A REVIEW ON VOLTAGE SAG EXTENUATION AND GRID SIDE CONVERTER CONTROL OF DOUBLY-FED INDUCTION GENERATOR

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Abstract: **The wind turbine technique is currently a developed technique. This research review paper conveys an overview of DFIG (Doubly Fed Induction generator) coupled with wind turbine. Recent wind technology includes each feature of grid integration, stability and power quality concerns in arena of reliable power production to consumer end or utility. The research paper offers collective rejuvenation of wind turbine technique over literature review of wind turbine configurations followed by means of discussion of dissimilar control schemes mostly of DFIG (Doubly Fed Induction generator) wind turbine. This research paper contributes appropriate understanding of conceptual experiments directed with DFIG and control schemes together with their physiognomies.**

Keywords: **Doubly-Fed Induction Generator (DFIG), Grid Side Converter (GSC), Rotor Side Converter (RSC).**

I. INTRODUCTION TO DFIG

When a WRIM (Wound Rotor Induction Machine) functions as a generator and is powered by rotor and stator side, it is so-called DFIG (Double Feed Induction Generator). Double Feed Induction Generator plan is used as a fixed frequency variable speed topology. In this illustration, stator is unswervingly associated to network while rotor circuit is associated to network through an AC-DC-AC return to save frequency converter. At this time rating is usually 25 % -30 % of total insignificant power of generator. This is foremost benefit of DFIG (Double Feed Induction Generator) over additional variable speed schemes topologies since it offers same types at a lesser cost and offers good efficacy. The subsequent figure demonstrates an archetypal DFIG (Double Feed Induction Generator) configuration.

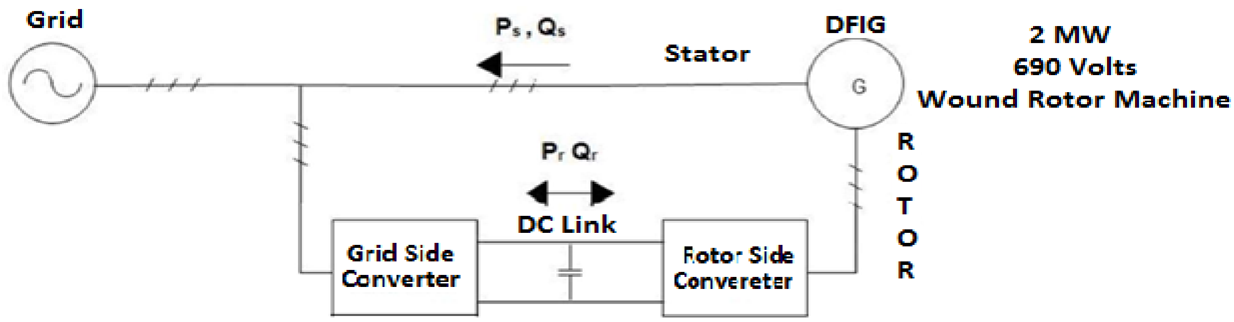

Fig 1.1 Double Feed Induction Generator Configuration

Q_r and P_r are reactive and active power of rotor and Q_s and P_s are the reactive stator and active stator power respectively.

In figure above, we can see that power flow on side of stator is uni-directional, viz., from a stator to a grid. But then again power flow in rotor circuit is bi-directional, viz. one or the other a rotor grid or a grid rotor. Typically power deviation because of the wind variation is bringing about by this rotor circuit. The insignificant power of circuit, other than that of converters, is consequently lesser than that of main machine (usually amid 20 % and 30 % of machine capacity).

WORKING PRINCIPLE

At any time a fixed speed SCIG (Squirrel Cage Induction Generator) is conditional on capricious wind its rotor speed vicissitudes with variation of speed of wind. Meanwhile it can't be compensated by any means (there is no provision permitting power to flow on side of rotor), so this rotor variation the speed consequences in a variation of output frequency (viz. stator frequency).

