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DVR COMBINATION WITH PHOTOVOLTAIC FOR IMPROVING THE OPERATION OF WIND FARM

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Abstract- Wind power is one of the most important kinds of renewable energies. Wind farm as a device which receives this energy needs some special conditions to work properly. The most common type of wind turbine is the variable-speed directly connected to the grid. Faults in the power system can originate the disconnection of wind farms. Dynamic voltage restorer (DVR) is a custom power device used for eliminating voltage sages and swells which is the result of the faults. This paper presents a simulation model of a 12-pulse DVR using photovoltaic (PV) as a mean of providing an alternative energy source for the DVR. Simulations were carried out using the Matlab Simulink. The simulation results proved the capability of PV-based DVR in eliminating voltage sag and swell distributed system. Improving the operation of wind farm as an energy generator and stabilizing its voltage is the main result of this work.

Keywords: Wind Farm, Photovoltaic, Stabilizing, Voltage Sag/Swell, DVR.

I. INTRODUCTION

In recent years, wind power is going to be one of the most important energy among those that are used due to low cost and renewability. Wind turbine as a device that receives wind energy must work in special condition. For example the generators of turbine should have been stabilized. Thus the voltage and current of generators which connected to the bus should be steady. This process eliminates voltage harmonic and voltage sag/swell in the generators that are connected to the bus. To achieve this, the device named Dynamic Voltage Restorer (DVR) is used. This device controls the voltage of bus and removes the voltage sag/swell through fault time. So the voltage quality in generators is increased.

Design details of various DVRs are described in a lot of researches [1, 2]. Also, several studies on DVR control methods have been done ([4]). Most researches are developed on the control strategy that uses open loop feed forward [3]. On the other hand there is another method that combines the open-loop feed forward approach and close loop feedback [4] to compensate the instability. The structure of DVR includes a DC source that can provide the power of injection.

In this paper, instead of DC source connected to the DVR, the Photovoltaic (PV) has been used. PV energy is derived from a completely safe energy that is renewable and the cost is low in compare with other energies. Use this type of energy, including wind energy, due to being natural in power system, is growing day by day. Recently, several studies about the connection of Distributed Generating (DG) to the power system by the Power Electronic Systems have been done. Energy from PV is an example of DGs [6-9].

II. POWER SYSTEM AND DVR MODEL

Studied power system as shown in Figure 1 includes a wind turbine. Specifications and parameters of the wind farm are taken from [5]. Wind turbine has six 1.5 MW variable speed generator that each of them is directly connected to the network with a capacitor bank and transformer. Wind energy converters which are discussed in mechanical system are divided into two major groups (wind turbine and rotor electrical) that these two parts are connected to the shaft. Gear Ratio in this model is 45 (N_{gb} = 45) and the number of pairs of poles is also 2. Nominal speed of the turbine is 30 rpm.

DVR is one of the important tools of power electronics. It is used to stabilize the amount of voltage in the bus of sensitive loads. The Primary work of DVR is the compensation of the voltage sag/swell. Although DVR is able to do functions such as mitigating harmonics, reducing the transient state of voltage and compensating the fault. DVR includes a DC source. In this paper instead of this source we use photovoltaic (PV). Details are described in Figure 1.

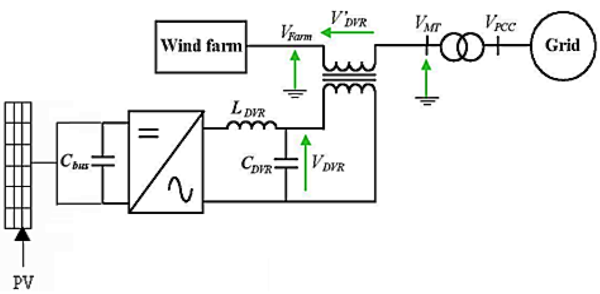

Figure 1. General system

III. PERFORMANCE OF DVR

DVR is used to protect sensitive electrical loads like large semiconductors, auto switches in power electronic and etc against power system disturbances. Using DVR for stabilizing the wind turbines is one of its new applications. In this paper, instead of maintaining sensitive load, protection of the variable speed generator which is sensitive to voltage changes is the main task of DVR. Recently, researches in this area are lead toward improving the behavior of wind turbines against severe disturbances [6]. DVR should provide necessary voltage to control power factor in the junction of wind turbine. It means that DVR should keep the voltage at a determined value. In fact the reactive power compensation is the main task of DVR. If the DVR has been used for protection of load, the voltage, current and power should be remained constant in the compensation period. Figure 2 shows the compensation mode as phase diagram in two cases of absorption and injection of reactive power. Compensating by reactive power absorption using DVR is shown in Figure 2(a). The Figure 2(b) shows the compensation by injecting reactive power using DVR.

