A Novel Control Strategy for Grid Connected Wind Turbines

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Abstract: In this paper a new method for connecting the wind power plants into global power network is presented. This controller injects active power generation of wind turbine into global network and moreover does a complete reactive and harmonic compensation for local loads. In this situation separate equipment for compensating non-linear loads won’t be needed. Complete compensating is done by using two parallel inverters based on MOSFET and IGBT switches. Such capability can make this plant economically reasonable. Also in some period of time, when wind energy will be less than minimum required for running wind turbine; the presented control method is capable of compensating nonlinear local load. Finally in order to verify accuracy of proposed control strategy, grid connected wind turbine is simulated based on MATLAB/Simulink.

Keywords—reactive and harmonic compensating, grid connected wind system, hysteresis current controller.

I. INTRODUCTION

The limitation of fossil energy sources and moreover the pollution caused by using these sources is increasing the usage of new and renewable energies. Nowadays various technologies have been improved for using these new and clean energy resources which is comparable to fossil based energies from view point of cost and reliability. Also the overall cost for using these energy resources is decreasing everyday which will be even lower when production rate is rising. In fact the challenges in reducing the cost of using renewable energy resources is one of the active research fields, and various papers are published in conferences and magazines each year in this field. It worth mentioning that several resources of renewable energies such as biomass, solar, wind, hydro power and the energy of water tide, are being used now but wind and photovoltaic power, which are based on modern power electronic technologies, have wider usage capabilities[1]. Considering the low efficiency of existing solar producing 7% (25777MW) of its overall consumed electricity by wind power plants in 2010 [3], WECSS(Wind energy conversion system) has been seriously considered as a reliable technology for producing electricity in recent years [4] and it has been shown that such systems can eliminate for separate reactive compensators and the active power filters[5,6].

Panels and also the high cost of using these power generators, using photovoltaic systems for electricity production is economically reasonable only for low power consumers which are far from the global network [2]. On the other hand, using wind farms has increased considerably in recent years. For instance Germany was This ability can be gained by applying suitable control patterns [7]. Nowadays wind power generation is based on IG (Induction Generators) and DC generators [4,8]. Two main groups of recent researchers have suggested use of wind farms for compensation of nonlinear loads (reactive and harmonic compensating). These applications are able to improve the power quality of electric network at the Point of Common Coupling (PCC).In the first group, use of induction generator with two inputs (DFIM: Doubly-Fed Induction Motor) for compensating of load is proposed. In this case by nonlinear load current is provided from windings of stator. In this situation separate equipment for compensating of load is not needed. Complete compensating is done by the output power of wind systems, application of IGBT switches is completely common for connecting these systems into grid. Considering low switching frequency of IGBTs (which is usually less than 5 KHz), it is not possible to compensate high frequency components of harmonic current. Improper response of this method in complete filtering of harmonic components of the load is considered as the main problem in real wind power plants. In this paper, a new topology for complete compensation of harmonic components and reactive power of local loads is presented. This method is based on using two parallel inverters in the structure of the wind farms. The high power inverter which is based on the IGBT switches has the role of injecting active power generated by wind turbine to the global network, reactive compensation and filtering low-order harmonic components. The second inverter, which is based on power MOSFETs and can switch in high switching frequency, has the role of compensating the high-order harmonic components. It is worth mentioning that considering the low power of harmonic components, this inverter has low capacity and connecting it to the network in the farms would not affect the overall cost of system much. The organization of this paper is as follow: in next section, structure of the proposed system will be presented. This part includes performance of grid connected wind system and hysteresis current controller. In section III proposed control strategy has been reviewed completely. Finally in order verify accuracy of the proposed controller, grid connected wind turbine is simulated based MATLAB/Simulink.
The structure of proposed system:

A. Performance of the grid connected wind power plant

The importance of using renewable resources for electricity generation is completely known. Input energy of these systems are free for consumers and also these clean and green energy resources don’t pollute the environment. Also, there is concern about decrease of fossil resources and possibility of running out of it in the next decades. For this reason growing use of these green energy sources is unavoidable. Use of wind energy has more importance due to technical-economical reasons. The purpose of this paper is designing and implementing a 5KVA grid connected wind turbine. In this academicals project, the idea of complete harmonic compensation of nonlinear and reactive loads to the wind turbines controller has been added. Use of the proposed controller has considerable advantage, which:

A) Reactive and harmonic compensating of local loads removes installation separate equipment for filtering. This case results in more economical wind systems.

B) Due to load compensation by wind system, the capacity of transmission lines will free up and for this reason energy loss in transmission and distribution lines will be decreased.

C) Complete compensating of nonlinear loads will be possible which is based on applying two separate and parallel inverters. This idea is proposed in this paper for the first time and its principal of operation have been reviewed in the next section of this article. This strategy will result in power quality improvement in the network. Better power quality will effect on the operation of electric loads and will improve the efficiency of them directly. The main goal of this study is designing, simulating and implementing of electric and electronic parts of a 5KVA wind system. In spite of injecting active power generation of wind turbine into grid, this system is capable of load compensation. The block diagram of the proposed system is shown in figure.

