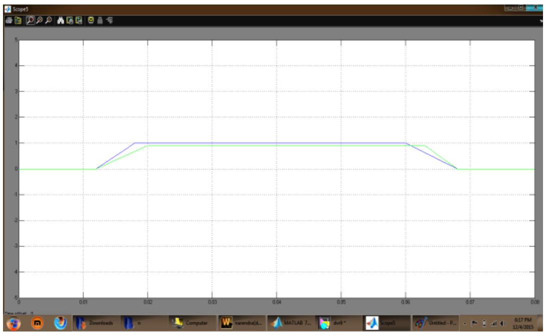

Fig 8 (d) Duty cycle of the choppers in phase- sag supporter

The duty cycles d_1 and d_2 of the choppers across phase-b and phase-c, respectively, are shown in Fig. 8(d). It can be observed that the scheme takes half-a-cycle to compensate sag.

C_b type sag with a characteristic voltage of 0.6 is considered. Since phases and are affected, both phase-c and a sag supporters are activated. From the characteristic voltage, the corresponding reference voltages are calculated. Fig.9(b) shows compensated voltages at the PCC, and it can be observed that the phase- voltage is compensated to the pre-sag condition, eliminating the 29 phase jump. Fig.9(c) shows injected voltages (v_{ic} and v_{ia}) with SF, which is set in $1/4^{th}$ of a power cycle for the case. Fig. 9(d) and Fig.9(e) shows the duty cycles of the choppers in sag supporters-c and a, respectively.

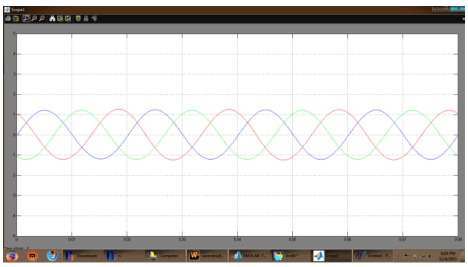

Fig.9 (a) Phase voltage at the PCC with sag

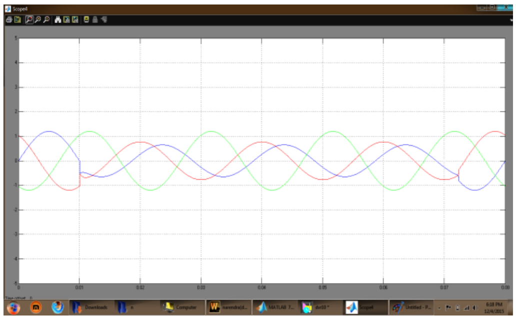

Fig.9 (b) Load voltage at the PCC.

It shows compensated voltages at the PCC, and it can be observed that the phase- voltage is compensated to the pre-sag condition, eliminating the 29 phase jump.

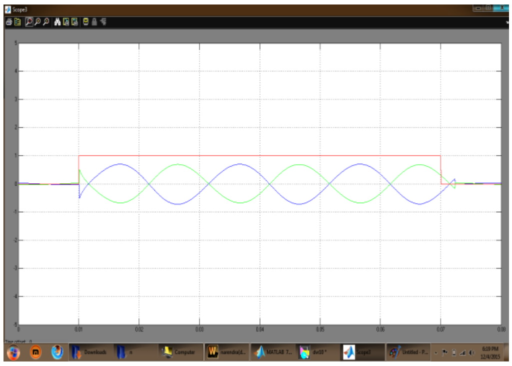

Fig.9 (c) Injected voltages with the SF

The figure shows injected voltages (v_{ic} and v_{ia}) with SF, which is set in $1/4^{th}$ of a power cycle for the case.

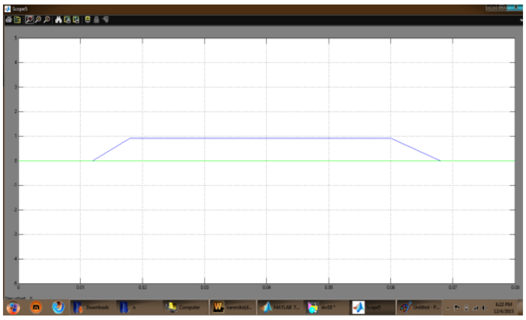

Fig.9 (d) The duty cycle of voltages in phase-c Sag supporter.

