Le 3ème Séminaire International sur les Energies Nouvelles et Renouvelables
The 3nd International Seminar on New and Renewable Energies
Unité de Recherche Appliquée en Energies Renouvelables, Ghardaïa – Algérie 13 et 14 Octobre 2014

Photovoltaic array based dynamic voltage restorer connected to grid system

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***Abstract*— In this work, a photovoltaic based dynamic voltage restorer connected to grid system is proposed to feed linear and nonlinear loads and to handle deep sags, swells voltage caused by any perturbation and the excess of the energy is injected into the mains. PV based DVR system is comprised of PV array system with PWM voltage source inverter, series injection transformer and semiconductor switches which is simulated using MATLAB / SIMULINK environment. The results Simulations results proved the ability and the efficiency of the proposed system in mitigation the voltage sag, swell and power quality enhancement in power grid network.**

***Keywords*— Photovoltaic (PV), Dynamic voltage restorer (DVR), Voltage sag, Voltage swell, Power quality**

I. Introduction

The increment of voltage-sensitive load equipment has made industrial processes much more vulnerable to degradation in the quality of power supply. Voltage deviations, often in the form of voltage sags, can cause severe process disruptions and result in substantial economic loss. Therefore, cost-effective solutions, which can help such sensitive loads, ride through momentary power supply disturbances, have attracted much research attention. Dynamic voltage restorer (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 voltage swells and long duration power interruptions [1].

The system of Photovoltaic power generation is a principal efficient technique of using solar energy, which can convert sunlight radiation directly into electricity through the photovoltaic effect, and has broad prospects for development with a series of advantages such as clean and pollution-free, noise-free, and renewable [2].

Through this work, the coupling system between the photovoltaic array and the dynamic voltage restorer is used to inject electricity from solar power to the grid under fixed photovoltaic power condition and operate as flexible fact to eliminate perturbation problems as sag and swell voltage in order to improve power quality.

A schematic diagram of the DVR incorporated into a distribution network is shown in Fig.1. In the figure, V s is the source voltage, V 1 is the incoming supply voltage before compensation, V dvr is the series injected voltage of the DVR, and I is the line current[3,4]. The restorer typically consist of an injection transformer, the secondary winding of which connected in series with the distribution line, a voltage-sourced PWM inverter bridge[5] connected to the primary of the injection transformer and an energy storage device connected at the dc-link of the inverter bridge. The inverter bridge output is filtered in order to mitigate the switching frequency harmonics generated in the inverter. The injection of an appropriate V_{dvr} in the face of an up-stream voltage disturbance requires a certain amount of real and reactive power supply from the DVR. It is quite usual for the real power requirement of the DVR to be provided by the energy storage device in the form of a battery, a capacitor bank, or a flywheel.

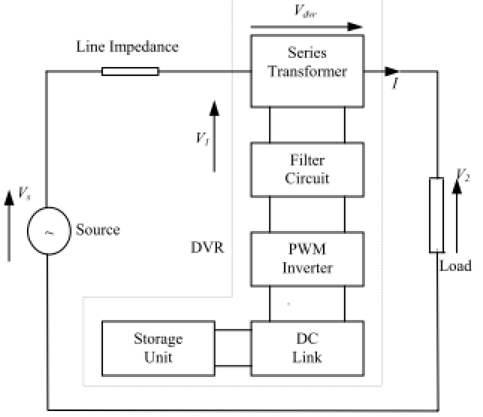

Fig. 1: General structure of power system compensated by dynamic voltage restorer

II. PHOTOVALTAIC MODELING SYSTEM

Electrical energy needs are still increasing over these last years but production constraints like pollution [6] and global warming lead to development of renewable energy sources, particularly photovoltaic energy. Due to very limited conversion efficiency, it is necessary to optimize all the conversion chain and specifically DC-DC converters by use to maximum power point tracking strategies. Photovoltaic generators consist usually of several modules interconnected in series and parallel for a given operating voltage an output power.

Photovoltaic generators modeling can then be deduced from those of solar cells; many studies have been already proposed using one diode or more precise two diodes models. In this paper we use the conventional single diode model presented in (figure 2).

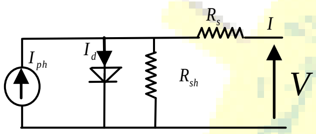

Figure 2: Conventional single diode model.

