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Reactive Power Management for Wind Electric Generator

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Abstract- Energy in the Wind is converted into Rotary Mechanical Energy by the Wind turbine. Most of the Wind Electric Generators are having Induction Motor, (Asynchronous Motor) with constant speed and drawing more Reactive Power from the Grid, during starting / low wind period. This thesis emphasized the need of replacing the existing conventional Asynchronous Induction motor of Constant Speed by Wound Rotor Synchronous Induction motor of variable speed, namely, Doubly Fed Induction Generator (DFIG). The control principle is either the Direct Torque Control (DTC) method, Or, Two – axis Current Vector Control Method. The Direct Torque Control Method is more effective than the two axis current vector control method, for Reactive Power Management for Wind Electric Generator. The minimum usage of only about 30% of Power Electronics results in considerable cost savings and reduction of harmonics when compared with Fully Converter Wind Electric Generators.

Index Terms- Asynchronous Generator, DFIG (Doubly Fed Induction Generator), Direct Torque Control Method, Generator Side Converter, Grid Side Converter, Two Axis Current Vector Control Method, Reactive Power Control, Synchronous Generator.

I. INTRODUCTION

THE mankind has witnessed the tremendous advancement in Science and Technology, modernization and industrialization in the last 100 years, which was not seen for millions of years. Energy had been a key issue to industrialization after discovery of Fossil fuels like Petroleum and Coal. This came together with Pollution of Environment like Air, Water, Earth, including vegetation, animals and even new born Babies. Burning of Fossil Fuel over the last 200 years had added 400 Giga tones of Carbon - di - Oxide into the atmosphere. (1 GT = 1000 Million tones)

The Plants have been able to absorb only 200 GT and the balance is still there in the atmosphere. This is the primary cause of Global Warming and climate change.

It is now felt by mankind through Climate changes, melting of Ice caps in Artic Zone, rise in the sea level reducing the Land area, threat to marine life etc.

The solution to the Global Warming lies in the development of the Green cover or forest cover to absorb the excess CO_2, together with harnessing Renewable Sources of Energy in lieu of Fossil fuel so as to arrest the Pollution level from further increasing.

Carbon Emission, a major cause of Global Warming is primarily due to use of fossil fuels such as Coal and Petroleum in Thermal power Plants and Automobiles. [2] It is proved that Fossil Fuels continue to diminish. [5]

Renewable Energy is energy which comes from Natural Resources such as Sun Light, Wind, Rain, Movement of Water (Hydro Power, ocean Surface Waves – Tide Energy), and Geothermal heat, which are Renewable (Naturally Replenished).[1] Among the said alternative Power Sources, Wind Power is one of the most promising New Energy Sources. Wind is appealing for several reasons. It is abundant, cheap, in-exhaustible, widely distributed, clean and climate-benign, a set of attributes that no other Energy Source can match.[5] Wind has considerable potential as a Clean Energy Source and producing no pollution during Power Generation – GREEN ENERGY DEVLOPMENT. [7]

Harnessing of Wind Energy could play a significant role in the Energy Mix of each Nation. Wind is caused due to the uneven heating of the earth surface by the Sun. The air in contact with the ground gets heated up and becomes light in weight by losing its density and starts rising up. Thus heated air is displaced by the cold air which is higher in density. This is how the air is displaced and set in motion to generate winds and it is called Wind Breeze. The most prominent feature of the Wind Climatology in India is the Monsoon Circulations.

Winds in India are influenced by the strong South-West Summer Monsoon, which starts in May-June, when cool, humid air moves towards the land and weaker North- East Winter Monsoon, which starts in the month of October, when cool dry air moves towards the ocean.

