Analysis of Dynamic Voltage Restorer with Ultra Capacitor for Power Quality Improvement

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Abstract— Power quality is one of the most important issues in present system. Power Quality problems like voltage sag, swell and harmonics are major concern of industrial and commercial electrical consumer. This is due to large number of sophisticated equipments, simple operation and variable switching electronics equipment such as computers, adjustable speed drives, programmable logic controllers and so forth. This equipment often requires high power supplies with high quality. Some devices are sensitive to the load voltage disturbances if these take up to several periods the circuit does not work. Various solutions are presented for this problem. One of the most cost effective methods is the use of Dynamic Voltage Restorer. The efficiency of the DVR depends upon the control techniques involved in switching the inverter. In this paper Ultra-capacitor is equipped with DVR as a energy storage as it has high energy density and it provides excessive power in short interval of time. U-cap is connected in a system through Bi-directional dc-dc converter at the dc link. PLL is used to generate unit sinusoidal wave in phase with main voltage. The load voltage and source voltage is used to produce the PWM pulses for VSI. The performance of the proposed model and achievement of desired compensation are confirmed by the results of the simulation using MATLAB/Simulink.

Index Terms— *Power quality, DVR, Voltage sag, Ultra capacitor, Bi-directional dc-dc converter, SRF control.*

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I. INTRODUCTION

The modern world is dealing with the quality of power deterioration. Power Quality is an issue that is becoming increasingly important to electricity consumers at all levels. The characteristic of power quality enables the power supply to work properly. Power quality refers to maintain a near sinusoidal power distribution bus voltage at the rated magnitude and frequency. Voltage magnitude, waveform, and frequency are the major factors that dictate the quality of power supply. Use of extensive nonlinear power electronics loads is one of the major reasons of deteriorating the quality of power supply. Faults at either the transmission or distribution level may also cause transient voltage sag or swell in the entire system. Also under heavy load conditions, a significant voltage drop may occur in the system. Such voltage variations are not desirable for sensitive loads. Voltage sags are a common power quality problem. Despite being a short duration (10ms to 1s) a small reduction in the system voltage can cause serious consequences. The definition of voltage sags is often set based on two parameters: Magnitude/depth and Duration of voltage sags. However, these parameters are interpreted differently by various sources.

II. POWER QUALITY ISSUES

While power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electroni9c devises makes them more susceptible to the quality of power supply. For some sensitive devises, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spikes can damage valuable components. Power quality problems encompasses a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortions, impulse transient, and interruptions.

1. **Voltage dip:** A voltage dip is used to refer to short-term-reduction in voltage of less than half a second.
2. **Voltage sag:** Voltage sag can occur at any instant of time. It is a decrease to between 0.1 p.u. to 0.9 p.u in rms voltage and current at power frequency for a duration lasting from half cycle to one minute.
3. **Voltage swell:** Voltage swell is defined as an increase in rms voltage or current at the power frequency for duration from 0.5 cycle to 1 min.
4. **Voltage Spikes, impulses or Surges**: These ar4e terms used to describe abrupt, very brief increase in voltage value.
5. **Voltage Transients:** They are temporary, undesirable voltages that appear on the power supply line and are momentary in nature. Transients are high over-voltage disturbances (up to 20 KV) that last for a very short time.
6. **Harmonics:** The fundamental frequency of the ac electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonics frequencies can be

even or odd multiples of the sinusoidal fundamental frequency.

7. **Flickers:** Flickers are visual irritation and introduction of many harmonics components in the supply power and their associated ill effects.

III. DISTRIBUTION SYSTEM

The present scenario of distribution system in India can be categorized in three types- High voltage distribution system, Medium voltage distribution system and Low voltage distribution system. Each type of distribution system encounters different levels of power quality problems. The fault occurring in the transmission system is of two different types – symmetrical as well as asymmetrical faults. Under balanced operation the system impedance in each phase are identical and the three phase voltage and currents throughout the system are completely balanced. Thus a balanced symmetrical fault i.e. line-line-line-ground (L-L-L-G) fault results in a balanced voltage and currents in all the three phase. Unbalanced system operation can result in an otherwise balanced system due to unsymmetrical faults, e.g. line-to-ground fault (L-G), Line to line fault (L-L), Line-line-ground (L-L-G). These faults are in fact of more common occurrence than the symmetrical three phase faults.

The distribution systems differ from transmission systems in several ways. Distribution system has two components (i) Feeder, (ii) Distributor. A feeder in the distribution network is a circuit carrying power from a main substation to a secondary substation such that the current loading is the same all along its length therefore the main criterion. The distribution system may be subdivided mainly into primary distribution, distribution transformer, secondary distribution and consumer's service connections. The proper voltage, locations sizes and protective equipment must be chosen for the various components of the distribution system.