I_{ph} is the photo generated current related to the illumination level, Id the diode current, R_{sh} and Rs are respectively the shunt and series resistances. Based on (figure 3), the output voltage and current dependence can be written in the form:

$$I = I_{ph} - I_0\left(e^{\frac{V+R_sI}{V_t}} - 1\right) - \frac{V+R_sI}{R_{sh}} \quad (1)$$

- Vt is the thermal voltage written as:

$V_t = (A*K*T)/q$ Where A is the ideality factor, K The Boltzmann constant T the temperature of the cell and q the elementary charge.

- I0 is the dark current. Compared to the measured photocurrent Iph_ref at standard tests conditions (STC: Gref =1000W/m², Tref =25°C), the photocurrent at another operating conditions can be expressed as:

$$I_{ph} = \frac{G}{G_{REF}}\left[I_{PH,REF} + \alpha(T - T_{REF})\right] \quad (2)$$

G is the solar irradiance, α is the short circuit current temperature coefficient. Iph_ref can be taken to be the short current at STC (Icc_ref), Icc_ref and α are generally given by solar module manufacturer [11]. In the case where the cell temperature Tamb not is determined directly by a temperature sensor, it can be deduced from the following relation:

$$T = T_{amb} + \left[\frac{N_{oct} - 20}{800}\right]G \quad (3)$$

T_{amb} is the ambient temperature, N_{oct} is the normal operating cell temperature given in most cases by the manufacturer. For the dark current I_0 and we can write:

$$I_0 = I_{0,REF}\left(\frac{T}{T_{REF}}\right)^{3/A}\exp\left[\frac{qE_g}{AK}\left(\frac{1}{T_{REF}} - \frac{1}{T}\right)\right] \quad (4)$$

I0,ref is the dark current at STC and Eg is the forbidden band energy. In the single diode model, we assumed Rsh to be infinite; the series resistance can be derived in the form [6]:

$$R_s = -\frac{dV}{dI_{(VOC)}} - \frac{AKT/q}{I_0\exp\left(\frac{qV_{oc}}{AKT}\right)} \quad (5)$$

Equation (1) can be solved by numerical method like Newton Raphsons.

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)} \quad (6)$$

The VSI is controlled in such a way that it can be used to inject sinusoidal voltage into the grid for energy extraction from the Photovoltaic system during linear or non-linear load conditions.

III. DYNAMIC VOLTAGE RESTORER (DVR)

Recently the demand for high power quality has increased significantly. The consequences of Industrial processes are classified into two; they are the presence of non-linear and unbalanced loads and high vulnerability to momentary deviations (voltage sags) in the distribution system’s voltage. The well-known custom power devices are D-STATCOM (Distribution side Static Synchronous Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner). They are available for protection of a critical load from disturbances [7]. Dynamic Voltage Restorer is thus a custom power device that is inserted between the power distribution system and the industrial load. Dynamic Voltage Restorer is a series connected device whose function is to generate three-phase voltages and to inject them in correct synchronism with the distribution system voltages to maintain the load voltages at their nominal values.

A Dynamic Voltage Restorer (DVR) is basically a controlled voltage source converter that is connected in series with the network. It injects a voltage on the system to compensate any disturbance affecting the load voltage. The compensation capacity depends on maximum voltage injection ability and real power supplied by the DVR. Energy storage devices like batteries and SMES are used to provide the real power to load when voltage sag occurs [8]. If a fault occurs on any feeder, DVR inserts series voltage and compensates load voltage to pre-fault voltage. A basic block structure for open loop DVR is shown in Figure.1

III.1 CONTROL SCHEME

The aim of the control system is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system of the general configuration typically consists of a voltage correction method which determines the reference voltage that should be injected by DVR and the VSI control which is in this work consists of PWM with PI controller. The controller input is an error signal obtained from the reference voltage and the value of the injected voltage (Figure. 3). Such error is processed by a PI controller then the output is provided to the PWM signal generator that controls the DVR inverter to generate the required injected voltage.