It can be seen that, with discrepancy of speed of rotor, stator frequency fluctuates, which is disagreeable. The solution to problematic is to use fixed capricious speed frequency generators. DFIG (Double Feed Induction Generator) is a widely held form of capricious speed generator whose stator frequency is given by subsequent formula:

$$F_{STATOR} = \pm F_{ROTOR} \qquad 1.1$$

From above equation, we can see that, although speed of rotor varies, modifying the rotor frequency properly, we can get a constant stator frequency. It's is the principle of DFIG (Double Feed Induction Generator).

When generator is in super-synchronous mode, viz. when it is running above synchronous speed and then to keep rotor frequency at a constant value we have to include a negative frequency factor ($-f_{rotor}$). At this time, negative components mean that energy is delivered by rotor at gate.
Correspondingly, when generator is running at a speed under synchronous speed, we need to include a positive rotor frequency ($+f_{rotor}$), in order to sustain the stator frequency at a constant value.

For the duration of synchronous speed, rotor frequency will be zero which is a pure DC current is sent to rotor. So we can say that in synchronous speed, DFIG (Double Feed Induction Generator) will be performing as a synchronous generator.

In other words, we can say that when turbine speed surpasses the synchronous speed, energy content of rotor intensifications, which tries to accelerate rotor. On the other hand with the help of a good control system in DFIG (Double Feed Induction Generator), this extra power in rotor is take out and transmitted to network, henceforth rotor speed as well as output frequency vestiges constant. This operational mode is so-called super-Synchronous mode in which power flow in rotor circuit is on side of rotor at gate side.

On the contrary, in sub-synchronous mode, when rotor is trying to slowdown, it is powered and it employs a driving action to sustain its speed at a synchronous speed and consequently in this mode power flow is on side of gate at side of rotor. The direction of DFIG (Double Feed Induction Generator) power flow in together super-synchronous and sub-synchronous mode is presented in the figure further down.

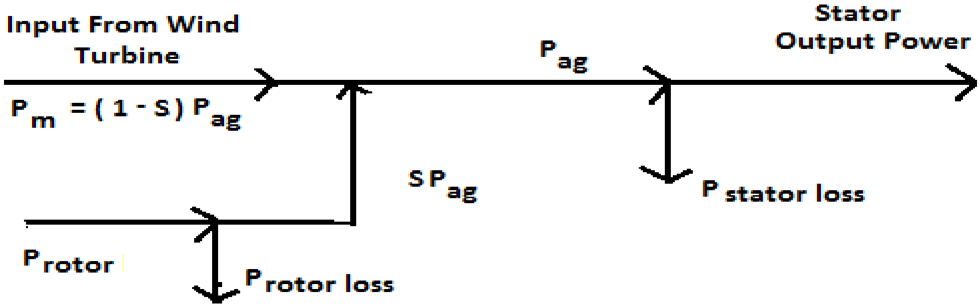

Fig 1.2 Sub-Synchronous Power Flow in DFIG

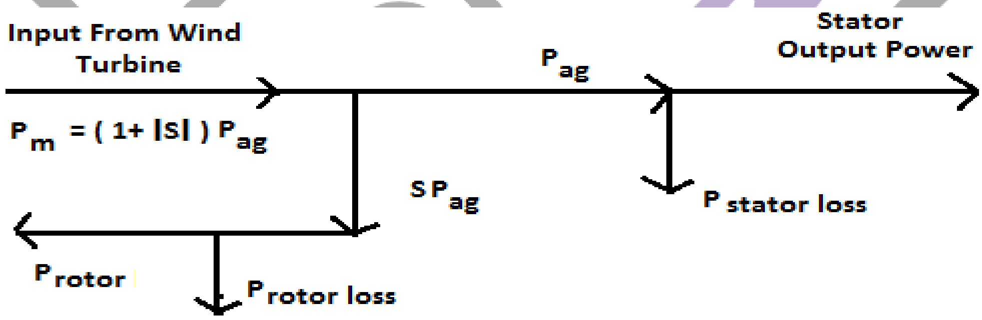

Fig 1.3 Super-Synchronous Power Flow in DFIG

SALIENT ASPECTS OF DFIG

i. Can produce constant frequency and amplitude at stator even if speed of wind is changing viz. capricious speed constant frequency operation.
ii. Can generate even at lesser wind speed.
iii. Permits a speed range of ± 30 % around synchronous speed.
iv. Use a reduced valued AC-DC-AC bi-directional converter (25 % - 30 % of entire rating), henceforth are inexpensive than additional capricious speed generator.
v. Can control power factor (Cos Φ) consequently as to run it as a unity power factor device.