During the period March to August, the kinds are uniformly strong over the whole Indian Peninsula, except the Eastern Peninsular coast. Wind speeds during the period November to March are relatively weaker, though higher winds are available during a part of this period on the Tamil Nadu Coastline. [2]

Also, the State of Tamil Nadu is blessed with conductive Natural Metrological and to geographical settings for wind Energy Generation. Three Passes namely, Palghat Pass, Shengottah Pass and Aralvoimozhi Pass are endowed with heavy Wind Flows due to the Tunneling Effect during South West Monsoon.

Tamil Nadu is endowed with 3 lengthy Mountain Ranges on the Western side with Potential of 1650 MW in Palghat Pass in Coimbatore District, 1300 MW in Shengottai Pass in the Tirunelveli District and 2100 MW in Aralvoimozhi Pass in Kanyakumari District and 450 MW in other areas totaling to 5500 MW. [7]

As on 31.03.2010, the installed capacity of the Wind Electric Generators in Tamil Nadu is 4907 MW, stand first among all the States in India; whereas, the capacity in Maharashtra is 2078 MW; in Gujarath, it is 1864 MW; and in Karnataka, it is 1473 MW. [8]

India stood 5th place all over the world as the installed capacity of the Wind Electric Generators is 13,065 MW; as on 31.12.2010. China stood 1st place, as the installed capacity is 44,733 MW. United States of America stood 2nd place, as the installed capacity is 40,180 MW; Germany stood 3rd place as the installed capacity is 27,214 MW; Spain is having 20,676 MW and stood 4th place. [9]

II. Power Conversion from Kinetic Wind Energy to Rotational Energy:

The Kinetic Energy of a Mass of Air 'm' having the speed v_W is given by:

$$E_k = \frac{m}{2} \cdot v_w^{\ 2}$$

The Power associated to this moving air Mass is the derivative of the Kinetic Energy with respect to time.

$$P_0 = \frac{\partial E_k}{\partial t} = \frac{1}{2} \cdot \frac{\partial m}{\partial t} \cdot v_w^{\ 2} = \frac{1}{2} \cdot q \cdot v_w^{\ 2}$$

Where q represents the mass flow given by the expression

$$q = \rho \cdot v_w \cdot A$$

ρ is the air density and A is the cross section of the air mass flow and 'q' represents the mass flow. Only a fraction of the total Kinetic Power can be extracted by a Wind Turbine and converted into Rotational Power at the shaft. This fraction of Power (P_{wind}) depends on the Wind Speed, Rotor Speed and Blade Position (for Pitch and active stall control turbines) and on the turbine design. (C_P) [3]

The best utilization of the Wind Energy in Wind Electric Generators (WEGs) establishing a theoretical limit for the Power Extraction, independently of the turbine design, at most $\frac{16}{27} \approx 0.593$ (theoretical maximum) of the Wind Kinetic Energy can be converted into Mechanical Energy. [4] Every particle in motion has an associated Kinetic Energy proportional to its mass and the square of its speed. Turbines convert this Kinetic Energy to a mechanical motion and during the conversion process the speed of the flow is reduced. (Bet'z limit)

Finally, the Mechanical Power extracted from the Wind is calculated using:

$$P_{Mech} = \rho / 2 \Pi R^2 \ C (\lambda, \varnothing) v^3 \quad [3]$$

Or, say

$$P_{Wind} = 1/2 \varrho A_{wt} C_p (\lambda,\theta) v^3_{wind} [W]$$

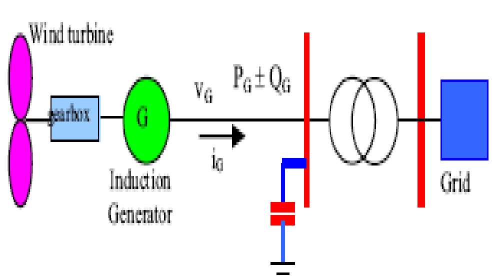
where ϱ is the Air density (Kg/m^3), A_{wt} is the Wind Turbine Swept area in m^2, v_{wind} is the Wind Speed in m/s ; Cp is the Power Co-efficient and dimensionless depends on both the Tip Speed Ratio λ (lower than Bet'z limit) and Pitch angle Ø (degrees) [4]

III. Types of the Wind Electric Generators:

Wind turbines can rotate about either a Horizontal for a Vertical axis, the former being both older and common.