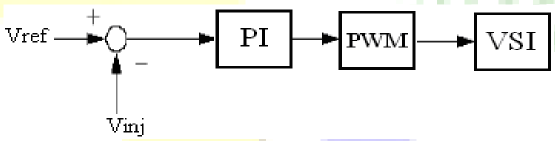

Figure.3. Conventional PI controller

III.2 OPERATING PRINCIPLE OF DVR

The basic function of the DVR is to inject a dynamically controlled voltage Vinj generated by a forced commutated converter in series to the bus voltage by means of a voltage injection transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage VL. This means that any differential voltages caused by disturbances in the ac feeder will be compensated by an equivalent voltage. The DVR works independently of the type of fault or any event that happens in the system. For most practical cases, a more economical design can be achieved by only compensating the positive and negative sequence components of the voltage disturbance seen at the input of the DVR (because the zero sequence part of a disturbance will not pass through the step down transformer which has infinite impedance for this component) [9].

The DVR has two modes of operation which are: standby mode and boost mode. In standby mode (Vinj=0), the voltage injection transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation, because the individual inverter legs are triggered such as to establish a short-circuit path for the transformer connection [8]. The DVR will be most of the time in this mode. In boost mode (Vinj>0), the DVR is injecting a compensation voltage through the voltage injection transformer due to a detection of a supply voltage disturbance.

III.3 SYNCHRONOUS REFERENCE FRAM METHOD (SFR)

In order to generate the references voltages ($v^*_{ca}, v^*_{cb}, v^*_{cc}$), the synchronous reference frame (SRF) method is used, which is founded on the instantaneous values of the source voltage v_{sa}, v_{sb}, v_{sc}[10]. When a disturbance occurs (abnormal condition) and supply voltage deviates from nominal value, they are spotted by estimate the deference between the d-voltage of the supply and the d-reference value. The control algorithm produces a three phase reference voltage. This reference voltage is fed through a controller and then the switching signal is generated to switch the power switching devices of the VSI such that the DVR will indeed to produce the reference voltage required by the system. Finally, maintaining the load voltage at its reference value. This method can be used to compensate all type of voltage disturbances, voltage sag/swell, voltage unbalance and harmonic voltage; nevertheless only voltage sag/swell are studied in this paper.

The difference between the reference voltage and the injected voltage is applied to the VSI to produce the load rated voltage. During the normal operating condition (without sag or swell conditions) DVR operates in a low loss standby mode. During this condition the DVR is said to be in steady state. The strategy of voltage reference calculation used in this work is shown in Figure 4.

IV. SIMULATION RESULTS AND DISCUSSION

The proposed system using photovoltaic panels to supply dynamic voltage restorer with energy from solar power is able to mitigate sag and swell voltage caused by any electrical perturbation and also feeds the power system from the exceed energy. In order to confirm the validity of the concepts discussed previously a simulation using MATLAB / SIMULINK environment is done as it is shown in Figure 5. The parameters of the system are shown in table I