IV. VOLTAGE SAG

A sag is a reduction to between 0.1pu to 0.9 p.u in RMS voltage or current at a given power frequency for the duration of 0.5 cycles to 1 minutes time [1]. Sags are usually caused by system faults, and are also often the result of energization of heavy loads with heavy start up currents. Voltage sags are characterized by RMS voltage variations outside the normal operating voltage. A common cause of sags includes starting large loads (such as one might see when they first start up a large air conditioning unit) and remote fault clearing performed by utility equipment. Similarly, the starting of large motors inside an industrial facility can result in significant voltage drop (sag) [9].A motor can draw six times its normal running current or more, while starting, creating a large and sudden electrical load such as this will likely cause a significant voltage drop to the rest of the circuit it resides on.

V. DYNAMIC VOLTAGE RESTORER

The DVR is a powerful controller that is commonly used for voltage sags and swells mitigation at the point of connection. The DVR employs the same blocks as the D-STATCOM, but in this application the coupling transformer is connected in series with the ac system, as illustrated in fig shown below.

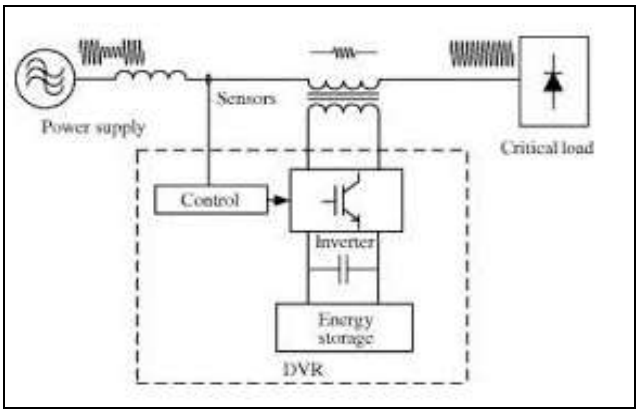

FIG.1 Block diagram of DVR

The main functions of DVR are:

i) Reactive power compensation
ii) Voltage regulation
iii) Compensation for voltage sag and swell
iv) Unbalanced voltage compensation (for 3 phase system)

The VSC generates a three phase ac output voltage which is controllable in phase and magnitude. Dynamic compensating signals are determine based on the difference between desired and actual values. These voltages are injected into the ac distribution system through transformer connected in series with line in order to maintain the load voltage at the desired voltage reference.

VI. DYNAMIC VOLTAGE RESTORER WITH ULTRA-CAPACITOR

The DVR is the most cost effective solution for protecting sensitive loads from voltage related PQ issues. Ultra Capacitor has ideal characteristics such as High power density and low energy density. It provides excessive power in short interval of time. Bidirectional DC-DC converter is required as an interface between the UCAP and DC link. Bidirectional DC-DC converter is required as an interface between the UCAP and DC link [2]. SRF control theory is used to control the DVR. PLL is used to generate unit sinusoidal wave in phase with main voltage. The load voltage and source voltage is used to produce the PWM pulses for VSI.

There are numerous reasons why DVR is preferred over other devices:

1. Although, SVC predominates the DVR but the latter is still preferred because the SVC has no ability to control active power flow.
2. DVR is less expensive compared to the UPS
3. UPS also needs high level of maintenance because it has problem of battery leak and have to be replace as often as five years.
4. DVR is smaller in size and costs less compared to DSATCOM
5. DVR is power efficient device compared to the UPS.

VII. SYSTEM ARCHITECTURE

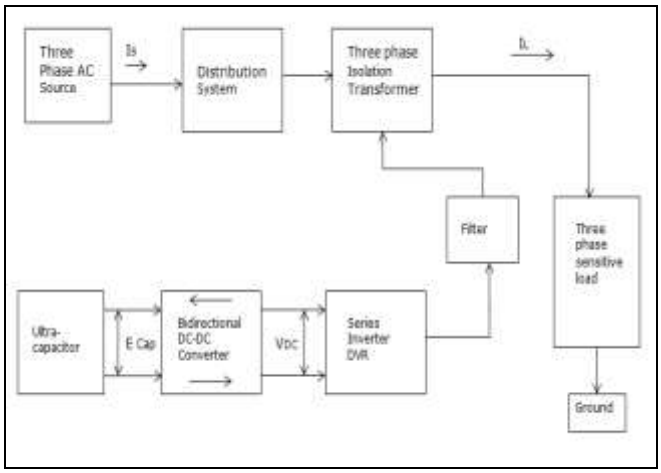

Fig. 2 Block diagram of DVR with Ultra-Capacitor

A. EQUIPMENT DESCRIPTION

- **Transformer less Dynamic Voltage Restorer :** Inject voltage of required magnitude and frequency so that it can restore the load side voltage to desired amplitude & waveform even when the source voltage is unbalanced or distorted.
- **Three phase VSI:** It is essentially a device that used to produce required voltage for compensation from fixed voltage. For DC link, energy storage VSI is used.
- **LC Filter:** It is used to remove harmonics distortion from the output of VSI.
- **DC-DC Converter (Buck-Boost Converter) :** Bidirectional DC-DC converter is required as an interface between the UCAP and DC link.
- **Ultra-Capacitor:** Ultra Capacitor has ideal characteristics such as High power density and low energy density. It provides excessive power in short interval of time.
- **SRF Control Theory:** is used to control the DVR. PLL is used to generate unit sinusoidal wave in phase with main voltage. The load voltage and source voltage is used to produce the PWM pulses for VSI.