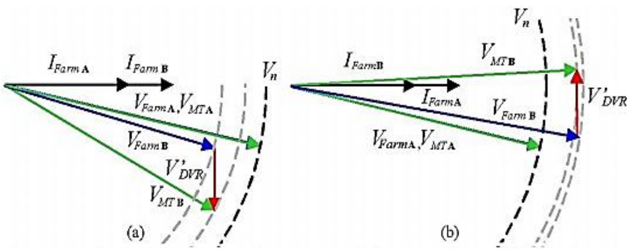

Figure 2. Reactive power compensation to control the power factor (a) reactive power absorption, (b) reactive power injection

Compensator absorbs reactive power when the lagging power factor in point of common coupling (PCC) is obtained and wind turbine voltage is less than Medium voltage (MT). Similarly DVR injects into the network when the leading power factor in PCC is obtained and wind turbine voltage is greater than MT voltage. The ideal case occurs when the wind turbine voltage is equal to MT voltage.

IV. DVR CONTROL

The main goal of DVR is defined as maintaining a constant voltage of sensitive load bus in the state of disturbance of power system. This control method is based on comparing source and load voltages. Difference of these voltages determines the dynamic behavior of DVR. It compares this voltage difference with the amount of reference voltage and makes voltage capture or voltage injection. In this control method, voltage of wind turbine is measured. This voltage is changed to “dqo” using Park converting:

$$f_{dqo} = T f_{abc} \tag{1}$$

$$(f_{qdo})^T = (f_q f_d f_o) \tag{2}$$

$$(f_{abc})^T = (f_a f_b f_c) \tag{3}$$

$$T = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ \sin\theta & \sin(\theta-\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{4}$$

$$\omega = d\theta / dt \tag{5}$$

Inverse matrix of Park converting is

$$T^{-1} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \tag{6}$$

Angular velocity ω and displacement θ are calculated by

$$\theta = \int \omega \, dt \tag{7}$$

After converting the voltage to dqo, Voltage is constant in the normal and balanced condition. d-voltage is unity in p.u. and q-voltage is zero in p.u. but during the abnormal condition it varies. After comparison d-voltage and q-voltage with the desired voltage in distributed condition, difference of these voltages is improved by PI controller and then it is converted into abc component using dqo to abc transformation. So the u_{ref} signal which is main signal in switching is produced. This process is shown in Figure 3.

