Voltage sag/swell Compensation using PV-Cell Based Dynamic Voltage Restorer

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***Abstract*— The Dynamic Voltage Restorer (DVR) is a commercially accessible, popular device to eliminate voltage sags & swells in the distribution lines. The basic function of DVR is to inject the voltage difference (difference b/w pre-sag & sag voltage) to the power line and maintains the pre-sag voltage condition in the load side. In this paper the PV cell based DVR (Dynamic Voltage Restorer), instead of a DC storage system is evaluated. A new topology with PV cell based DVR is presented which comprises of low & high boost converter, Pulse Width Modulated voltage source inverter, series injection transformer & semiconductor switch. Simulation results are carried out in MATLAB/SIMULINK model.**

***Keywords*—DVR (Dynamic Voltage Restorer), voltage sag, voltage swell, photo-voltaic cell.**

I. Introduction

DYNAMICVoltageRestorer (DVR) can provide the most cost effective solution to mitigate voltage sags, swells and outages by establishing the proper voltage quality level that is required by sensitive loads. Problems facing industries and residential regarding the power qualities are mainly due to voltage sag, short duration voltages wells and long duration power interruptions. Voltage sag is a sudden reduction of utility supply voltage which may vary from 90% to 10% of its nominal value. On the other hand, voltage swell is a sudden rise of supply voltage which may vary from 110% to 180% of its nominal value. The voltage sags and swells often caused by starting of large induction motors, energizing a large capacitor bank and faults such as single line tog round fault, three phase to ground fault, double line to ground fault on the power distribution system [1-2]. Voltage sag and swell in power systems produce an important effect on the behavior of sensitive loads. Tripping of power adjustable speed drives (ASD) is one of the greatest voltage sag problems, causing critical loads to stop with the resultant interruption of the manufacturing process several times a year. The resulting loss of time and production, or damaged equipment may cause significant economical losses. To solve the above problems a new method is proposed in this paper.

In general, the voltage injection from DVR compensates the voltage sag, swell and outage. However, it needs a high capacity DC storage system. In the proposed DVR design A PV system with low and high power DC–DC boost converters are incorporated to function as a high capacity DC voltage source [4].

Advantages of photo-voltaic cell are:

- Solar power is pollution free.
- Reduced production end wastes and emissions.
- PV installations can operate for many years with little maintenance, so after the initial capital cost of building of any solar power plant, operating costs are extremely low compared to existing power technologies [3].

Disadvantages of photo- voltage cell are:

- Photo-voltage cells are costly.
- Solar electricity is more expensive than other forms of small
- Scale alternative energy production.
- Solar electricity is not produced at night and is much reduced in cloudy conditions. Therefore, a storage system is required.
- Solar cells produce DC which must be converted to AC.

This paper presents a simulation model of a PV based dynamic voltage restorer capable of handling 10% voltage sags, 190% of voltages wells and outages on a low voltage distribution system.

II. Power Quality Problems

The power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices make them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, System crashes and equipment failure etc [5]. A power voltage spike can damage valuable components. Power quality problems encompass a wide range of disturbances such as voltage sags, swells, flickers, harmonic distortion, impulse transients, and interruptions.

A. Sources of Power Quality Problems:

When a large induction motor starts it leads to high current drop which ultimately leads to voltage sag.

- A large capacitive loads or open circuit causes to voltage swell.

B. Causes of voltage sags and swells:

- Rural location remote from power source.
- Unbalanced load on three phase system.
- Switching of heavy loads.
- Long distance from a distribution transformer with interposed loads.
- Unreliable grid systems.
- Equipments not suitable for local supply.

C. Solutions to Power Quality Problems:

There are two approaches to mitigate power quality problems. The solution to the power quality can be done from customer side or from utility side; first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion [6]. The other solution is to install line conditioning systems that suppress or counteract the power system disturbances. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Some of the effective and economic measures can be identified as following [5]:

1. Lightning and surge Arresters
2. Thyristor Based Static Switches
3. Energy Storage Systems
4. Electronic tap changing transformer
5. Harmonic filter

