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Some Studies on PWM Converter Controlled Wind Energy Conversion System

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Abstract: ***Wind power is a green renewable source of energy that can compete effectively with fossil fuel as a generator of power in the electricity market. The main parts of a Wind Turbine System (WTS) are rotor, gearbox, generator, transformer and possible power electronic system (PES). Wind turbines require certain control systems. Horizontal-axis wind turbines have to be oriented to face the wind. In high winds, it is desirable to reduce the drive train loads and protect the generator and the power electronic equipment from overloading by limiting the turbine power to the rated value up to the furling speed. At gust speeds, the machine has to be stalled. At low and moderate wind speeds, the aim should be to capture power as efficiently as possible. The high efficient power electronics in power generation, power transmission/distribution and end-user application is being used to control. This paper deals with the discussion and control of the most em****erging renewable energy source****, wind energy, with the help of PWM converter. Due to this power electronics system, it is changing from being a minor energy source to be acting as an important power source in the energy system.***

Keywords: Wind Energy Conversion System, Power Electronic System, PWM Converter, Double Fed Induction Generator, Rotor Side Converter, Grid Side Converter.

1. Introduction

In classical power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centers over long distance transmission lines. The system control, monitor and regulate the power system continuously to ensure the quality of the power, namely frequency and voltage. However, now the overall power system is changing, a large number of dispersed generation (DG) units, including both renewable and non-renewable sources such as wind turbines, wave generators, photovoltaic (PV) generators, small hydro, fuel cells and gas/steam powered Combined Heat and Power (CHP) stations, are being developed [1], [2] and installed.

Wind energy is recognized as a viable source of renewable energy, mainly because it is considered as inexhaustible and can be converted into electrical energy through various conversion systems. Many researchers have recently focused on conversion systems in their works in order to maximally benefit from this nonpolluting and promising energy source. As far as variable-speed generation is concerned, it is necessary to produce constant frequency electric power from a variable speed source. A typical wind energy conversation system consists of three major devices making up a wind turbine that convert wind energy to electrical energy. The first device is the rotor which consists of two or three fiber glass blades joined to a hub that contains hydraulic motors that change each blade according to prevailing wind conditions so that the turbine can operate efficiently at varying wind speeds. The nacelle is a large housing behind the rotor that houses the drive shaft, gearbox, transformer and generator. The nacelle is usually mounted over a yaw gear which turns it and the rotor so that the wind is normal to the rotor plane all the time for maximum tapping of energy from the wind. The tower supports the rotor and the nacelle.

The kinetic energy in the wind is converted into the mechanical energy by the turbine by way of shaft and gearbox arrangement because of the different operating speed ranges of the wind turbine rotor and generator. The generator converts this mechanical energy into electrical energy. The main parts of a Wind Turbine System (WTS) are rotor, gearbox, generator, transformer and possible power electronic system (PES). The turbine rotor converts the fluctuating wind energy into mechanical energy, which is converted into electrical power through the generator and then fed into the grid through transformers and transmission lines. In a variable speed WTs, the generators are controlled and connected to the grid via a PES, which makes it possible to control the rotor speed. The power fluctuations caused by wind variations can be more or less absorbed by changing the rotor and thus power variations originating from the wind conversion and the drive train can be reduced. Mainly for variable speed wind systems, SCIG or wound rotor induction generator (WRIG), synchronous generator (SG) or permanent magnet synchronous generator

(PMSG) and doubly fed induction generator (DFIG) are used. The DFIG is a wound rotor induction generator having three phase windings on the rotor and stator. The stator is directly connected to the grid and the rotor power is fed by variable frequency bidirectional. The PES consists of two widely used back to back PWM voltage fed current regulated converters (VSC) namely, the rotor side converter (RSC) and grid side converter (GSC) which are controlled independently. The RSC is used to convert the rotor frequency power to DC power and then feedback to the AC utility grid using the GSC, which converts DC power to AC power at the grid frequency. The converter model in DFIG system comprises of two pulse width modulation inverter connected back to back via a DC link. The rotor side converter (RSC) is a Controlled voltage source as since it injects an AC voltage at a slip frequency to the Rotor. The grid side converter (GSC) acts as a controlled voltage source and maintains the dc link voltage constant. This paper will first discuss the basic development in power electronics and power electronic conversion and also the control of wind turbine.