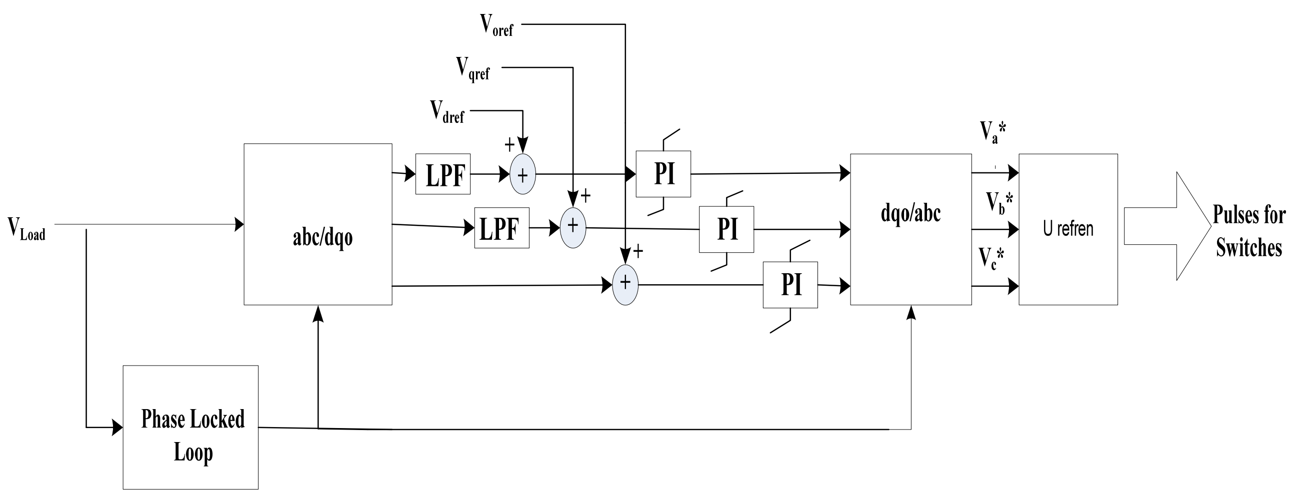

Figure 3. Control block diagram for DVR

In Figure 3, Phase Locked Loop (PLL) is used to produce cosine and sine wave in the main phase of voltage. The u_{ref} which comes from the control block in Figure 3 is used to generate pulses in switching logic. This logic is shown below:

- If $u_{ref} > h$, then $u = +1$ and if $u_{ref} \leq h$, then $u = -1$

For switching in DVR we should do like below:

- If $u = 1$, then turn on the pair a_1-a_3, if $u = -1$, then turn on the pair a_2-a_4

The other two phases are like them too.

V. PV AND DC/DC CONVERTER

Photovoltaic is known as one of the perfect generators of the Dispersed Generation (DG) which use is increasing rapidly. Photovoltaic systems (PV) use massive source of solar energy and play a key role in future situation of energy sources. The reason of heavy use of photovoltaic (PV) is that it could generate a fast, clean and non-polluting power for consumer and its energy is free after installation .

The DC voltage produced by photovoltaic systems (PV) is fluctuated and its amplitude is small, an amplifier DC/DC converter which regulating DC voltage is necessary. DC/DC Converters should absorb the generated power of photovoltaic. So it should be designed in a way that be consistent with the ripple of current of photovoltaic system and has no interference with the positive current of PV system.

In this paper, multi-input and single output (MISO) DC/DC converter for regulating and strengthening the PV system output voltage is presented and analyzed. This converter has a simple structure and its components are limited and it's cheap. The Converter topology which is used to combine and strengthen the DC output of the PV units is shown in Figure 4.

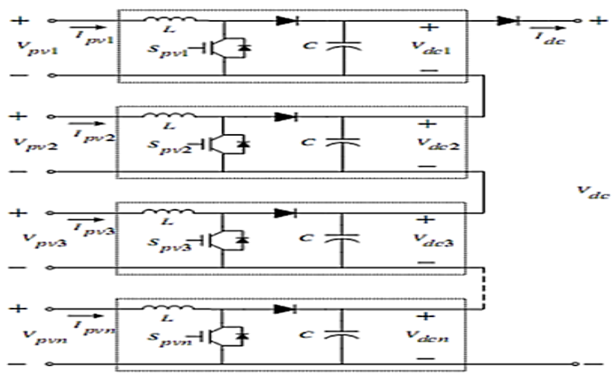

Figure 4. The Converter topology which is used to combine and strengthen the DC output of the PV units.

In the Figure 4 the low voltage which is produced by the PV modules and shown as $V_{pv1}, \ldots, V_{pvn}$ are connected to the DC bus by amplifier convertor in series. The bus converters of DC amplifier are series connected. The DC/DC Converter output feed the voltage source inverter to generate AC output for AC distribution system. The power and output voltage of PV modules should be controlled by controlling the IGBT switching.

Total output voltage of DC/DC converter system is presented by the following relation:

$$V_{dc}=V_{dc1}+\ldots+V_{dcn}=\frac{V_{pv1}}{1-D_{pv1}}+\ldots+\frac{V_{pnv}}{1-D_{pvn}} \tag{8}$$

In the Equation (8), $D_{pv1}, \ldots, D_{pvn}$ are the duty cycle of amplifier convertors and $V_{dc1}, \ldots, V_{dcn}$ are the output voltage of amplifier convertors. If the duty cycle of convertors and their inputs are equal, total output voltage of DC/DC convertor (MISO) will be determined by the equation below.

$$V_{dc}=\frac{n}{1-D_{pv}}V_{pv} \tag{9}$$

Capacitance of each converter can be obtained by the equations below.