The wind turbine converts wind energy to mechanical torque and the gearbox increases the speed of turbine up to the nominal speed DC machine. Also, this generator converts the mechanical energy of wind turbine to electricity. Considering the voltage range of DC generators, which is usually 100 V, a DC-DC switch based converter is used to match DC generator output and voltage of the global network. This block increases only the output voltage of DC generator based on the fixed gain. This converter became open when wind speed is not fast enough. The 3-phase inverter which is used in close loop mode is involves two separate DC to AC converters. One of these inverters uses IGBT switches, which is responsible for transferring electric power from the wind system to the grid. This includes the active power generation of wind turbines, the reactive power of local load and low-frequency harmonic components of local load’s current. The second inverter operates in high switching frequency and is based on fast power-MOSFET switches. The nominal power of the recent inverter is very limited and it is only used for compensation of high frequency harmonic components. The proposed strategy for controlling these two parallel inverters is relatively straightforward: first apparent and active power of nonlinear local load is measured at the PCC. Since voltage of PCC is constant, apparent and active current of nonlinear load can be calculated. The difference between recent currents (which is called non-active) which includes reactive and harmonic current should be supplied via wind turbine. Finally in order to calculate reference current of the system, active power which is generated by wind turbine should be added to the previous current. The amplitude of the active power is selected in a way that the input voltage of the inverter is fixed and it is determined by a simple PI controller.

The purpose of adding this active component is injection of wind power to the global network. In a brief, the reference current of the inverters include two different parts: A) non-active item for load compensation and B) Active item for injecting the generated energy in the wind turbine into the network.

In the simplest situation, we have two basic options for selection of electric generators: A) Use of DC generators and B) Use of induction generators.

The maintenance cost of induction generator is very low and taking into account the recent developments in power electronic, application of induction generators increasing dramatically. However it is not possible to generate reactive power based on them. DC generators have lower price and it is easier to control. Main problem of these generators is their high maintenance cost. However according to the recent developments, this problem has been solved and due to this DC generators will be used in this paper.

Hysteresis current controller

Current controlled inverters in grid connected systems are better because:

- Since utility is voltage source, it is only enough to control the current flow in order to control power flow between grid connected systems and the utility.
- If the voltage control method is used, small phase error in the output voltage of inverter may cause very large power current error [15].

Different methods have been proposed for current control of inverters; for example: ramp comparison, predictive current control.
method and hysteresis band technique [16]. Hysteresis current controller has been used widely due to fast dynamic response and its simplicity of implementation. Operation principal of hysteresis current control method is relatively simple. According to the situation of power switches in a single-phase inverter (Fig.3), two different areas can be considered:

A) If we turn Q1: on and Q2: off, inductive load current (i_a) will increase

B) If we turn Q2: on and Q1: off, load current will decreases.

It is clear that by applying appropriate switching, we can control the variation of output current and it will always remain inside of specific range. where H is called hysteresis band. Obviously reduction of hysteresis band decreases error, but on the other hand, the switching frequency and power losses will increase. During implementation of this method, actual output current of inverter is compared to i_ref (Up) and i_ref (Down) (Fig.5). Values of A and B in different regions is given in Fig (6). It is clear that due to nature of the system, state A=B:1 is not taking place and it is don’t care state. This sequential circuit is specified in Table.1. This table is written for determination of desired switching command (S(t+1)) and according to the amount of A, B and the previous state of switch (S(t)). For example, when A=B=0, the current is in the desired range, and the switch should keep its previous state, thus: S(t+1)=S(t). Finally it is clear that Table.1 could be implemented with Set/Reset Flip-Flop simply.

II. PROPOSED CONTROLLER

Fig.8 shows grid connected systems in more detail. In this system, the wind turbine is connected into utility based on two voltage source inverter. One inverter is based on IGBT and operates at 2.5 KHz. Second inverter is based on high frequency MOSFET and operates at 25 KHz. From the viewpoint of the utility and according to control strategy, grid connected system may be considered as a AC power source, resistive load, inductance or capacitance, all with the same apparent power. In normal conditions, this system can inject produced power by the wind turbine into the network and also compensates harmonic and reactive components of local loads current. In this case, current drawn or injected to the network perfectly will be sinusoidal and corresponding power factor will be uni. Also in general, control strategy of these systems must have the following abilities:

1. Production of reference current waveform in order to inject active power of wind turbine to grid and load compensation
2. Voltage stabilization of input capacitors (DC side of inverter) in this section, instantaneous reactive power theory which is proposed by H.Akagi [10] in Active Power Filters will be used in order to calculate the reference currents. In this case if reference currents are generated by inverters then wind turbine power will be injected into grid and local loads compensation will be done completely. This theory is based on transformation of voltage and current variables to the αβ coordinates:

\[
\begin{bmatrix}
 v_a \\
 v_b \\
 v_c \\
\end{bmatrix}
= [A]
\begin{bmatrix}
 i_a \\
 i_b \\
 i_c \\
\end{bmatrix}
(5)
\]