2. Wind Energy Conversion System

A Wind Energy Conversion System (WECS) is a system which helps to produce electricity from natural source. It transforms the kinetic energy of the incoming air stream into electrical energy. Wind turbine rotor turns under the wind stream action and hence produces mechanical energy. A rotating electrical machine, generator, driven by the rotor converts the mechanical energy to electrical energy and hence produces electric power.

The wind turbine has two basic configurations; one is Vertical Axis Wind Turbines (VAWT) and Horizontal Axis Wind Turbines (HAWT). HAWT is dominating now in the world, with either two or three blades.

The energy conversion chain is organized into four subsystems:

- Aerodynamic subsystem, consisting mainly of the turbine rotor, which is composed of blades, and turbine hub, which is the support for blades;
- Drive train, generally composed of: low-speed shaft – coupled with the turbine hub, speed multiplier and high-speed shaft – driving the electrical generator;
- Electromagnetic subsystem, consisting mainly of the electric generator;
- Electric subsystem, including the elements for grid connection and local grid.

To make the blades perpendicular to the wind direction, the nacelle is being moved, which is a part of a mechanism for all types of wind turbines. While converting the power, some losses occur because of non-zero wind velocity behind the wind turbine rotor one can easily understand that its efficiency is less than unity. WT can operate either at a fixed speed (actually within a speed range of about 1%) or at variable speeds. Here, we will deal with a variable speed wind turbine. So, we will discuss the variable speed WECS.

2.1 Variable Speed WECS

Variable speed WTs are currently the most used WECS. The variable speed operation is possible due to the power electronic system converters interface, allowing a full (or partial) decoupling from the grid. The DFIG is a Wound Rotor Induction Generator (WRIG) with the stator windings connected directly to the three phases, constant-frequency grid and the rotor windings connected to a back-to-back (AC–AC) voltage source converter. Thus, the term "doubly-fed" comes from the fact that the stator voltage is applied from the grid and the rotor voltage is impressed by the power converter. This system allows variable-speed operation over a large, but still restricted, range, with the generator behavior being governed by the power electronics converter and its controllers. The power electronics converter comprises of two IGBT converters, namely the rotor side and the grid side converter, connected with a direct current (DC) link. As it is discussed further, briefly we can say that the main idea is that the rotor side converter controls the generator in terms of active and reactive power, while the grid side converter controls the DC-link voltage and ensures operation at a large power factor. The stator outputs power into the grid all the time. The rotor, depending on the operating point, is feeding power into the grid when the slope is negative (over synchronous operation) and it absorbs power from the grid when the slip is positive (sub-synchronous operation). In both cases, the power flow in the rotor is approximately proportional to the slip. The size of the converter is not related to the total generated power but to the selected speed variation range. Typically a range of 45% around the synchronous speed is used DFIG-based WECS are highly controllable, allowing maximum power extraction over a large range of wind speeds. Furthermore, the active and reactive power control is fully decoupled by independently controlling the rotor currents. Finally, the DFIG-based WECS can either inject or absorb power from the grid, hence actively participating at voltage control.