$$C=\frac{n^2D_{pv}}{1-D_{pv}}\cdot\frac{V_{pv}}{Rf_s\Delta V_{pv}} \tag{10}$$

In the Equation (10), f_s is the switching frequency, R is the equivalent resistance of load and ΔV_{pv} is the ripple of output voltage of DC/DC converter. Inductance value of each converter can also be determined by the following equation:

$$L=\frac{(1-D_{pv})^2}{2nf_s}D_{pv}.R \tag{11}$$

In the control system of DC/DC converter (MISO), the output voltage of convertor is compared with a reference value and the error signal is given to the PI controller. Control signal output is a PWM switch input for adjusting the duty cycle. Figure 6 shows the DC voltage produced by non-amplified PV system and the DC voltage produced by PV system with a MISO amplifier.

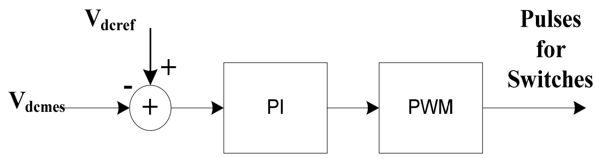

Figure 5. Control system of DC/DC converter

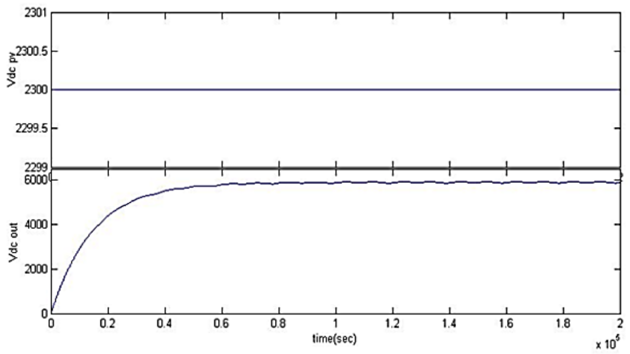

Figure 6. DC voltage of PV and DC/DC converter

VI. WIND FARM

Wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system. Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources.

The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

VII. SIMULATION AND RESULTS

DVR that is used in simulation as well as wind turbines and transmission line is shown in Figure 7. The DVR is connected in series with transmission line. DVR is composed of a half-bridge converter for each phase that each converter has four switches. MOSFET is used in this sample. For switching each phase we need two pulses. Switching frequency is about 2 KHz. Also we use an AC filter (usually a capacitor) at DVR output for removing the harmonics of switching.

In this case we use PV instead of batteries for feeding of DC link which is connected to the DC capacitor.Wind turbine used in this simulation consists of six generators 1.5 MW with DFIG and the average wind speed is considered 15 m/s. For making disturbance in the circuit we use a three phase fault which is applied to the network at the time between t = 0.05 s and t = 0.1 s. Parameters of the power network and used in the simulation are expressed in Table 1. Characteristics of wind turbine are expressed in Table 2.