DFIG CONTROL SCHEMES

DFIG (Doubly Fed Induction Generator) control can be attained by controlling side of rotor power flow. Consequently By controlling side of rotor power converter (viz. Grid Side Convertor and Rotor Side Convertor), we can control DFIG (Doubly Fed Induction Generator) entirely. To confirm appropriate functioning, the technique of vector control is usually accepted on both sides. In vector control system, the 3-phases are transmuted into 2-orthogonal repositories amid them and then controlling these 2-components self-sufficiently, decoupled control is acquired. The foremost benefit of this kind of control is that, response will be first and we can self-sufficiently control reactive and active power.

II. GRID SIDE CONVERTER

GSC (Grid Side Converter) control is used to standardize the potential across DC-link and sometime also to compensate harmonics. This is a two-stage controller system which is attained by Grid potential oriented vector control system viz. by line up the dq-axis in direction of grid potential.

The grid converter is usually a 2-level 3-phase VSC (Voltage Source Converter) that uses IGBT (Insulated-Gate Bipolar Transistor) as a switching device. As previous, the foremost aim on grid side. The converter is controlled to adjust the in-between circuit potential. A voltage oriented control system used for network.

MODELLING OF GRID SIDE CONVERTER

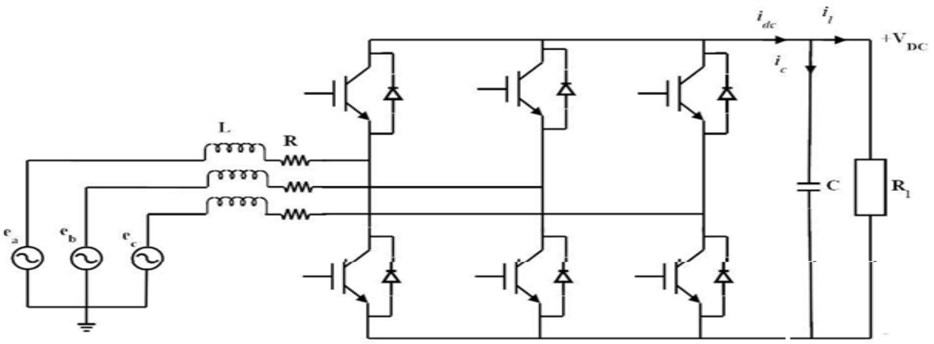

Fig 2.1 Grid Converter Configuration

At this time in figure shows a balanced 3-phase circuit with a network-side converter circuit. A VSC (Voltage Source Converter) switch composed of IGBT (Insulated-Gate Bipolar Transistor) is used now. As presented in figure, the incessant link contains of a filter capacitor (C) feeding a load resistor (R). The foremost goal of the GSC (Grid Source Converter) is to sustain a constant DC-link potential and, if essential, to feed limited reactive power.

At this time, dq-basic frame is specified by:

$$L_g \frac{didg}{dt} = V_{dg} - R_g i_{dg} - V_{dc}\omega_g L_g i_{qg} \quad 2.1$$

and, $$L_g \frac{didg}{dt} = V_{qg} - R_g i_{qg} - V_{dc}\omega_g L_g i_{dg} \quad 2.2$$

Consequently, the GSC (Grid Source Converter) coupled with reactive power (Q_g) and active power (P_g) are specific as follows,

$$P_g = \frac{3}{2}\left(V_{dg} i_{dg} + V_{qg} i_{qg}\right); \quad 2.3$$

$$Q_g = \frac{3}{2}\left(V_{qg} i_{dg} - V_{dg} i_{qg}\right); \quad 2.4$$

CONTROL OF GSC

At this point, the vector-oriented voltage control arrangement is used to control network-side converter for network side. In this figure the dq-axis of rotating reference frame will pivot end to end the grid voltage. So, V_{dg} will be equivalent to the full network voltage ($V_{dg} = V_g$) and V_{qg} will become zero. This diminishes power equation in subsequent form.

$$P_g = \frac{3}{2}\left(V_{dg} i_{dg}\right); \quad 2.5$$

$$Q_g = -\frac{3}{2}\left(V_{qg} i_{dg}\right); \quad 2.6$$

The grid converter control has 2-control loops. The control system of GSC (Grid Source Converter) is as presented below.