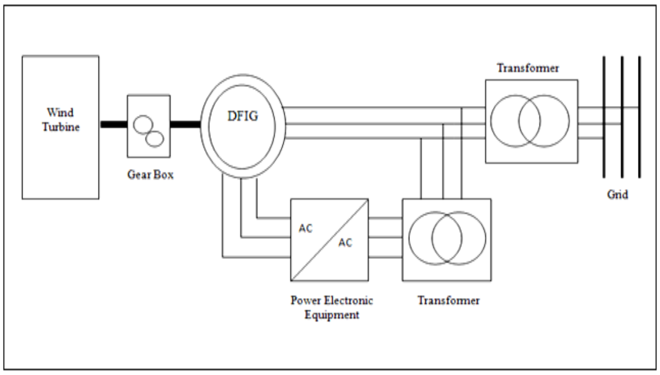

Figure 1: Schematic of variable-speed wind turbine with DFIG

3. Back to Back PWM Converter in DFIG

Doubly Fed Induction Generator is an induction generator of the wound rotor type consisting of 3ϕ windings on the rotor and stator. As shown earlier in Figure (1) that the stator is directly connected to the grid and the rotor power is fed by variable frequency bidirectional PES. The Power Electronic System consists of two widely used back to back PWM voltage fed current-regulated converters (VSC), the converters are Rotor Side Converters (RSC) and Grid Side Converters (GSC). Both RSC and GSC are controlled independently. DFIG can be operated as a generator as well as motor in both sub-synchronous and super synchronous speeds utilizing the RSC control appropriately as RSC is used to convert the rotor frequency power to dc power and then feedback to ac utility grid using the GSC, which converts dc power to ac power at the grid frequency.

To decrease the harmonic distribution and to increase the controllability of the system and to improve the dynamic performance, this PWM technique is used [3]-[6].There are some drawbacks, among which main is the high cost and the reduced lifetime due to the presence of a DC-link capacitor.

To achieve full control of the grid current, the dc-link voltage must be boosted to a level higher than the amplitude of the grid line voltage. The control of the generation side is set to suit the magnetization demand and the reference speed while the power flow of the grid side converter is controlled in order to keep the dc-link voltage constant [7]-[15].

The vector control method [16]-[20] is very extensively used in DFIG systems. The vector control method for the RSC ensures a decoupled control of stator side active and reactive power exchanges from the grid. For the GSC, the vector control method is to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power, while keeping sinusoidal grid currents.

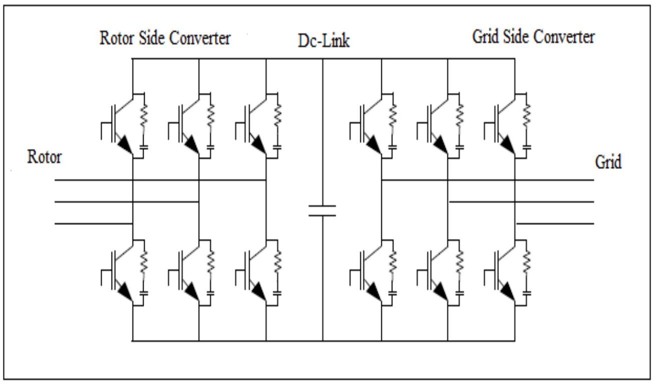

Figure 2: Back to back connected power converter bridge

As in Figure (2), the standard three-phase bridge topology is employed for the converters. The rotor currents can be controlled in a desired phase with a PWM converter in the rotor circuit. This enables the bidirectional flow of active power between the rotor and grid and the system can operate in sub-synchronous and super-synchronous speeds. The capacitor in the dc-link acts as a source of reactive power and it is possible to supply the magnetizing current, partially or fully, from the rotor side. The stator side power factor can thus be controlled.

3.1 Equivalent Circuit Diagram of DFIG

In the Figure (3) given below, the equivalent circuit diagram of the DFIG is shown by the inclusion of the magnetizing losses.