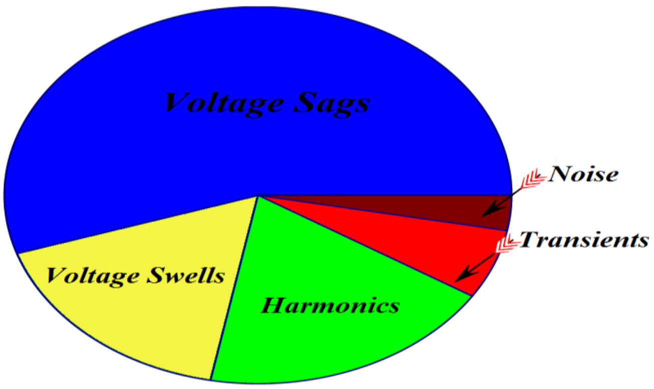

Fig.1 Percentage of Power Quality Problems

III. DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. Its main function is to monitor the load voltage waveform constantly by injecting missing voltage in case of sag. To obtain above function a reference voltage waveform has to be created which is similar in magnitude and phase angle to that of supply voltage. During any abnormality of voltage waveform it can be detected by comparing the reference and the actual waveform of the voltage [7,8].

The DVR usually consists of an injection transformer, which is connected in series with the distribution line, a voltage source PWM Converter Bridge which is connected to the secondary of the injection transformer and an energy storage device connected at the dc-link of the converter bridge. A typical schematic of the DVR is shown in Fig.2 [8]. The converter bridge output is filtered before being fed to the injection transformer in order to nullify switching frequency harmonics. The series injected voltage with a variable amplitude, phase and frequency of the DVR is synthesized by modulating pulse widths of the converter bridge switches. The injection of an appropriate series voltage component in the face of a voltage disturbance requires a certain amount of real and reactive power supply by the DVR.The real and reactive power supplied by the DVR however depends on the type of voltage disturbance experienced as well as the direction of the DVR injected voltage component with reference to pre-sag voltage.

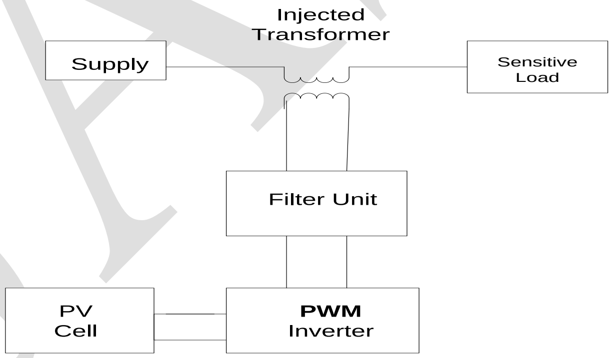

Fig. 2 Dynamic Voltage Restorer

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IV. OPERATING MODES OF DVR

The Dynamic Voltage Restorer is categorized into three operation mode- Protection mode, Standby mode & injection mode.

Mode A: Protection Mode- Due to short-circuit on the load or large inrush currents, the DVR is protected from the over current in the load side. If the over current on the load side exceeds a permissible limit, the DVR will be isolated from the systems by using the bypass switches (S2 & S3 will open) and supplying another path for current (S1 will be closed). The bypass switches remove the DVR from the system by supplying another path for current as shown in figure.

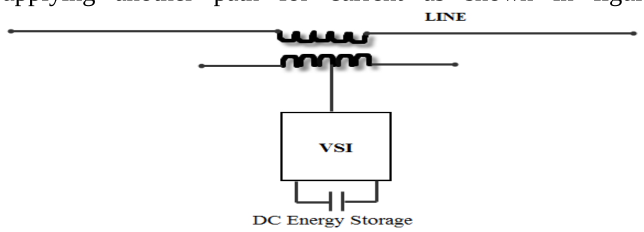


Fig. 3 Protection mode of DVR

Mode B: Standby Mode – In this mode the voltage injected has zero magnitude (V_{DVR}= 0), the booster's transformer low voltage winding is shorted through the converter. The DVR will be most of the time in this mode. No switching semiconductors occur in this mode of operation. Therefore only the comparatively low conduction losses of the semiconductors in this current loop contribute to the losses.

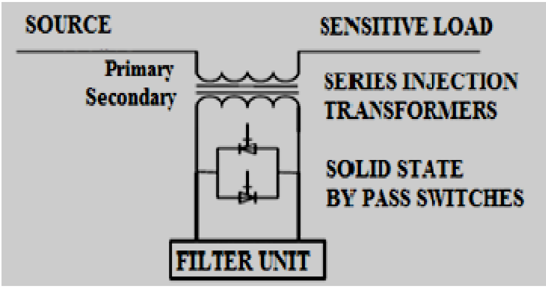


Fig. 4 Standby mode of DVR

Mode C: Injection/Boost Mode- The DVR goes into injection mode as soon as the sag is detected. The DVR injects a required voltage of appropriate magnitude and phase to restore the pre-fault load bus voltage ($V_{DVR>}$0). Three single phase ac voltages are injected in series with required magnitude, phase & wave shape for compensation. The possibility of voltage sag compensation is determined from the type of voltage sags, load condition and power rating of DVR. The DVR should ensure the unchanged load voltage with minimum energy dissipation for injection due to the high cost of capacitor.

