The effect of reactive power compensation on voltage profile of hybrid PV-Wind Grid connected power generation system

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ABSTRACT

This paper presents a novel method to enhance the voltage profile of a PV-wind hybrid system suitable for grid connection. A single stage power electronic converter is used for maximum power point tracking (MPPT), Feeding AC power to the grid and reactive power compensation to enhance the voltage profile of the system.

INTRODUCTION

Due to the wind speed variation from hour to another during the day and from season to another during the year, the use of another energy resource in a hybrid system becomes more sustainable power source. The hybrid systems have two main types; Stand alone System which is used for feeding a definite load far away from the national grid and the grid connected which is feeding the generated power to the national grid and controlled by utility control and dispatching centers. The hybrid system was studied from different points of view in different presentations such as the proposed study in [1].This study is based on comparing the different types of reactive power compensation strategies of wind farm based on optimal slip wound rotor induction generators. This comparative study investigates the enhancement of voltage stability by using different types and ratings of SVCs. A novel method is presented in [2] for maximizing the utilization factor of PV grid connected system to be 100%.This method is based on using PV arrays converter for MPPT during sun shining hours while using it as a Static VAR Compensator (SVR) during night to support grid voltage. The MATLAB SIMULINK tools are used in [3] for modeling a standalone hybrid wind-PV-Diesel generation system. This model is suitable for control and power quality study. The proposed model in [4] is used for studying the power quality of a hybrid wind-PV grid connected system. The total harmonic distortion (THD) of the inverter output current and voltage waveforms are monitored. The proposed system converts the wind energy to DC then supplying the total PV-wind power during one main inverter which reduces the system stability. The method presented in [5] is based on using multi input inverter for feeding the power of a hybrid PV-wind to the grid. This scheme has three converters, accordingly it will have high cost and it will need more maintenance. The proposed study in [6] depends on investigating the dynamics and transients of a distribution subsystem with multiple distributed energy resources. The study presented in [7] focuses mainly on the voltage recovery and transients during wind turbine starting and after faults in a small diesel-wind power generation network. In this study a hybrid PV-wind grid connected system will be modeled with its MPPT and reactive power control schemes to show its effect on the voltage profile mainly during wind turbine starting and after faults.

SYSTEM MODELING

The studied system is a hybrid grid connected PV-wind power generation system. The modelling of this system has to satisfy the equations that describe its two main components (Wind energy conversion system and photovoltaic energy conversion system) as will be shown in the following subsections.

Wind Energy conversion system modelling

Wind energy conversion system consists of three main parts (Wind Turbine, Pitch Regulator and Induction Generator). Each one will be described individually.

Wind turbine with pitch regulator model

The wind turbine is the system which converts the available wind energy into mechanical energy, therefore the equations used to model wind turbine are related directly to air flow equations as follow:

$$P = 0.5\,\rho\, A\, V^3\, C_P(\lambda, \beta) \quad (1)$$

$$\lambda = r * \omega / V \quad (2)$$

$$C_P(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3 * \beta - C_4\right) e^{\frac{-C_5}{\lambda_i}} + C_6 * \lambda \quad (3)$$

$$\lambda_i = \frac{1}{\lambda + 0.08 * \beta} - \frac{0.035}{\beta^3 + 1} \quad (4)$$

[P is the output power in Watt, ρ is the air density (in this study is 1.225 Kg/m3), A is the swept area of the turbine in m^2, V is the wind speed in m/sec, λ is the tip speed ratio, β is the pitch angle in degree, Cp is the power coefficient or wind turbine coefficient, r is the wind turbine radius of rotation or blade length in meter and ω is the generator rotational speed in rad/sec, C1= 0.5176, C2 = 116, C3= 0.4, C4 = 5, C5= 21, C6 = 0.0068]

Plotting Eqn. (3) shows the relationship between the power coefficient and tip speed ratio of wind turbine at different pitch angles as displayed in Fig. (1). Therefore, each turbine must have; pitch controller or pitch regulator. It represents the main component in the turbine mechanical system that is used to vary the blade pitch angle at high wind speed in order to provide constant rated output from wind turbine.

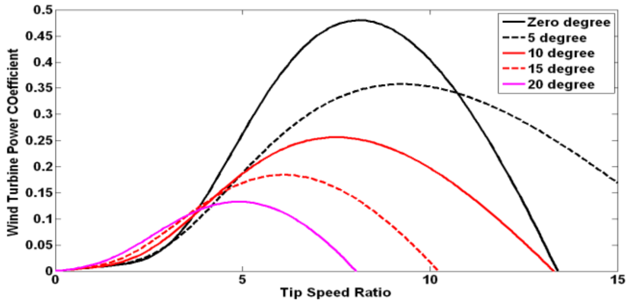

Fig. (1)- Wind Turbine Characteristics

The actual pitch regulator consists of position sensor, controller and actuator. The proposed model in this study is simplified as a PI controller as shown in Fig. (2).The values of Kp and Ki constants of the controller are calculated as in [8]. Eqns. (1) – (4) are modelled in MATLAB SIMULINK power tool library with parameters given in [9].