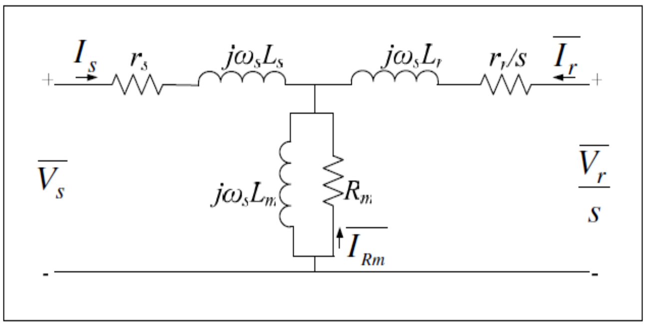

Figure 3: Equivalent circuit diagram of doubly fed induction generator

The equivalent circuit for the DFIG becomes the equivalent circuit for an ordinary SCIG, if the rotor voltage, $\overline{V_r}$ is short circuited. Now, on the rotor side, the resistance and leakage reactance per phase of the rotor winding are r_r and $j\omega_s L_r$ respectively and similarly on stator side the r_s and $j\omega_s L_s$ are the resistance and leakage reactance per phase of the stator winding. The mutual reactance is $j\omega_s L_m$. The rotor resistance, r_r, is modified as r_r / s, when the rotor rotates at angular velocity of ω_r electrical rad/s, where s is the slip and equals $(1-\omega_r / \omega_s)$. The RSC injects balanced three phase voltages (V_{ra}, V_{rb}, V_{rc}) at slip frequency, $s\omega_s$. Because Figure (3) is represented based on the stator-side frequency, ω_s, the voltage phasor, $\overline{V_r} = V_r \angle \delta$, has also to be divided by the slip, s, resulting in the equivalent rotor voltage $(V_r \angle \delta)/s$. Applying Kirchhoff's voltage law to the equivalent circuit shown in Figure (3), one can obtain

$$\overline{V}_s = r_s \overline{I}_s + j\omega L_s \overline{I}_s + j\omega_s L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) \tag{1}$$

$$\frac{\overline{V}_r}{s} = \frac{r_r}{s}\overline{I}_r + j\omega L_r \overline{I}_r + j\omega_s L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) \tag{2}$$

$$0 = R_m \overline{I}_{Rm} + j\omega_s L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) \tag{3}$$

Where, $\overline{V_s}$ is the stator complex voltage per phase, $\overline{I_{Rm}}$ is the core loss current. The air-gap flux, stator flux and rotor flux are defined as

$$\overline{\psi}_m = L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) \tag{4}$$

$$\overline{\psi}_s = L_s \overline{I}_s + L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) = L_s \overline{I}_s + \overline{\psi}_m \tag{5}$$

$$\overline{\psi}_r = L_r \overline{I}_r + L_m(\overline{I}_s + \overline{I}_r + \overline{I}_{Rm}) = L_r \overline{I}_r + \overline{\psi}_m \tag{6}$$

3.2 DC-link Model

The rate of change of energy in the dc-link capacitor is dependent on the power delivered to the grid through GSC, P_g and the power delivered to the rotor circuit of the DFIG, P_r. The losses in the converter is very small, hence they are neglected.

$$\frac{d}{dt}E_{dc} = \frac{1}{2}C_{dc}\frac{d}{dt}V_{dc}^2 = -P_g - P_r \tag{7}$$

Where, E_{dc} is energy stored in the dc-link capacitor, C_{dc}. V_{dc} is the dc-link voltage. This means that the dc-link voltage will vary as

$$C_{dc}V_{dc}\frac{d}{dt}V_{dc} = -P_g - P_r \tag{8}$$

Which means that, if $P_g = -P_r$, the dc-link voltage will be constant

3.3 Rotor Side Converter (RSC) control

The controlling principle of the Rotor Side Converter (RSC) allows the control of active and reactive power and the extraction of maximum wind power. For easy control, both stator and rotor quantities are transformed to a reference frame that rotates at an angular frequency identical to the stator magneto-motive force. The reference frame speed equals the synchronous speed at steady state. The active power or torque can be controlled by the q-axis rotor currents and reactive power can be controlled by controlling the d-axis rotor current in stator flux oriented control. The stator flux angle, which is determined dynamically to map the stator and rotor quantities into the new reference frame, is used. The flux angle $\left(\rho_s\right)$ is the angle between the stator flux linkage phasor and the stationary d-axis (assuming that all the stator and rotor currents are calculated in a stationary reference frame).

$$\rho_s = \tan^{-1}\left(\frac{\psi_{qs}}{\psi_{ds}}\right) \quad (9)$$

Where, ψ_{qs} and ψ_{ds} are the d-q axis stator flux linkage components in the stationary reference frame. It can be shown that the choice of the stator flux-oriented reference frame results in a decoupled control of stator side active and reactive powers. The stator flux linkages expressed in the new reference frame are

$$\left.\begin{aligned} \psi_{ds}^{\psi_s} &= L_s i_{ds}^{\psi_s} + L_m i_{dr}^{\psi_s} \text{ and} \\ \psi_{qs}^{\psi_s} &= L_s i_{qs}^{\psi_s} + L_m i_{qr}^{\psi_s} \end{aligned}\right\} \quad (10)$$