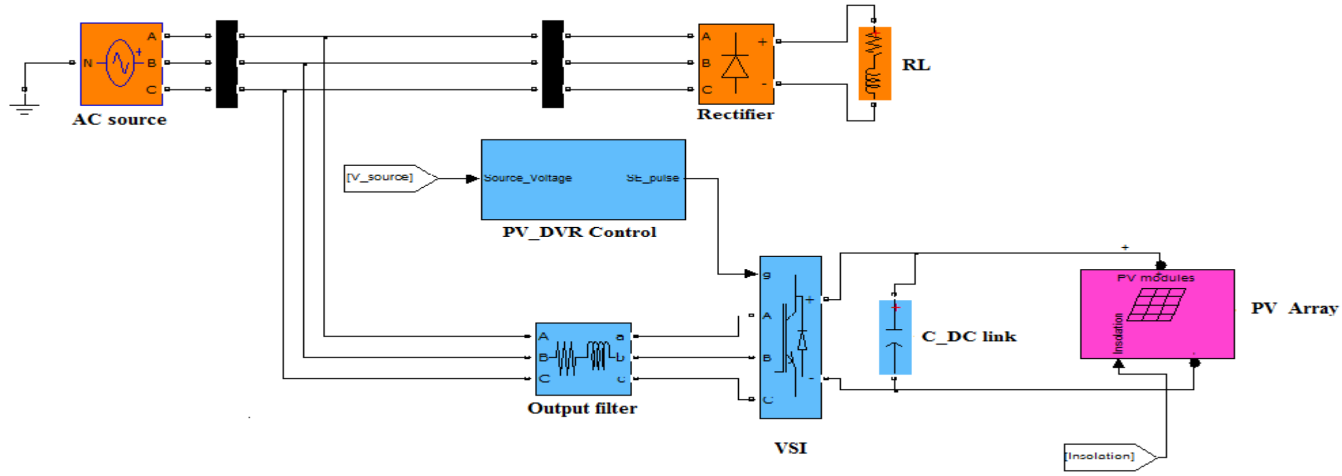

Fig. 5. MATLAB/SIMULINK model for the studied system configuration (PV_DVR and power system)

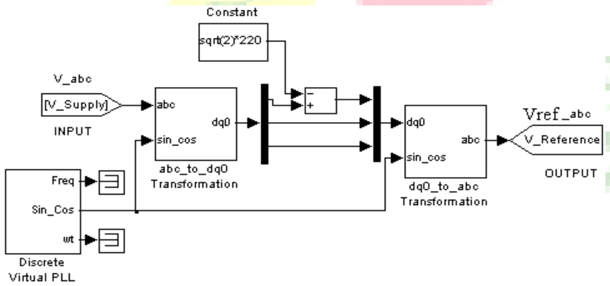

Figure.4. SIMULINK model of SRF method for voltage reference calculation

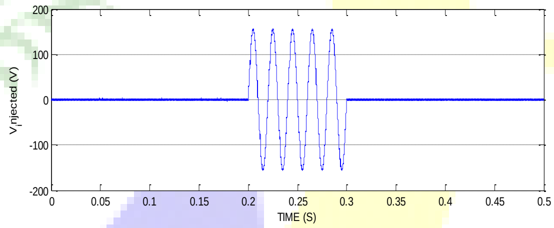

Fig7.DVR injected voltage

a) First case: Sag voltage

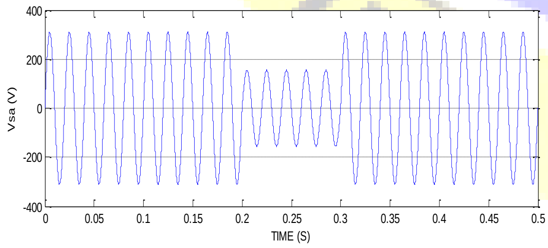

Fig6. Source voltage with 50 % voltage sag in phase A

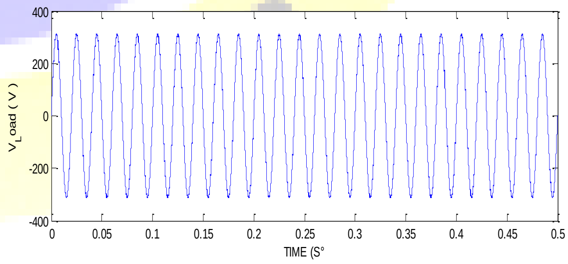

Fig8. Load voltage after mitigating voltage sag

TABLE I :
PARAMETERS OF THE PROPOSED PV_DVR SYSTEM

GRID	
Source Voltage V_s	220 V
Load Power P_L	150 kVA
Frequency f_s	50 Hz
PHOTOVOLTAIC SYSTEM	
Nominal Power P_T	24 kwc
Voltage U_{co}	850 V
DVR	
Switching Frequency	5 kHz
Output Filter	1 mH
DC Link Capacitor	15 mF
Capacitor DC Voltage	2300 V
reference Voltage	PLL method
VSI control	PWM + PI