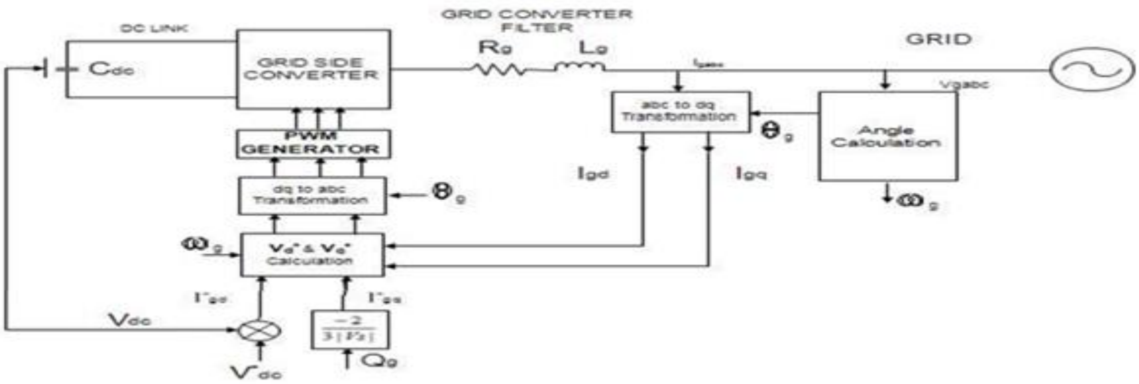

Fig 2.2 Grid Converter Control Scheme

The DC-link potential control loop is developed on principle of power balance on both sides of GSC (Grid Source Converter), that is, DC-link side and grid side. Consequently, in mathematics, we can write:

$$V_{dc} i_{dc} = V_{dg} i_{dg} + V_{qg} i_{qg} \quad 2.7$$

Meanwhile the reference d-axis is oriented in the direction of foremost potential; the V_{qg} component will be zero. So, the equation above will be inscribed as follows:

$$V_{dc} i_{dc} = V_{dg} i_{dg} \quad 2.8$$

But,

$$i_{dc} = i_c + i_1 = C + i_1 \quad 2.9$$

Therefore this equation will be in short form as:

$$\frac{dVdc}{dt} = \frac{V_{dg} i d_g}{CV_{dc}} \quad 2.10$$

If take i_1 as disturbance then, V_{dc} can be controlled by controlling i_{dg} without help. In figure above, DC-link potential is compared with a reference DC-link potential. This reference value of DC-link potential can be calculated from subsequent formula.

$V_{dc,\ min} = V_{gm}$ (For SVPWM switching) 2.11

The difference of two potentials then fed to a PI (Proportional-Integral) controller to attain the reference value i_{gd}^*. In the same way from reactive power (Q_g) we can get reference value of i_{gq}^*. These 2-values are compared with unique dq-value of grid current viz. i_{gd} and i_{gq}. Resultant signal is yet again fed to PI (Proportional Integral) controllers to attain V_{gd}^* and V_{gq}^*. These signals are then converted- reference frame and fed to SVPWM (Space Vector Pulse Width Modulation) generator to generate control pulses. Value of reactive power (Q_g) can be calculated using the formula deliberated earlier.

III. VOLTAGE SAG

The sag of potential is terms specified to this condition of potential irregularity in which the potential will be diminution to a value of 0.1 p.u. at 0.9 p.u. and May well exist for a period of 5 cycles to 1 minute. The most common cause for sagging potential is faults in network. These flaws may be symmetrical 3-phase or asymmetric sort faults Line to Line (L-L), Line to Line to ground (L-L-G) or Line to Ground (L-G) fault. An additional cause for sagging of potential is unexpected load of power system. Sagging can also arise because of powering up weighty loads or starting up large industrial engines. When a hefty load is allied to network unexpectedly, it draws its reactive energy from network. As Synchronous generator excitation scheme will take certain time to compensate for this intensification reactive power demand, reactive power contained in network diminutions. This will outcome in pressure drop.