Where

$$L_s = L_{ls} + L_m \quad (11)$$

Since, the x-axis of the new reference frame is aligned with the stator flux linkage vector, $\psi_{sq}^{\psi_s} = 0$. Thus,

$$\left.\begin{aligned} i_{qs}^{\psi_s} &= -\frac{L_m}{L_s} i_{qr}^{\psi_s} \text{ and} \\ i_{ds}^{\psi_s} &= \frac{L_m}{L_s}\left(i_{ms} - i_{dr}^{\psi_s}\right) \end{aligned}\right\} \quad (12)$$

Where the stator magnetizing current is

$$i_{ms} = \frac{\psi_s^{\psi_s}}{L_m} = \frac{\psi_{ds}^{\psi_s} + j\psi_{qs}^{\psi_s}}{L_m} = \frac{\psi_{ds}^{\psi_s}}{L_m} \quad (13)$$

The stator side active and reactive powers are given by

$$P_s = \frac{3}{2}\mathrm{Re}\left(V_s^{\psi_s} i_s^{\psi_s^*}\right)$$
$$= \frac{3}{2}\left(V_{ds}^{\psi_s} i_{ds}^{\psi_s} + V_{qs}^{\psi_s} i_{qs}^{\psi_s}\right) = -\frac{3}{2}\left|\overline{V}_s\right| \frac{L_m}{L_s} i_{qr}^{\psi_s} \quad (14)$$

$$Q_s = \frac{3}{2}\mathrm{Im}\left(V_s^{\psi_s} i_s^{\psi_s^*}\right)$$
$$= \frac{3}{2}\left(V_{qs}^{\psi_s} i_{ds}^{\psi_s} + V_{ds}^{\psi_s} i_{qs}^{\psi_s}\right) = -\frac{3}{2}\left|\overline{V}_s\right| \frac{L_m}{L_s}\left(i_{ms} - i_{dr}^{\psi_s}\right) \quad (15)$$

Where in the stator flux-oriented reference frame, $V_{ds}^{\psi_s} = 0$, $V_{qs}^{\psi_s} = \left|\overline{V}_s\right|$.

Thus, the variations in rotor currents will also reflect in the variation of stator side currents $i_{ds}^{\psi_s}$, $i_{qs}^{\psi_s}$ and hence, in the stator side active and reactive powers as well. This principle has been used in the control of stator active and reactive powers. The control scheme uses a conventional PI controller to obtain the reference value for, $i_{qs}^{\psi_s}$ from active power error, i.e., the difference between desired and actual values of active power. Similarly, a PI controller can be tuned to get the reference value for $i_{ds}^{\psi_s}$ from the reactive error. Since, the objective is to capture the maximum available energy in the wind; the active power reference is made equal to the maximum available WT power. This can be done by implementing a maximum power point tracking (MPPT) algorithm in the outer control loop. The reactive power reference value is derived from the active power reference and the desired value of the power factor. Usually, the reactive power reference is made equal to zero, in order to operate the DFIG at unity power factor. In order to keep the switching frequency constant, it is necessary to calculate the required rotor voltages. The inner loops of the controllers can be derived as follows. The equations of the DFIG rotor variables in the stator flux reference frame can be written as

$$V_{dr}^{\psi_s} = r_r i_{dr}^{\psi_s} + \frac{d}{dt}\psi_{dr}^{\psi_s} - (\omega - \omega_r)\psi_{qr}^{\psi_s} \quad (16)$$

$$V_{qr}^{\psi_s} = r_r i_{qr}^{\psi_s} + \frac{d}{dt}\psi_{qr}^{\psi_s} - (\omega - \omega_r)\psi_{dr}^{\psi_s} \quad (17)$$

$$\psi_{dr}^{\psi_s} = \left(L_{lr} + L_m\right) i_{dr}^{\psi_s} + L_m i_{ds}^{\psi_s} \quad (18)$$

$$\psi_{qr}^{\psi_s} = \left(L_{lr} + L_m\right) i_{qr}^{\psi_s} + L_m i_{qs}^{\psi_s} \quad (19)$$