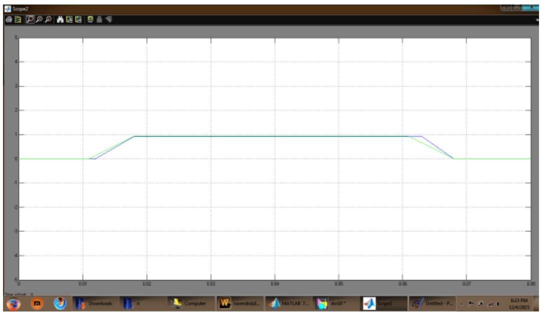

Fig.9 (e) The duty cycle of choppers in phase-a sag supporter

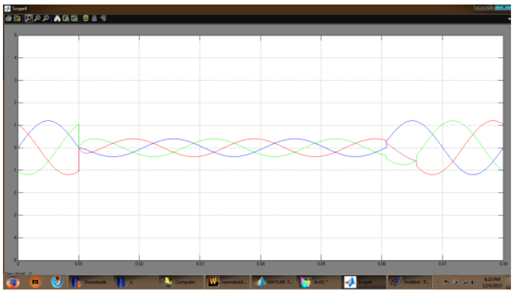

Fig.10 (a) Phase voltage at the PCC with sag

Symmetrical sag exceeding the pre-sag compensation limit is considered in Fig.10 (a) with 50% sag magnitude and 60^0 phase jump.

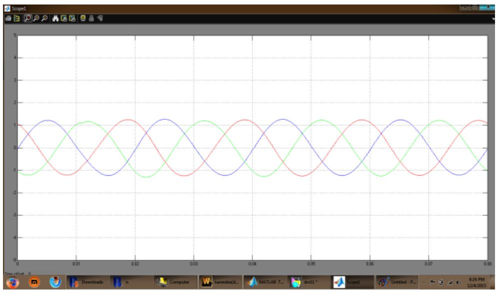

Fig.10 (b) Load voltage at the PCC

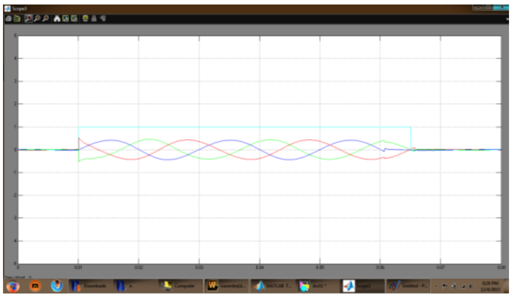

Fig.10 (c) Injected voltages with the SF

It shows the compensated voltages at the PCC, injected voltages, and the duty cycles of the choppers, respectively.

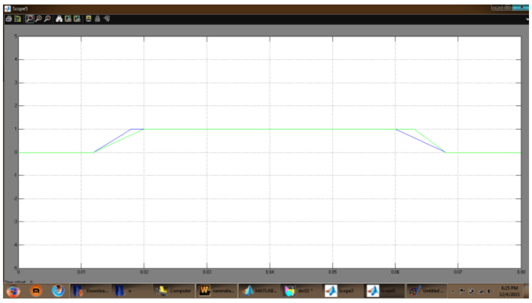

Fig.10 (d) The duty cycle of choppers in all sag supporters

Though sag duration of 2.5 cycles is compensated in the simulations from before; the compensation can be for a longer duration too.

V. CONCLUSION

A control scheme based on the characterization of voltage sag is proposed. It is tested on inter phase ac–ac converter topology and it is found that the scheme besides compensation gives insight on the limits on compensation imposed by various sag types. Therefore, it aids in the flexible compensation by switching between pre-sag and in-phase compensation. The scheme provides 100% compensation for type sag, and for all other types, compensation up to 50% sag magnitude with phase jumps ranging from 60 to 60 for inter phase ac–ac topology. The algorithm takes, at most, half a cycle to compensate and it works in the presence of harmonics and unbalance, since the Fourier transform is employed to extract the fundamental component.

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