EFFECT OF VOLTAGE SAG

One of the foremost expectations of control of network converter is that network necessity be stiff. Right here stiffness of network essentially suggests, there will be no irregularity in network potential. On the other hand in practical cases a stiffness of 100 % is not achievable. This fluctuation of grid will source fluctuation of in-between circuit voltage. When this DC-link potential powers a DFIG (Doubly Fed Induction Generator) rotor by means of another converter circuit, this potential variation will supply rotor with reduced potential. In other words, the DFIG (Doubly Fed Induction Generator) rotor will supply inadequate reactive power. So to sustain reactive power demand of machine, DFIG (Doubly Fed Induction Generator) will draw reactive power of network. As reactive power provided by side of rotor is of capricious in nature, so stator will also entice quantity of reactive power. This wills consequence in a potential variation at common point coupling. Consequently, to evade this problem, we necessity take the essential remedies.

MITIGATION OF VOLTAGE SAG

The diminution of voltage fluctuation can be conceded out in two means. A power excellence solution can be completed on load side and on 2nd method we can diminish this voltage loss on network side itself. The first technique is so-called conditioning of load and 2nd a conditioning of line.

UPQC (Unified Power Quality Conditioner) and DVR (Dynamic Voltage Regenerator), STS (Static Transfer Switches) are some instances of conditioning devices used for SAG voltage compensation.

DYNAMIC VOLTAGE RESTORER

Static Compensator Series or usually mentioned to as DVR (Dynamic Voltage Regulator) is a tradition feed device used to diminish difficulties for instance sagging of tension and swell.

It is a series allied device that injects dynamically controlled potential to accurate the disturbance of potential in network. It contains of an energy accumulator, a VSC (Voltage Source Converter), an AC filter and a coupler transformer. The diagram beneath displays an archetypal block diagram of DVR.

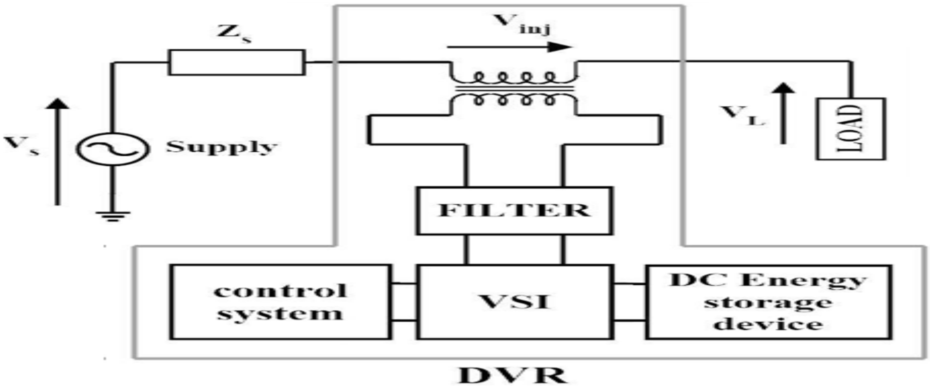

Fig 3.1 Block Diagram Representation of DVR

The energy storage device delivers the energy requisite to overawe this voltage sag. Generally, the insignificant voltage of energy storage devices is fairly low. So for interface with VSI (Voltage Source Inverter), the boost converter is used amid an energy storage device and a DC storage device.

The response of boost converter is allied to a DC-link capacitor which is a usual voltage source for inverter. The inverter produces a compensation potential that is conveyed to grid through a series transformer. The explanation of numerous tools will deliberate as follows.

ENERGY STORAGE DEVICE

Numerous kinds of energy storage devices are commercially accessible, for instance BES (Battery Energy Storage) device, SCES (Super Capacitor Energy Storage) device, SMES (Superconductor Magnetic Energy Storage) device, etc. Every one device has benefits over others and also has restrictions.