By substituting fluxes with currents in Equations (16) (17), we get

$$V_{dr}^{\psi_s} = r_r i_{dr}^{\psi_s} + L_{rr}\sigma\frac{d}{dt} i_{dr}^{\psi_s} - s\omega_s L_{rr}\sigma i_{qr}^{\psi_s} \quad (20)$$

$$V_{qr}^{\psi_s} = r_r i_{qr}^{\psi_s} + L_{rr}\sigma\frac{d}{dt} i_{qr}^{\psi_s} - s\omega_s\left(L_{rr}\sigma i_{dr}^{\psi_s} + L_{rr}(1-\sigma) i_{ms}\right) \quad (21)$$

Where

$$\sigma = L_{rr} - \frac{L_m^2}{L_{ss}} \quad (22)$$

Equations (20) and (21) indicate that the dynamics of direct and quadrature components of the machine rotor current are coupled. However, these can be decoupled if they are expressed in terms of auxiliary variables (V_{dr} and V_{qr}) as,

$$V_{dr} = V_{dr}^{\psi_s} + s\omega_s L_{rr}\sigma i_{qr}^{\psi_s} \quad (23)$$

$$V_{qr} = V_{qr}^{\psi_s} - s\omega_s\left(L_{rr}\sigma i_{dr}^{\psi_s} + L_{rr}(1-\sigma)i_{ms}\right) \quad (24)$$

By substituting Equations (23) and (24) in Equations (20) and (21), we get

$$V_{dr} = r_r i_{dr}^{\psi_s} + L_{rr}\sigma \frac{d}{dt} i_{dr}^{\psi_s} \quad (25)$$

$$V_{qr} = r_r i_{qr}^{\psi_s} + L_{rr}\sigma \frac{d}{dt} i_{qr}^{\psi_s} \quad (26)$$

Then, a PI controller can be designed such that

$$V_{dr} = \left(K_{p2} + \frac{K_{i2}}{s}\right)\left(\left(i_{dr}^{\psi_s}\right)^* - i_{dr}^{\psi_s}\right) \quad (27)$$

$$V_{dr} = \left(K_{p2} + \frac{K_{i2}}{s}\right)\left(\left(i_{qr}^{\psi_s}\right)^* - i_{qr}^{\psi_s}\right) \quad (28)$$

The complete block diagram of the RSC is shown in Figure 4.

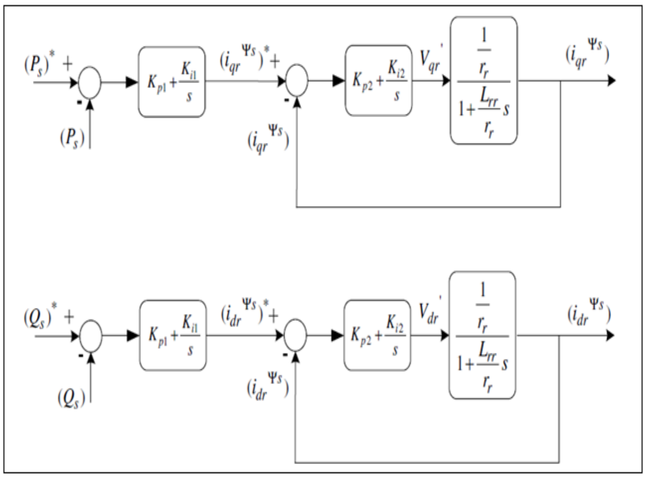

Figure 4: Rotor-side converter control scheme

3.4 Grid Side Converter (GSC) control

The dc-link voltage has to be kept constant irrespective of the direction of rotor power flow. Decoupled controls of active and reactive powers flowing between rotor and grid are performed by using supply voltage vector oriented control.