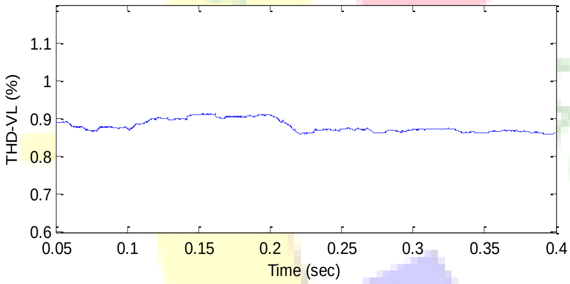

Fig9. Load side total harmonic distortion

b) Second case: Swell voltage

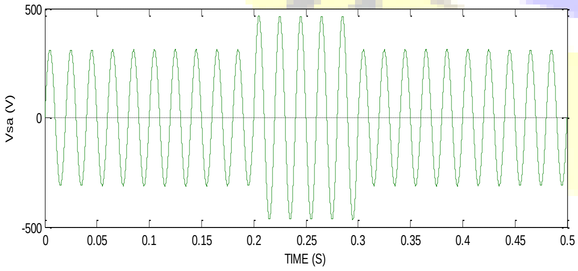

Fig10. Source voltages with 50 % voltage swell in phase A

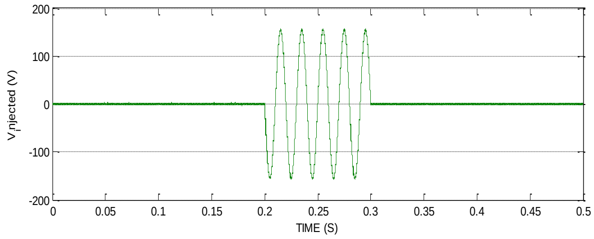

Fig11.DVR injected voltage

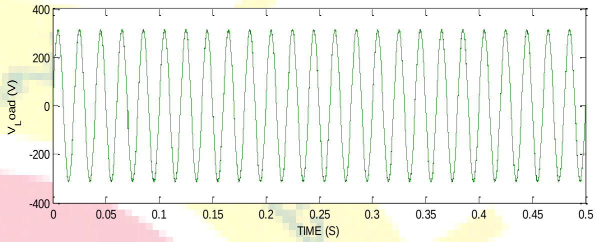

Fig12. Load voltage after mitigating voltage swell

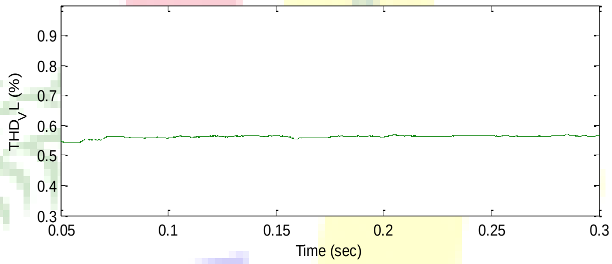

Fig13. Load side total harmonic distortion

TABLE II:
DYNAMIC VOLTAGE RESTORE SYSTEM WITHOUT PV

	Current (A) RMS value	**Active power (kw)**	**Reactive power (Kvar)**
Load	75.26	14.07	8.675
Source	75.26	14.07	8.675

TABLE III :
DYNAMIC VOLTAGE RESTORE SYSTEM WITH PV

	Current (A) RMS value	**Active power (kw)**	**Reactive power (Kvar)**
Load	75.26	14.07	8.675
PV_DVR	20.58	3.85	1.35
Source	54.65	10.22	7.325

Three-phase 50% voltage sag is simulated and for simplification the results of only one phase are shown. Sag and Swell of 50 % magnitude is generated at source side in phase A.

The simulation results of the proposed DVR with PV (figure5) are shown in the figures 6-13 for the two cases. PV cells are connected in series and parallel in order to produce appropriate voltage and current the DVR which is connected to the grid system, from 0.2 second to 0.3 second the photovoltaic power is increasing for battery charging, it means that the DVR energy stored is used in this time to correct the voltage perturbation. The used of PV makes the absorbed current from the source by the nonlinear load decreases Table II. At approximately 27 % power production of the photovoltaic system for the power needed by the nonlinear load and the current of the source decreases to from 75.26 to 54.65 A (RMS). It is clear that the DVR_PV injects appropriate amount of voltage to mitigate sag and swell caused by electrical perturbation and at the same time deliver the excess active power to the grid.

V. CONCLUSION

Photovoltaic appears one of the promising clean energy sources of the future which is used in different applications. For that, for evaluate its use the DVR-PV system is proposed in this studies. From the results obtained, it is clear that by using this approach based on the PLL method, PV power can powerfully extracted by PV system and injected to feed nonlinear load and to supply power into the mains. Finally and according to the obtained results we can consider the proposed system to be efficient solution to the growing demand of power at the present and in the future.

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