V. Photo Voltaic Cell

PV cell is very similar to that of the classical diode with a pn-junction. In fig 5 when the junction absorbs light, the energy of absorbed photons is transferred to the electron–proton system of the material, creating charge carriers that are separated at the junction. The charge carriers may be electron-ion pairs in a liquid electrolyte or electron–hole pairs in a solid Semiconducting material. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit. The square of the current multiplied by the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the Cell and dissipates into the surroundings.

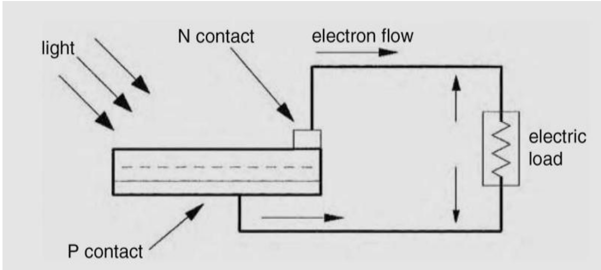


Fig. 5PV effect converts the photon energy into voltage

The solar cell described in the preceding subsection is the basic building block of the PV power system shown in fig 6. Typically, it is a few square inches in size and produces about 1 W of power. To obtain high power, numerous such cells are connected in series and parallel circuits on a panel (module) area of several square feet shown in fig 7. The solar array or panel is defined as a group of several modules electrically connected in a series– parallel combination to generate the required current and Voltage shown in fig 8

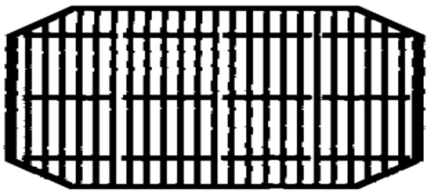


Fig. 6 PV Cell

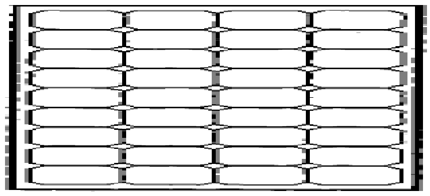


Fig. 7 PV Module

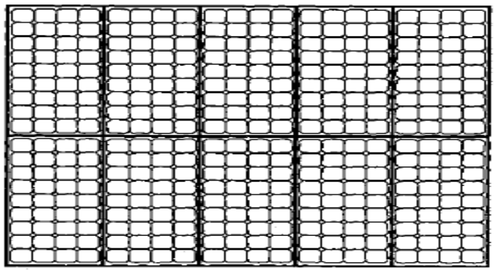


Fig. 8 PV Array

The PV model is developed using basic equations of photo voltaic cells including the effects of temperature changes and solar irradiation. The PV cell output voltage is a function of the photo current that mainly determined by load current depending on the solar irradiation level during the operation. The solar cell output voltage is given by

$$Vc = \frac{AKTc}{e}\ln\left(\frac{Iph + Io - Ic}{Io}\right) - RsIc$$

Where *Vc* is cell output voltage in volts. *A* is fitting factor. *e* is electron charge (1.602×10^{-19}c). *Iph* is Photo current (10 A). *Io* is reverse saturation current of diode (0.0002 A). *K*is Boltzmann constant (1.38×10^{-22} J/°k). *Ic* is cell output current in A. *Rs* is solar cell internal resistance (0.001 X). Tc is operating temperature of the reference cell (40 °C).

When the irradiation and ambient temperature change, the solar cell operating temperature also changes, resulting in a new output voltage and a new photo current. The solar cell operating temperature varies as a function of solar irradiation level and ambient temperature.