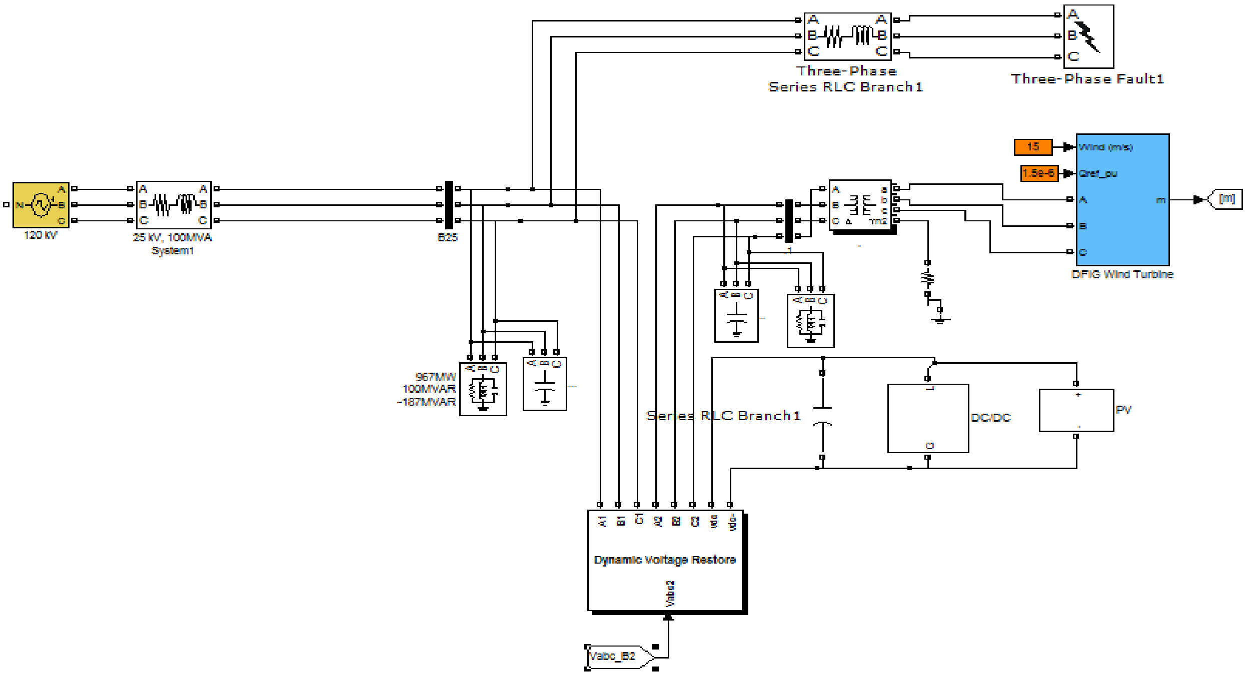

Figure 7. Overall control circuit of DVR

Table 1. Power network parameters

System frequency	50 Hz
Source voltage	25 KV
Line Impedance	(0.605+4.84j) Ω
3-phase transformer	10 MVAR, 25 KV/600V
Capacitor filter	50 μF
DC capacitor	10000 μF
Single phase transformer	10 MVAR, 10 KV/25 KV
PV	800 KW

Table 2. Wind turbine characteristics

Nominal power	500 KW
Induction gen	600 V, 50 Hz
Air density	2.22 kg/m3
Sweep area	176.6 m2
$C_{p,\max}$	0.411

The simulation begins with 50% voltage swell of source. Figure 8 shows the network voltage in swell condition which is occurred during the time between t = 0.05 s and t = 0.1 s. DVR injects voltage to compensate voltage swell and wind farm. Voltage will remain constant. The injection voltage of DVR is shown in Figure 9. Figure 10 shows the stable wind farm voltage.