The first electricity generating Wind Turbine was a battery charging machine installed in July 1887 by Scottish academic, James Blyth to light his holiday home in Marykirk, Scotland. The first automatically operated wind turbine, built in Cleveland in 1888 by Charles F. Brush. It was 60 feet (18 m) tall, weighed 4 tons (3.6 metric Tones) and powered a 12 KW Generator. [1]

In the 1990s, wind power turbines were characterized by a fixed-speed operation. Basically, they consisted of the coupling of a Wind Turbine, a Gearbox and an Induction Machine directly connected to the Grid.



Additionally, a soft starter is used to energize the machine and a bank of Capacitors to compensate the machine Power Reactive absorption. Although being simple, reliable and robust, the fixed-speed wind turbines were inefficient and power fluctuations were transmitted to the network due to wind speed fluctuations. [4]

The Induction Generators are gaining the popularity due to its simplicity and no Synchronization problem. However, the major drawback of the Induction Generator is its additional Reactive Burden on the system, where it is connected.

The two most common modern Wind Power Plant configurations are: a) Wind power plants with a Synchronous generator and two full-sized converters or b) doubly-fed induction generators with two converters in the Rotor Circuit. Schematic representations are shown below.

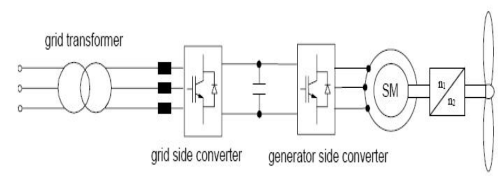


Fig (2) Synchronous Machine – Fully Converter WEG (Using Power Electronics).

In order to enable variable speed operation Synchronous Generators are decoupled from the Power Grid with its fixed frequency (50 or 60 Hz) through two back-to- back frequency converters, which have a common DC-link. The main disadvantage of this topology is that the frequency converters are designed to handle the full Generator power output. This inevitably means higher costs.

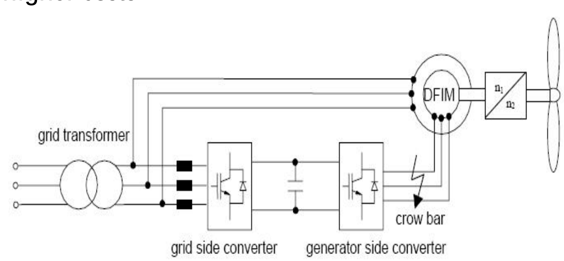


Fig (3) Doubly Fed Induction Generator (Using Power Electronics only on Rotor Side)

Doubly - fed electric machine has windings on both stationary and rotating parts, where both windings transfer significant Power between Shaft and Electrical System. It is useful in applications that require varying speed of the machine's shaft for a fixed Power System Frequency. [6]

III. Analysis and Comparison at par with the P.F (KWhr, rKVAh, and iKVAh) components of the existing Conventional and Fully Converter types WEG(other than DFIG):

Case Study-1:

A conventional WEG ('S'make) having the Induction Squirrel Cage - synchronous Motor, which is directly coupled with the utility Grid, kept installed at Tirunelveli district in Tamil Nadu of India and in working condition till date, is taken for the study purpose.