A. BATTERY ENERGY STORAGE SYSTEM (BESS)

Batteries are electro-chemical devices, which changes chemical energy into electrical energy and vice-versa. In common, for application of conventional energies, rechargeable batteries or secondary batteries are used. Archetypally, the insignificant voltage and current of each cell are very small. Consequently, to get anticipated voltage and at current level, we attach these cells in parallel series. Numerous kinds of batteries are commercially obtainable. Lithium Ion kind, Lead acid kind, Valve-Regulated Lead-Acid (VRLA) kind, Air Metal, Sodium Sulphur (NaS) are some archetypal instances of batteries. Energy function of a archetypal battery is specified by:

$$E(t) = E_0 + \int V(t).\, i_t \qquad 3.1$$

Where, E_0 exemplifies the initial battery voltage level.

The foremost benefit of BESS over other energy devices is its great energy density.

B. SUPER CAPACITOR ENERGY STORAGE (SCES)

Super Capacitors (SC) are devices that have a high power density and energy compared to conventional electrolytic kind of capacitors. It delivers a high value of capacitance (typically in 1500 F ranges). Different conventional capacitors, SC (Super Capacitor) doesn't use dielectric. It uses actuated carbon to create a physical barrier amid capacitor plates. When electric field is functional to this a double electric field is generated, which performs as a virtual dielectric. The surface created by actuated carbon is very enormous.

Consequently it absorb huge amount of ions. Energy function of SCES (Super Capacitor Energy Storage) is specified by:

$$E(t) = ½\, C\, V_{SC}^2 \qquad 3.2$$

C. SUPERCONDUCTING MAGNETS ENERGY STORAGE (SMES)

SMES (Superconducting Magnets Energy Storage) Devices store energy as a magnetic field, created when an incessant current the current passes through a super-conducting coil. This super-conducting coil is set aside very small temperature (below its critical super-conducting temp.) inside a cryogenic reactor fridge.

The energy function of SMES is specified by:

$$E(t) = ½\, L_{smes}\, I_{smes}^2 \qquad 3.3$$

D. FLYWHEEL ENERGY STORAGE

Flywheel Energy Storage (FES) devices are mechanical energy storing devices which stock energy in form of rotational energy. This scheme is constantly revolving in nature. When energy is stowed in device its speed rise and likewise when energy is take out from it, its speed diminutions. Energy function of archetypal flywheel is specified by:

$$E(t) = \frac{1}{2} J \omega_{fw}^2 \qquad 3.4$$

The subsequent table displays comparison amid numerous energy storage devices.

TYPES OF ENERGY	POWER RANGE	ENERGY RANGE	CHARGE TIME	POWER STORAGE DENISTY
BESS	5 KW-10MW	0.1-600MJ	Hours	10-300
SCES	5-100KW	1KJ-10MJ	Sec to Minutes	2000-10000
SMES	1-50 MW	1-100MJ	Minutes	300-1000
Flywheel	1KW-10MW	1-15MJ	Minutes	1000-10000

Table 3.1 Comparison amid Numerous Energy Storage Devices

Each one of devices has benefits and drawbacks compared to others. BESS (Battery Energy Storage System) has a very great energy density compared to others, but its drawback is its charging and discharging time that is high. In the same way, SCES (Super Capacitor Energy Storage) has a high power density and less charging time, on the other hand its energy density is small compared to BESS (Battery Energy Storage System). SMES (Superconducting Magnets Energy Storage) resides in amid SCES (Super Capacitor Energy Storage) and BESS (Battery Energy Storage System). It has a virtuous power range and its energy density and power are both well. But the foremost drawback in SMES (Superconducting Magnets Energy Storage) is prerequisite of cryogenic filter, which make scheme bulky and affluent. The flywheel has a virtuous power density however modest energy density. Though, the choice of devices depends completely on the kind of operation. For great power application, flywheels are usually used. For DFIG (Doubly Fed Induction Generator) application, BESS (Battery Energy Storage System) or SCES (Super Capacitor Energy Storage are normally used.