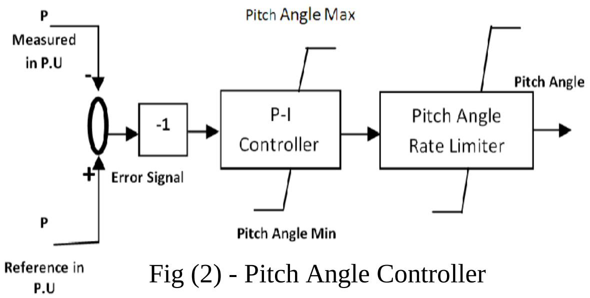

Fig (2) - Pitch Angle Controller

Induction generator model

The induction generator is modelled using park's equations transformed into the d-q axis as follow:

$$V_{qs} = R_s\, i_{qs} + \frac{d}{dt}\varphi_{qs} + \omega\, \varphi_{ds} \quad (5)$$

$$V_{ds} = R_s\, i_{ds} + \frac{d}{dt}\varphi_{ds} - \omega\, \varphi_{qs} \quad (6)$$

$$V'_{qr} = R'_r\, i'_{qr} + \frac{d}{dt}\varphi'_{qr} + (\omega - \omega_r)\, \varphi'_{dr} \quad (7)$$

$$V'_{dr} = R'_r\, i'_{dr} + \frac{d}{dt}\varphi'_{dr} - (\omega - \omega_r)\, \varphi'_{qr} \quad (8)$$

$$T_e = 1.5\, p\, (\varphi_{ds}\, i_{qs} - \varphi_{qs}\, i_{ds}) \quad (9)$$

$$\varphi_{qs} = L_s i_{qs} + L_m\, i'_{qr} \quad (10)$$

$$\varphi_{ds} = L_s i_{ds} + L_m\, i'_{dr} \quad (11)$$

$$\varphi'_{qr} = L'_r i'_{qr} + L_m\, i_{qs} \quad (12)$$

$$\varphi'_{dr} = L'_r i'_{dr} + L_m\, i_{ds} \quad (13)$$

$$L_s = L_{ls} + L_m \quad (14)$$

$$L'_r = L'_{lr} + L_m \quad (15)$$

[Rs, Lls, Rr̀, Llr̀, Lm are stator resistance, leakage inductance, referred rotor resistance, leakage inductance and magnetizing inductance respectively. Ls, Lr̀ are the total stator and referred rotor inductance .Vqs, Vds, iqs, ids are stator q-d axis voltages and currents respectively. Vqr̀, Vdr̀, iqr̀, idr̀ are the referred rotor q-d axis voltages and currents .Φqs, φds are the stator d-q axis fluxes. Φqr̀, φdr̀ are the referred rotor d-q axis fluxes]

The mechanical motion of the generator and wind turbine tied by gear box is described as follow:

$$\frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - F\, \omega_m - T'_m) \quad (16)$$

$$\frac{d}{dt}\Theta_m = \omega_m \quad (17)$$

[Θr, ωr, p are the electrical angular position, velocity and number of pole pairs respectively. Te is the electromagnetic torque, Tm̀ is the wind turbine driven torque and H, F are the total inertia and friction coefficients for wind turbine, gear box and the generator] The above Eqns. are modelled in MATLAB SIMULINK library while the other electrical components in the system such as transformers, cables and grid are used directly from SIMULINK power tool library with parameters given in [10].

Photovoltaic Energy Conversion System

Photo Voltaic system consists of PV Modules, power Electronic Converters and system controllers which will be discussed as follows.

PV Modules

PV modules consist of PV cells which are connected in series and parallel to provide the required output power. For modelling the PV modules, the main equations of PV cell and its equivalent circuit must be studied. PV cell is a P-N junction which converts sun light into DC output power for that the equivalent circuit of PV cell is as shown in Fig(3) and its main equation is

$$V_C = \left(\frac{A\, K\, T_C}{e}\right) \ln\left(\frac{I_{ph} + I_d - I_o}{I_d}\right) - R_s * I \quad (18)$$

[VC is the terminal voltage of PV cell, A is the ideality factor of the PV cell, and K is Boltzmann constant (1.38 × 10−23J/K), TC is the cell's working temperature in Kelvin, e is the electron charge (1.6×10−19C),I_{ph} is the short circuit current of PV cell, I_d is the reverse saturation current, I is the output PV cell current, ,Rs is the series resistance of PV cell]