In this type of control, the d-axis current (i_d) is controlled to keep the dc-link voltage constant and the q-axis current (i_q) is used to obtain the desired value of reactive power flow between the GSC and the point of common coupling (PCC). The control makes use of the supply voltage angle determined dynamically to map the supply voltage, the converter terminal voltage and the phase currents onto the new reference frame. First, the supply voltage angle (θ_s) has to be determined. By definition, the supply voltage angle is

$$\theta_s = \tan^{-1}\left(\frac{V_{qs}}{V_{ds}}\right) \quad (29)$$

Where, V_{ds} and V_{qs} are the d-q axis stator voltages in the stationary reference frame. The active axis (d-axis) is aligned with the supply voltage phasor. Thus, $V_{qs}^{V_s} = 0$. Hence, the active and reactive powers between the GSC and the grid are

$$P_g \approx \frac{3}{2} V_{ds}^{V_s} i_{dg}^{V_s} \quad (30)$$

$$Q_g \approx -\frac{3}{2} V_{ds}^{V_s} i_{dg}^{V_s} \quad (31)$$

The energy balance in the dc-link capacitor is governed by

$$\frac{1}{2} C_{dc} \frac{d}{dt} V_{dc}^2 = -P_r - P_g = -P_r - \frac{3}{2} V_{ds}^{V_s} i_{dg}^{V_s} \quad (32)$$

From equation (32), it can be seen that the dc-link capacitor voltage can be controlled through the direct-axis component of the GSC. To get the d-axis current reference from the dc-link capacitor voltage error, the control scheme uses a PI controller. The q-axis current reference can be obtained from the grid voltage error. Usually, no reactive power to the grid is supported from the GSC. So, the q-axis current reference can be set to zero. But advanced GCR requires active support from wind power generation to the utility grid; hence, reactive power can be demanded from GSC.

The equations of the grid side converter in the stator voltage reference frame are given below (as shown in Figure (5))

$$V_{ds}^{V_s} = R_f i_{dg}^{V_s} + L_f \frac{d}{dt} i_{dg}^{V_s} - \omega_s L_f i_{qg}^{V_s} + V_{dg}^{V_s} = \left|V^s\right| \quad (33)$$

$$V_{qs}^{V_s} = R_f i_{qg}^{V_s} + L_f \frac{d}{dt} i_{qg}^{V_s} - \omega_s L_f i_{dg}^{V_s} + V_{qg}^{V_s} = 0 \quad (34)$$

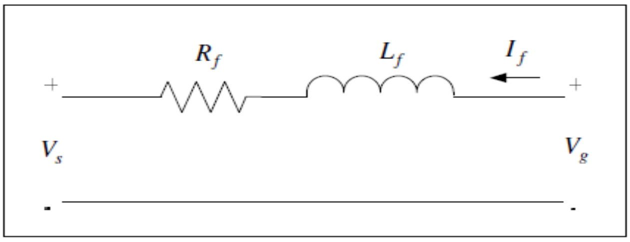

Figure 5: Grid-side converter filter model

Where R_f and L_f are the grid filter resistance and inductance, respectively; $i_{dg}^{V_s}$ and $i_{qg}^{V_s}$ are the d-q axis grid filter currents in grid currents in grid voltage reference frame; $V_{dg}^{V_s}$ and $V_{qg}^{V_s}$ are the d-q axis GSC voltages at the AC terminals in the grid voltage reference frame. Equations (33) and (34) indicate that the dynamics of direct and quadrature components of the GSC current are coupled. However, these can be decoupled if these are expressed in terms of auxiliary variables (V_{dg} and V_{qg}) as

$$V_{dg} = V_{dg}^{V_s} + \omega_s L_f i_{qg}^{V_s} - V_{dg} \quad (35)$$

$$V_{qg} = -\omega_s L_f i_{dg}^{V_s} - V_{qg} \quad (36)$$

By substituting Equations (35) and (36) in Equations (33) and (34), we have

$$V_{dg} = R_f i_{dg}^{V_s} + L_f \frac{d}{dt} i_{dg}^{V_s} \quad (37)$$

$$V_{qg} = R_f i_{qg}^{V_s} + L_f \frac{d}{dt} i_{qg}^{V_s} \quad (38)$$

Then, a PI controller can be designed such that

$$V_{dg} = \left(K_{p4} + \frac{K_{i4}}{s}\right)\left(\left(i_{dg}^{V_s}\right)^* - i_{dg}^{V_s}\right) \tag{39}$$

$$V_{qg} = \left(K_{p4} + \frac{K_{i4}}{s}\right)\left(\left(i_{qg}^{V_s}\right)^* - i_{qg}^{V_s}\right) \tag{40}$$

The complete block diagram of the GSC is shown in Figure 6.