CONTROL OF DVR

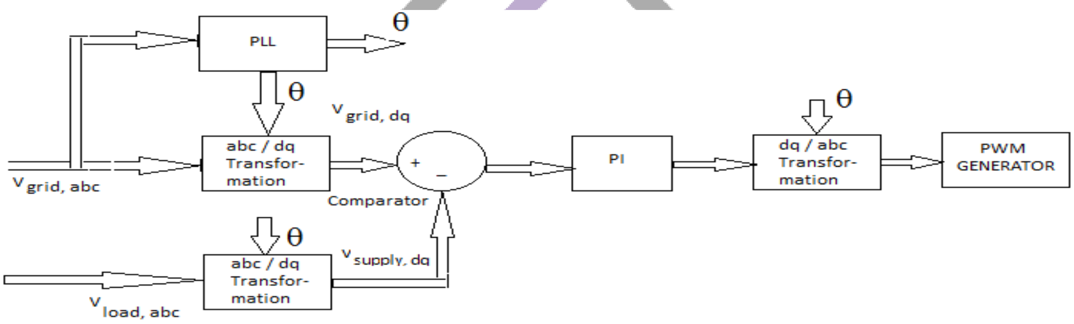

Fig 3.2 DVR Control Scheme

The above control system is used to control inverter circuit of DVR (Dynamic Voltage Regenerator). The potential is detected on side of gate and load and changed into axis dq-axis in rotation. Then both d-axis & q-axis components of each one signal compared and generated error signal are conveyed to the PI (Proportional Integral) controller. Then dq-axis element is changed to a-b-c reference frame and sent to PWM (Pulse Width Modulation) generator for create a pulse signal from inverter.

The DVR (Dynamic Voltage Regenerator) uses numerous methods to compensate for sagging of potential. Some of techniques are pre-slump compensation technique, phase compensation technique, etc.

In pre-slump technique, a potential is detected incessantly and if a disturbance arises will be cleared instantaneously by DVR (Dynamic Voltage Regenerator). In this technique, compensation for both load angles and magnitude arise. Figure (a) displays a technique of compensation of Pre-sag system.

The phase compensation technique is simplest compensation system for sagging of voltage compensation. In this technique only amplitude compensation is completed viz. injection voltage and voltage supply are in similar phase. Figure (b) displays phasor demonstration of in-phase voltage compensation method.

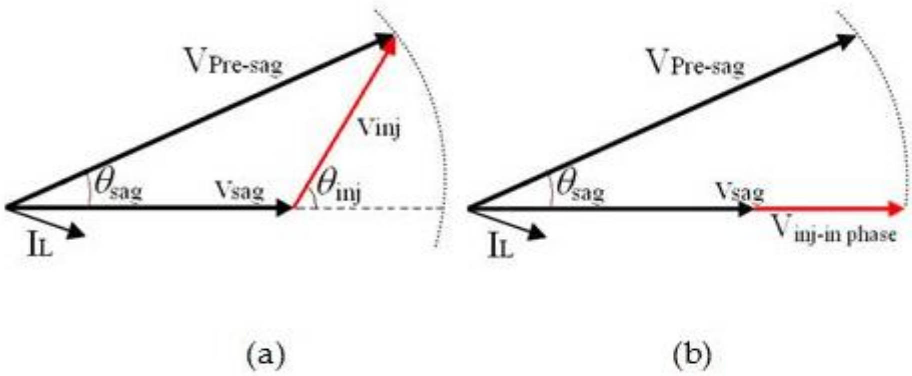

Fig 3.3 Sag compensation Methods (a) Pre-Sag Control System (b) In-Phase Control System

CONCLUSION

This review paper is to analyze a DFIG based wind energy power system and control technique for maximum energy extraction and grid synchronization under stator voltage orientation reference frame and conditions. A rotor-side converter control design has been presented which is the key to work conducted in this paper. The performance assessment of the controller designed has been carried out by analyzing its real/reactive power control in stator-voltage oriented frame, and analyzing its effectiveness in speed control, and the ability of the controller in facilitating effective synchronization with the power grid.

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