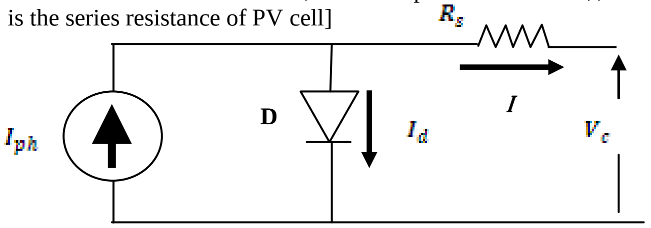

Fig (3) - Approximated Equivalent Circuit OF PV Cell

There are two main factors, that affect the output power of the PV cell which are solar radiation in ($\frac{WATT}{m^2}$) and atmosphere temperature in (Kelvin) as shown in the following relationships.

$$C_{TV} = 1 + K_V\, (T_{ref} - T_C) \quad (19)$$

$$C_{TI} = 1 + \frac{K_I}{W_{ref}}\, (T_C - T_{ref}) \quad (20)$$

$$C_{SV} = 1 + K_V\, K_P\, (W_C - W_{ref}) \quad (21)$$

$$C_{SI} = 1 + \frac{1}{W_{ref}}\, (W_C - W_{ref}) \quad (22)$$

$$V = C_{TV}\, C_{SV}\, V_{ref} \quad (23)$$

$$I_{phn} = C_{TI}\, C_{SI}\, I_{ph} \quad (24)$$

[Wref, Tref are the solar radiation and temperature at standard testing conditions which in this case has value of 1KW/$m^2$and 25 °C , WC, TC are the actual solar radiation and Temperature respectively. KP is the temperature effect on power (its value is one of PV catalogue values).

KV is the temperature effect on voltage (its value is one of PV catalogue values), KI is the temperature effect on short circuit current (its value is one of PV catalogue values)].

The equations of (18)-(24) [11] are modelled by MATLAB software with the usage of MSX-30 PV module catalogue which consists of two strings of 18 series connected PV cells. The main parameters of the module are calculated as in [12] and the output characteristics are shown in Figs, (4, 5). There are near to actual module characteristics that are shown in the catalogue.

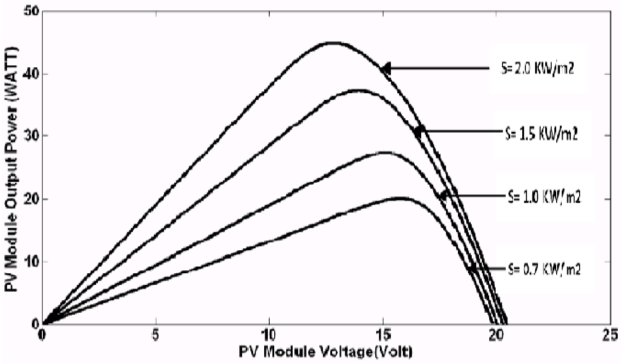

Fig (4) - PV module power characteristic At different solar radiation

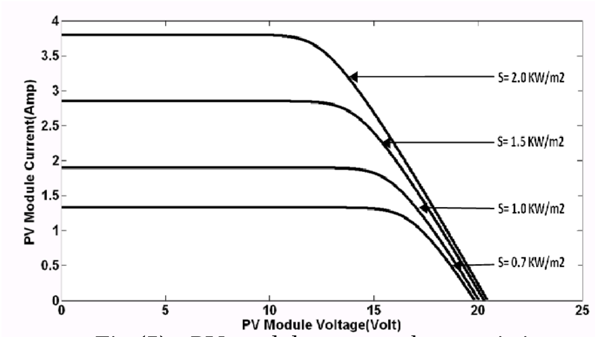

Fig (5) - PV module current characteristic At different solar radiation

PV modules controller

The controller of PV modules has two functions in this study as shown in Fig (6). The first function is maximum power point tracking (MPPT) of PV modules which is used for forcing the modules to supply its maximum available power at different solar radiation and temperature values. There are different methods of MPPT; the used one in this study is Incremental step method (Inc Method) as it is the highest efficiency one. The second function is maximizing the utilization factor of PV modules by using its converter as a static VAR compensation to control the reactive power of the hybrid system. The PV modules will be used to generate power and reactive power control during day and reactive power control only during night [2]. The switching pattern of power electronic switches will be provided by hysteresis control system due to its easiness in implementation. [13]