VI. SIMULATION& RESULTS

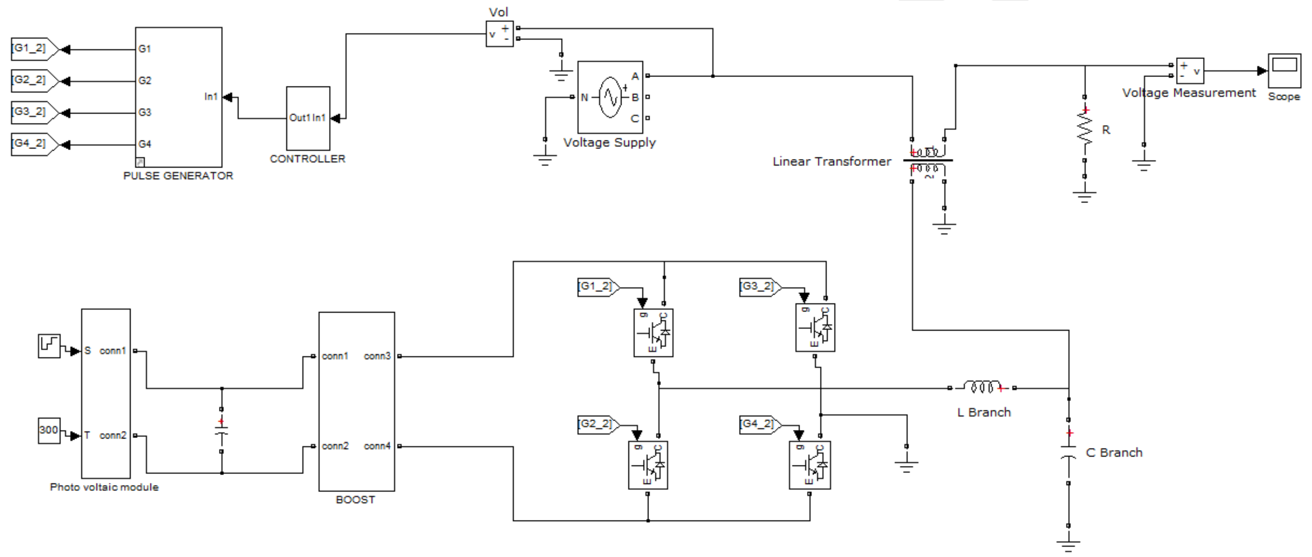


Fig. 9 Simulation Model of PV Based DVR

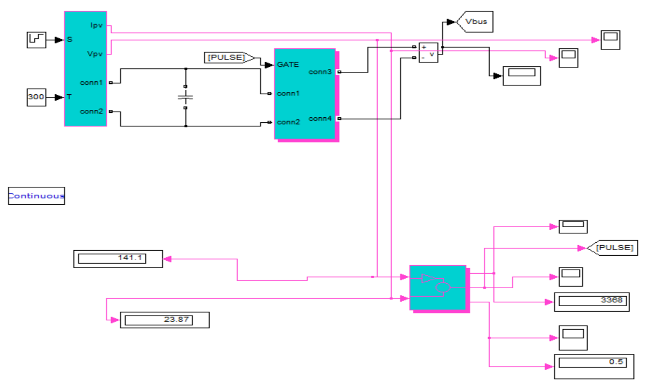


Fig. 10 Matlab/Simulink model of solar array with boost-converter

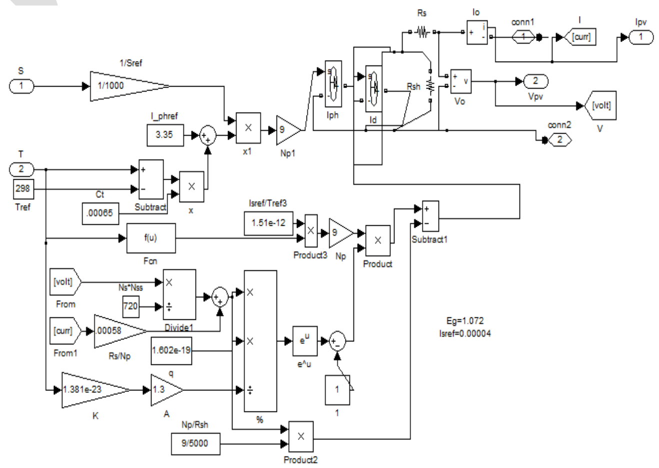


Fig. 11 Matlab/Simulink model of MPPT

The simulation model of PV based DVR is shown in the figure 9 for single phase distribution system. The input voltage supply is 200 Volt phase to phase. The DVR model is simulated is simulated in MATLAB Simulink to compensate voltage sag and swell. The total simulation time period is 0.3 seconds. DVR injects the voltage to the system only when supply voltage differs from nominal value. Battery is used to store the PV array energy and during night this battery is used as an energy source .A programmable voltage source has been used to generate voltage sag and swell. The voltage sag and swell occurs during the period 0.1 s to 0.2 s. The voltage sag and swell occurs at source point at 20 % with respect to reference voltage. The supply voltage, injected voltage and the load voltage (after removing sag and swell voltage) is shown in the figure. Figure 12 and 14 shows voltage of affected load before and after the mitigation of sag by proposed DVR model. Similarly figure 15 and 17 shows voltage of affected load, before and after the mitigation of swell by proposed DVR model.