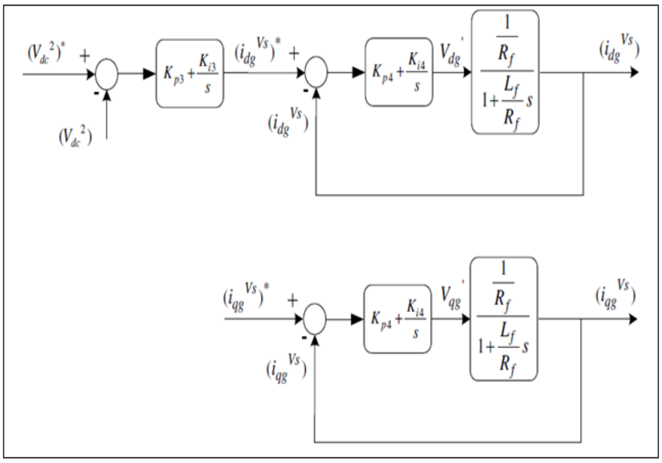

Figure 6: Grid-side converter control scheme

4. Discussion and Conclusion

Power Electronic System (PES) is being used widely and due to its varied fast development, both enlargement of capabilities and lower price per KW capacity is offered. Advancement of the wind power technology set very high targets for wind power generation in the world. However, large amount of wind power integration into the grid causes power quality and stability problems due to the intermittent characteristics. Therefore, strict grid codes are being developed for wind farm connections. Voltage control capability, frequency control ability and fault ride through capability are among their primary concerns. Nowadays, to remain connected to the grid during grid events MW size wind farms is required else it can cause blackouts.

In the electronic world, PES is being preferred for this type of conditions. Due to this solution, variable speed wind WT concept is used. DFIGs are popular in wind power development due to their variable speed operation capability. The voltage control at the DFIG wind farm has been identified as the latest challenge with the present grid code requirements. The advantage of this method is that it does not involve any mechanical action and is smooth in operation. Consequently, the variable speed variation is attraction WT within wind farms for a number of reasons, including reduced mechanical stress, increased power capture, reduced noise and its controllability which is a prime concern for the grid integration of large and wind farms. A disadvantage of this PES is that fast variation of speed requires a large difference between the input power and the output power which scales at the moment of inertia of the rotor. This results in a large torque and hence increased stress on the blades. Moreover, continuous control of the rotor speed by this method implies continuous fluctuation of the power output to the grid which is usually undesirable to the to the power system.

The variation in speed can cause change in frequency, which can be controlled by PES. The presence of wind generators operating with a frequency control may contribute to increase system robustness, reducing frequency excursions following system disturbances. Such a control approach allows increasing wind power penetration in a system, with particular benefits for isolated systems. During wind turbulences, controllers like pitch angle controller actuates and the output power is maintained within the desired value. Pitch control is an effective way to satisfy these power requirements, since it regulates the wind power extraction directly. Nonlinear controllers, such as gain scheduling and neural network controllers, are suitable for the pitch control due to the high nonlinear property of turbine aerodynamics. The pitch control is coordinated with the generator speed control and can be used for limiting the generator speed range. The dc-link voltage is chosen as the control target for the active power balancing purpose. For active and reactive power control the back to back converter or PES is being used. To have a better control in the reactive power, FACTS devices (such as STATCOM, SVC) can be integrated. These FACTS devices will help to control the power in more advanced way. Moreover, these devices are more attractive, because their operation is not so strongly dependent on the grid conditions. In the future, further developments of these wind turbines as well as the power converter based WTs are expected, focusing on more optimized turbines and thus, towards more cost-effective machines.

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