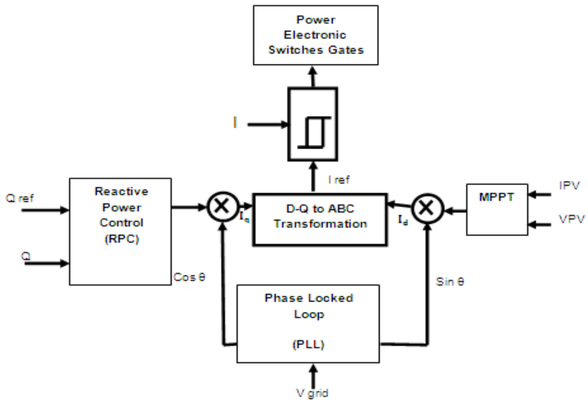

Fig (6) - PV module MPPT and Reactive Power Control Scheme

Power Electronic Converter and Filters

The power scheme of PV modules is shown in Fig (7). The AC filter has two main types. The first is the L-C with high inductive element slows the response of the system during transients. The second type is L-C-L filter which has two low inductive elements one in the side of the PV modules and the other in the side of AC grid as shown in Fig (8). The design of DC and AC filters is shown in [13-14-15] respectively also MATLAB SIMULINK power electronics toolbox is used for modeling the IGBT power electronic switches.

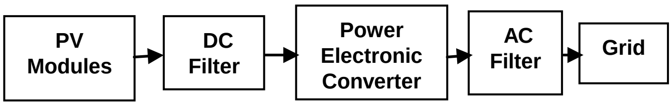

Fig (7) - AC PV System

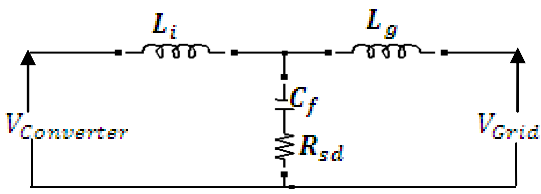

Fig (8) - L-C-L Filter Scheme

Results and Discussion

The effect of PV modules reactive power control on voltage profile of the system will be investigated in two operation cases (wind turbine starting and three phases to ground system fault). In this study wind speed can be considered as a constant value as the electrical time constant of these two cases are too small compared with mechanical time constant of wind speed variation. In this study wind speed value is 10 m/s [1].

Wind Turbine Starting

At the instant of wind turbine starting the induction generator absorbs more and more reactive power for internal magnetic field building up and speed rising which causes a high distortion in system voltage. The converter of PV modules is controlled to supply maximum power and feeding reactive power in a lead mode of operation.

As shown in Fig (9) the phase voltage of induction generator with this compensation is fastest in recovery and highest in its steady state value compared with induction generator without compensation.

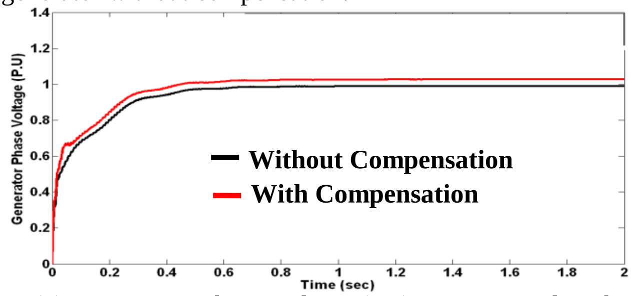

Fig (9) - Generator Phase Voltage (PU) During Wind Turbine Starting [without compensation, with 250 KVAR compensation]

Three phase grounded system fault

As shown in Fig (10) the system is subjected to three phase grounded fault at induction generator terminals for a period of 0.1 sec. The PV converter is controlled to feed lead reactive power at instant of 1.3 sec to study the effect of this compensation on voltage profile. As shown the system voltage was recovered with highest value at shortest time comparing with system without compensation for that the PV modules converter as a STATCOM enhance system fault ride through ability.

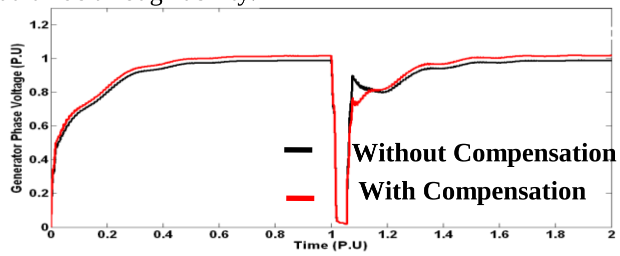

Fig (10) - Generator Phase Voltage (PU) During Three Phases Grounded Fault [without and with 250 KVAR Compensation]

Conclusion

This study suggests the use of the free area between wind turbines in wind farm by having PV modules in it. This study will be more economical and increases the environmental friendly generated power on the grid. This study used the maximization of PV modules converter utilization factor as a STATCOM beside its main function of feeding power to the grid to support the voltage profile of a hybrid system. Use of PV modules as a STATCOM with this large area supports strongly the voltage profile of the grid mainly at large disturbances like machine starting and short circuits which enhances system stability.

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