The Reactive Power compensation is fed by using the Capacitors, in to the circuit, on switched / relay mode, whenever required to carryout the compensation and not by adopting the method of full Controlling mechanism, as available in the Modern Wind Electric Generators. All the parameters have been studied and the details of the month wise Power Factor for the year of 2009 and 2010 are displayed below:

YEAR: 2009 YEAR: 2010

Import

Mon	KWHr	iKVAh	P.F
Jan	234	882	0.27
Feb	630	2574	0.25
Mar	1602	6120	0.26
Apr	2592	9900	0.26
May	648	2250	0.29
June	450	1710	0.26
July	216	990	0.22
Aug	378	1908	0.20
Sep	936	4068	0.23
Oct	756	3438	0.22
Nov	2232	9810	0.23
Dec	1098	4428	0.25

KWHr	iKVAh	P.F
558	2250	0.25
486	1746	0.28
1674	6390	0.26
2070	7668	0.27
2106	7344	0.29
882	2304	0.38
738	2682	0.28
630	2052	0.31
918	3348	0.27
1332	5274	0.25
1260	5148	0.24
2016	8676	0.23

It is understood that the 'S' type WEG is drawing Reactive Power from the Grid and the Power Factor ranging from 0.2 to 0.38 only.

Case Study- 2:

A Modern WEG ('E' make) having Synchronous Motor, with AC-DC-AC Converter and Inverter (Fully equipped with Power Electronics) and kept connected with the Grid, installed at Dindukul district in Tamil Nadu of India and in working condition till date, is taken for the study purpose.

The details of the month wise Active and Reactive Power generated and drawn from the Grid are studied and the Power Factor at the Grid side is charted below.

YEAR: 2010

Import

Mon	KWHr	iKVAh	P.F
Jan	528	1176	0.45
Feb	312	576	0.54
Mar	840	1488	0.56
Apr	768	1272	0.60
May	744	1224	0.61
June	4	144	0.67
July	216	360	0.60
Aug	4	48	1.00
Sep	7	144	0.50
Oct	816	1632	0.50
Nov	768	1272	0.60
Dec	744	1224	0.61

It is understood that the 'E' type WEG is drawing Reactive Power from the Grid with the P.F ranging from 0.45 to 1.00. The Unity P.F has been achieved during August 2010. The reason for the U.P.F is due to the application of Power Electronics & the availability of the continuous Wind and the good condition of the Machine (WEG) during the study period.

IV. The Doubly Fed Induction Machine Concept:

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in Wind Turbines. It is based on an Induction Generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (Brushless Doubly– Fed Electric Machines), but there are problems with efficiency, cost and size. A better alternative is a Brush less Wound Rotor DFIG.

The principle is that Rotor Windings are connected to the Grid via slip rings and back - to - back Voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz).

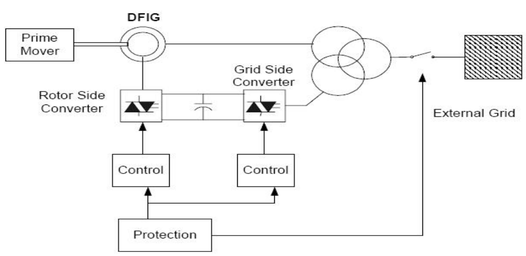


Fig (4) WEG with DFIG Concept

By using the converter to control the rotor currents, it is possible to adjust the Active and Reactive power fed to the Grid from the Stator independently of the Generator's turning speed. The control principle used is either the two-axis current Vector control or Direct Torque Control (DTC) has turned out to have better stability than current vector control especially when high Reactive currents are required from the Generator [1]

The Prime Mover, consisting of a pitch-angle controlled wind turbine, the shaft and the gear-box drives a slip-ring Induction Generator. The stator of the DFIG is directly connected to the Grid; the slip-rings of the rotor are fed by self-commutated converters. These converters allow controlling the rotor voltage in magnitude and phase angle and can therefore be used for Active- and Reactive Power control. [3]

V. Function of the D. F. I. G (Reactive Power Control)

The Wound -Rotor Doubly - Fed Electric Machine is the only Electric Machine that operates with rated torque to twice Synchronous speed for a given frequency of excitation (i.e., 6000 rpm @ 50 Hz and one pole-pair versus 3000 rpm for singly-fed electric machines). Higher speed with a given frequency of excitation gives lower cost, higher efficiency, and higher power density.