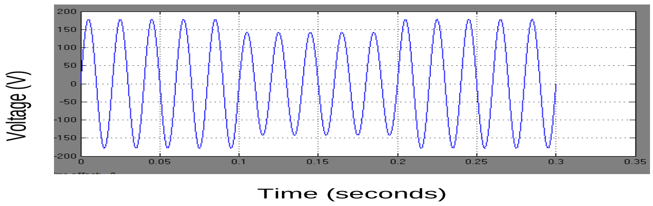


Fig. 12Supply Voltage (sag)

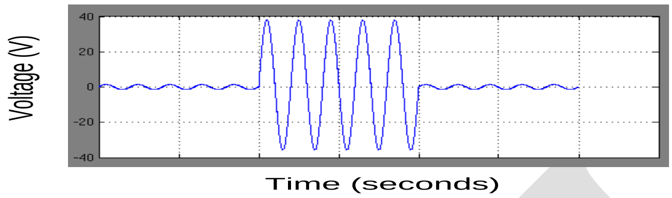


Fig.13 Injected Voltage

Fig. 17 Compensated Voltage

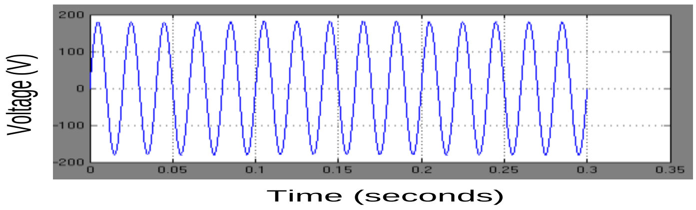
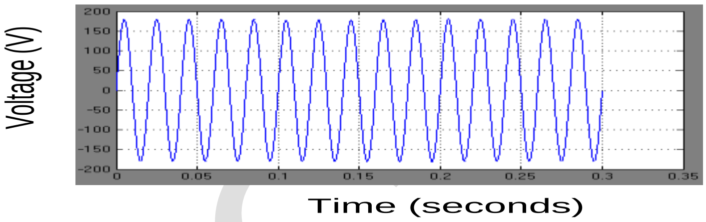


Fig. 14 Compensated Voltage



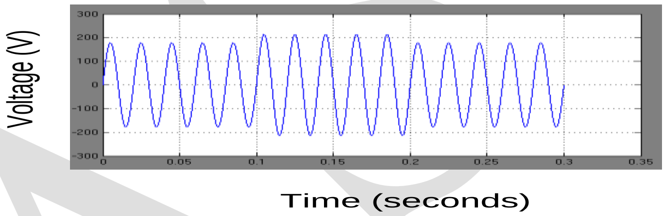


Fig. 15 Supply Voltage (swell)

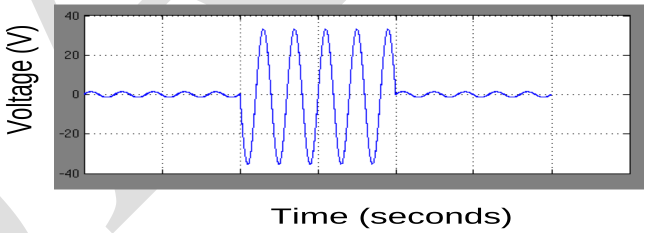


Fig. 16 Injected Voltages

VII. CONCLUSIONS

In this paper, voltage sag/swell compensation using PV cell based Dynamic Voltage Restorer is implemented. The whole paper describes about the voltage compensation for sag and swells in DVR system. The proposed DVR utilizes the energy drawn from the PV array and the utility source during normal sag, swell and outage. The simulation result shows that the PV based DVR performance is satisfactory in mitigating the voltage variations by energy stored in batteries which is converted to an adjustable single phase ac voltage for mitigation of load voltage sag and swell.

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