In this equations [A] is the transfer matrix:

\[
[A] = \begin{bmatrix}
 2 & -1 & -1 \\
 0 & \sqrt{3} & -\sqrt{3} \\
 0 & 0 & 0 \\
\end{bmatrix}
(6)
\]

These equations are valid if \( V_a+V_b+V_c = 0 \). Instantaneous active and reactive power on the αβ coordinates could be calculated by the following equation:

\[
P(t) = v_a(t)i_a(t) + v_b(t)i_b(t) + v_c(t)i_c(t)
(7)
\]

\[
Q(t) = -v_a(t)i_b(t) + v_b(t)i_a(t)
(8)
\]

Currents \( i_a \) and \( i_b \) in terms of instantaneous power values can be written as follows:

\[
\begin{bmatrix}
 i_a \\
 i_b \\
\end{bmatrix}
= \begin{bmatrix}
 \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
 \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\
\end{bmatrix}
\begin{bmatrix}
 v_a \\
 v_b \\
\end{bmatrix}
(9)
\]

\[
P = \bar{p} + \tilde{p}
(10)
\]

\[
Q = \bar{q} + \tilde{q}
(11)
\]

In these equations:

\( \bar{p} \) is DC component of instantaneous active power and it is related to the main component of active current.

\( \tilde{p} \) is AC component of instantaneous power \( P \) which is related to those harmonic currents that are produced by the active component of instantaneous power.
\( q \) is DC component of instantaneous power \( Q \) and it is related to the main component of reactive current. \( q \) is AC component of instantaneous power \( Q \) which is related to those harmonic currents that are produced by the reactive components of instantaneous power.

In order to compensate nonlinear loads completely, reference current of grid connected system should involve \( P \), \( q \), and \( q \). In this case, these harmful components don’t enter into the utility. An important advantage of this theory is that in this case main components of active and reactive power are in the DC form and could be easily removed if it is necessary.

Beside reactive and harmonic compensation, the control strategy of grid connected systems must inject active power generated by the wind turbines into the grid. According to the maximum power point of turbine, total active power which should be injected into grid could be determined as follow [19]:

\[
P_m = V_m I_m (12)
\]

In the above equation \( V_m \) and \( I_m \) are voltage and current of DC generator in maximum power point and these both could be measured/calculated easily [19]. According to equation (9), reference currents of system in \( \alpha \beta \) coordinates which will compensate for nonlinear load and also injects wind turbine active power into grid could be expressed as follow:

\[
\begin{bmatrix}
i_{\alpha}^* \\
i_{\beta}^*
\end{bmatrix} = \frac{1}{v_{\alpha}^2 + v_{\beta}^2} \begin{bmatrix}
v_{\alpha} & v_{\beta} \\
v_{\beta} & v_{\alpha}
\end{bmatrix} \begin{bmatrix}
i_{\alpha} + P_m \\
i_{\beta} + q_i
\end{bmatrix} (13)
\]

In the above equation, \( v_{\alpha} \) and \( v_{\beta} \) are grid voltage and \( (i_{\alpha})^* \) and \( (i_{\beta})^* \) are reference currents of system at \( \alpha \beta \). Reference current could be written in abc coordinates as follow:

\[
\begin{bmatrix}
i_{a}^* \\
i_{b}^* \\
i_{c}^*
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & 0 & 0 \\
-1/2 & \sqrt{3}/2 & 0 \\
-1/2 & -\sqrt{3}/2 & 0
\end{bmatrix} \begin{bmatrix}
i_{\alpha}^* \\
i_{\beta}^* \\
i_{\gamma}^*
\end{bmatrix} (14)
\]

In order to divide reference current between inverters, low-pass filter is used to separate high and low frequency components. Low frequency component is compensated based on first (IGBT) inverter and MOSFET based inverter is used for high frequency reference current. Finally note that, for balancing and controlling of DC capacitors voltage, converter may absorb small amount of active power from the utility which is not subject of this paper.

### III. SIMULATION RESULTS

In this section, in order to investigate accuracy of proposed control strategy, grid connected system is simulated according to equations...
of section III with MATLAB / Simulink. In this simulation the DC link capacitors totally assumed to be 10 mF and coupling inductor is 500 Micro-Henry. The hysteresis width is adjusted so that the switching frequency of first inverter is near 2.5 kHz.

Performance of B6 inverters in sinusoidal reference current situation is shown in Fig.9. Performance of grid connected wind system during reactive power compensation is illustrated in Fig. 10. It could be seen that in spite of phase difference between voltage and current of load, system compensates all reactive power demand of load and finally grid voltage and current are in the phases (Fig. 10). It should be mentioned that during operation of wind turbine, it is possible to generate active power and it will be injected into the network, there will be 180 degree phase difference. Finally, response of the proposed control strategy beside nonlinear loads is shown in figure (11). It is observed that in despite of severe harmonic components in load current (three-phase diode rectifier with highly inductive load is used as a non-linear load in this case) grid current is perfectly sinusoidal without harmonics.

### REFERENCES