In concept, any electric machine can be converted to a Wound – Rotor Doubly -Fed Electric Motor or Generator by changing the rotor assembly to a multiphase wound rotor assembly of equal stator winding set rating. If the rotor winding set can transfer power to the electrical system, the conversion result is a Wound - Rotor Doubly - Fed Electric Motor or Generator with twice the speed and power as the original singly-fed electric machine. The resulting dual-ported transformer circuit topology allows very high torque current without core saturation, all by electronically controlling half or less of the Total Motor Power for Full Variable Speed Control. [1]

Due to the main advantage of allowing Variable - Speed Operation, the Power Extraction from the Wind can be optimized. The converters feed the Low- Frequency Rotor circuits from the Grid. The converters are partially scaled requiring a rated power of about 30% of the generator rating. Usually, the slip varies between 40% at Sub-Synchronous speed and -30% at Super-Synchronous speed. The Grid-Side Converter is controlled to have a Unity Power Factor and a constant voltage at the DC-link.

The Rotor-Side Converter is usually controlled to have (a) Optimal Power Extraction from the Wind and (b) a specified Reactive Power at the Generator terminal. (Sinusoidal 3 Phase Voltages at the Slip Frequency).

Therefore, assuming that the converters are lossless, the Net Power injected by the Generator to the grid is given by

$$P_{gen} = P_s - P_r \qquad Q_{gen} = Q_s \quad [4]$$

VI. Conclusion

It is concluded that a DFIG is a Wound-Rotor Doubly-fed electric machine (basically operates similar to a Synchronous Generator), and as its rotor circuit is controlled by a Power Electronics Converter, the Induction Generator is able to Manage (Control) Import and Export Reactive Power.

Apart from the Reactive Management, the control of the rotor voltages and currents enables the Induction Machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine,especially during light wind conditions.

The cost of the converter is low when compared with other variable speed solutions because only a fraction of the Mechanical Power, typically 25-30 %, is fed to the Grid through the Converter, the rest being fed to Grid directly from the Stator. [1]

The Mechanical Efficiency in a Wind Turbine is dependent of the Power Co-efficient. The Power Co-efficient of a rotating Wind Turbine is given by the Pitch Angle and the Tip Speed Ratio. Adjustable speed will improved the system efficiency since the turbine speed can be adjusted as a function of Wind Speed to maximize output Power.

Also, the Cost of inverter filters is reduced. Filters are rated for 0.25 to 0.30 p.u of the total System Power and Inverter Harmonics represent smaller fraction of Total System Harmonics.

VII. References:

1. Wikipedia Collections – http://en.wikipedia.org/wiki/Wind_power and http: // en.wikipedia.org/wiki/Doubly-fed_electric_machine

2. Karnataka Renewable Energy Dev. Limited., http: // kredl. kar.nic.in/Wind.htm

3. Technical Documentation on Dynamic Modeling of DFIG - http://www.digsilent.de

4. DFIG Machine in Wind Power Generation by Hector A. Pulgar- Painemal, Peter W. Sauer. http: //www. magelab. Com/uploads/4c51ddb 1e2c90.pdf

5. DFIG Control for an Urban Wind Turbine by A. Naamane and N.K.Msirdi. http:// www.irec.cmerp. net /papers /WOE/Paper% 20ID%20160

6.Transients in Doubly Fed Induction Machine due to supply Voltage Sags by Y. Plotkin, C Saniter, D.Schulz and R.Hanitsch. www.ansoft.com/new/ articles /Pape rPCIM05_Plotkin.pdf

7. Tamil Nadu Energy Regulatory Commission (TNERC) Order No: 3 of 2010 Dated 31.07.10.

8. Indian Wind Energy Association Web. http://www.inwea.Org/about windenergy.htm

9.cleantecnica : http://cleantechnica.com/ 2011/04/07/ world-wind-power-capacity-an-idea/

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