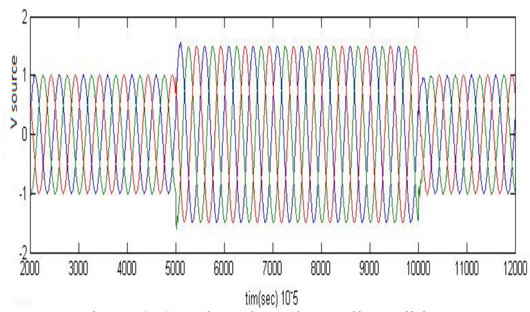

Figure 8. Supply voltage in swell condition

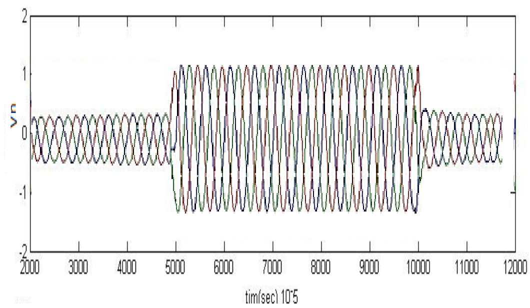

Figure 9. DVR injection voltage in swell condition

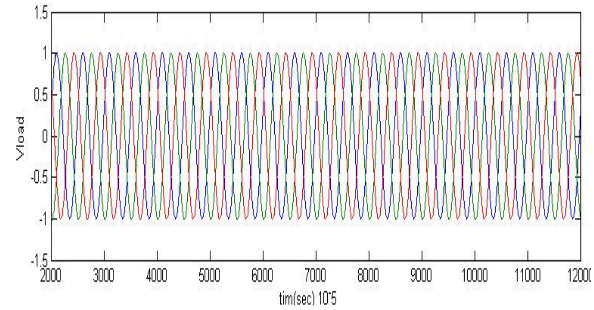

Figure 10. Wind farm voltage in swell condition after compensation

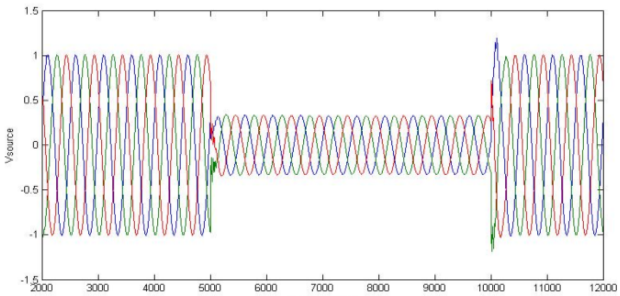

Figure 11. Supply voltage in sag condition

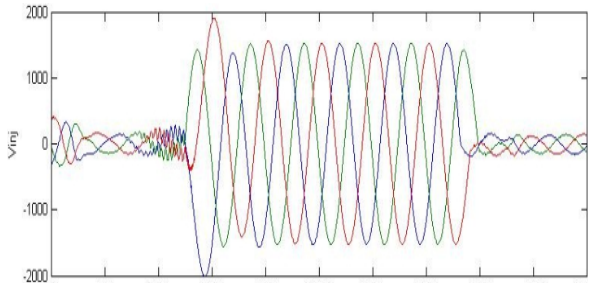

Figure 12. DVR injection voltage in sag condition

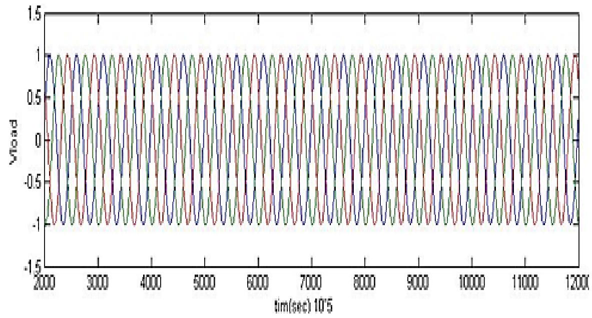

Figure 13. Wind farm voltage after compensation

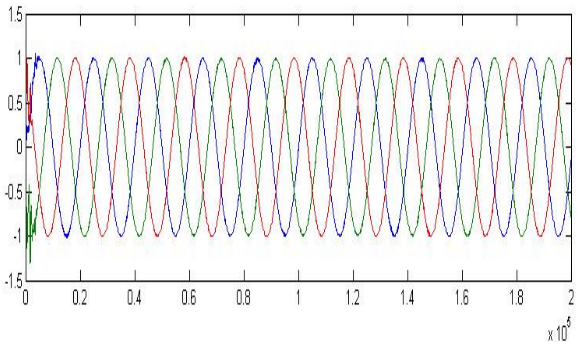
Figure 14. Wind farm current after compensation (in both sag and swell conditions)

Terminal current of wind turbine is shown in Figure 14. It is reached to stable condition after a little time.

VIII. CONCLUSIONS

In this paper, a 12-pulse DVR is designed and through using new control method all voltage sags and swells in the circuit are generally compensated. The DVR is modeled with a new feedback controller scheme to control the 12 IGBT switches of the inverter. The DVR output is filtered in order to mitigate the harmonics generated from switching.

In this case the terminal voltage which is connected to the wind turbine stay constant and despite the voltage instability in network wind generators will be able to remain connected to the network and work in stable condition through using DVR. Also in this paper to provide a DC source of DVR we have used PV which is a kind of natural energy source. Simulation results prove that the PV can be a useful alternative DC source for the DVR.

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BIOGRAPHIES

Murtaza Farsadi received the B.Sc. and M.Sc. degrees in Electrical Engineering from Middle East Technical University (Ankara, Turkey) in 1982 and 1984, respectively. He received Ph.D. from Electrical Engineering (High Voltage) Department of Electrical and Electronics Engineering, Middle East Technical University and Istanbul Technical University (Istanbul, Turkey) in 1989. He is now an Assistant Professor in University of Urmia (Urmia, Iran). His research interests are high voltage DC defibrillator, hybrid an electrical vehicle, wind energy, new methods of electrical machine control, biomedical engineering apparatus, and electrical treeing.

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