B. WORKING OF PROPOSED MODEL

The basic principle of the dynamic voltage restorer is to inject a voltage of required magnitude and frequency, so that it can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. In normal conditions, the dynamic voltage restorer operates in stand-by mode. However, during disturbances, nominal system voltage will be compared to the voltage variation. This is to get the differential voltage that should be injected by the DVR in order to maintain supply voltage to the load within limits.

The amplitude and phase angle of the injected voltages are variable, thereby allowing control of the real and reactive power exchange between the dynamic voltage restorer and the distribution system. The DC input terminal of a DVR is connected to an energy storage device i.e U-Cap of appropriate capacity through Bidirectional DC-DC converter. The SRF control theory is used to control DVR. The reference voltage and source voltage is used to produce the PWM pulses for VSI. The real power exchanged at the DVR output AC terminals is provided by the DVR input DC terminal by an external energy source or energy storage system.

VIII. SIMULINK MODEL OF PROPOSED SYSTEM

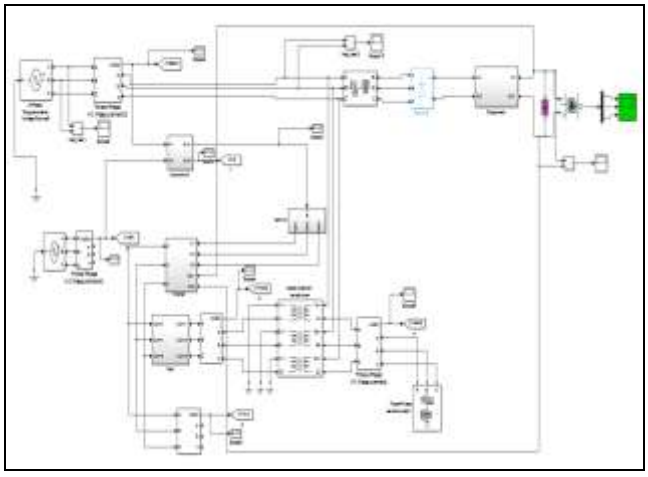

Fig. 3 Simulink Model of DVR with U-Cap

The Simulation model for three phase distribution system is shown in fig 3 and voltage sag is created for a time period of 0.2 to 0.8 s. The voltage sag can be mitigated efficiently by using DVR with U-Cap.

IX. SIMULATION RESULTS

The Simulation of Dynamic voltage restorer with ultra capacitor for mitigation of voltage sag is carried out in MATLAB/Simulink.

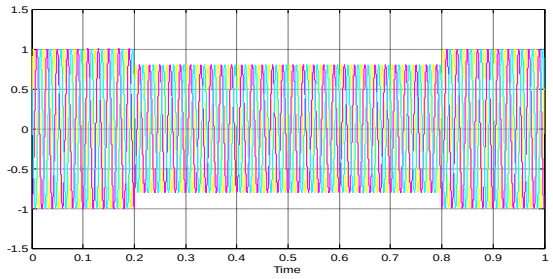

Fig. 4 Source Voltage with Sag

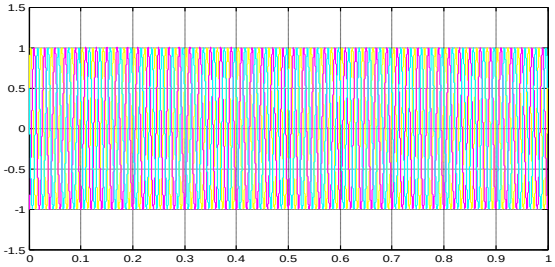

Fig.5 Reference Voltage

Fig. 6 Injected Voltages by DVR

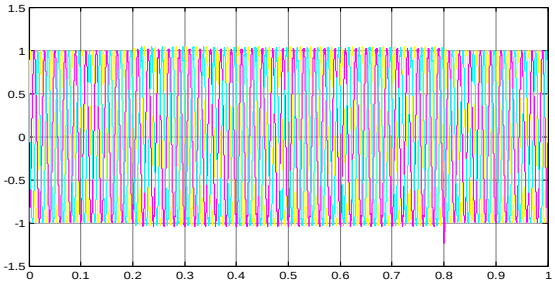

Fig.7 Load Voltage with DVR

CONCLUSION

A MATLAB/SIMULINK model for dynamic voltage restorer with ultra capacitor was developed and presented in this paper. In this paper a new approach for power quality improvement is proposed. As the U-cap is rechargeable energy storage and having large energy storage capability, it is used with DVR to improve its voltage restoring capability. A bi-directional dc-dc converter is proposed to charge the U-cap. The proposed system of DVR with U-cap provides cheap and reliable solution to improve power quality i.e to compensate voltage sag compensation. The simulation results are obtained. The U-cap can be employed in future in distribution system to improve voltage profile to prevent sensitive load from disturbances.

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