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Active and Reactive Voltage Control for DFIG Interface

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ABSTRACT

As the demand for load compensation increases, renewal energy systems are rapidly evolving as a favorable approach in addition to the traditional energy system. Renewable Energy systems are developed to compensate demanded energy based on the renewable resource availability such as the wind, solar, tidal etc. wherein renewable resources are dynamic in nature, the power generation is highly variable and this limits the usage of renewable resource efficiently. Among the renewable power generation, wind power generation has gained higher attention and research is made on the development of new controllers for the design development of new induction generator to improve the generation capability. This paper develops an approach of design of a doubly fed induction generator (DFIG) and its model and presents simulation of method of control.

Key words: DFIG, electrical characteristic, MATLAB modeling, wind turbine.

1. INTRODUCTION

Power generation using wind energy has already taken an advantageous development for load delivery in various real time applications. There are many organizations that have entered into the development of energy from the wind source. At present, a large wind energy industry is growing in many parts of the globe. Wind power generates stimulus to convert from a small generation to a considerable large generation of electricity in power system. Wind power generation using doubly fed induction generator (DFIG) were presented in [1],[2]. Wind energy modeling and control operation for a DFIG design is presented in [3]. Wind power generation is very fast in its growth and the most efficient nontraditional source of energy available in nature. Fixed pitch under variable speed condition [4] or large-grid-connected wind farms [5] have a wide range of applications ranging from a few kilowatts to a few megawatts. Over the last two decades, high energy from the wind generation is linked to the electrical system with the different controlling technologies [6],[7]. In such cases, doubly-fed machines are focused for wind-based generation systems. The most important usage of these machines is by control of rotor current monitored by the applicable field orientation control [8]. They are implemented with inverters, active and reactive power controllers and with regulation of the energy supply to the process, which not only results in a small generation of the system's total power but also compensate the dynamic load demand in the power system. In [9] a steady state modeling of a DFIG design unit is presented. In [10] a DFIG unit controlled by the vector control is presented which is an optimal approach for high performance variable speed drives and applications. In the dynamics of wind variability, the design of DFIG unit, is the important need for developing complete wind power system and to increase the wind energy efficiency. For the design implementation of DFIG unit and control operation, in this paper a mathematical modeling and control operation using the direct and reactive component is presented. To present the outlined design this paper is defined in six sections. Section 2 presents DFIG operation. A simple model of DFIG is given in section 3. Simulation results and electrical analysis for such a system are given in section 4. The presented work is concluded in section 5.

2.DFIG OPERATION

The traditional induction machine may have its rotor as cage type or wound rotor type. When this machine is singly fed either by electrical energy to stator or mechanical energy to rotor, it works as motor or generator respectively. The machine that is fed from two sides is an essentially a generator whose rotor is with winding and is doubly fed as shown in Figure 1. The rotor is mechanically fed by wind turbine and electrically fed by converter.

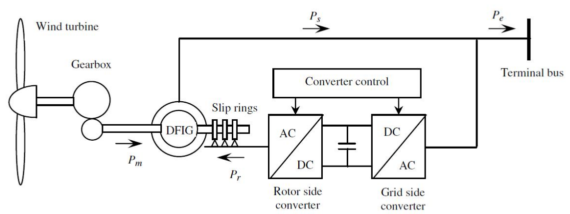


Figure 1: DFIG Scheme

There is direct connection between stator and power network and connection between rotor and grid is done via two converters. The system allows variable speed operation. When wind speed is low, the DFIG runs below synchronous speed and absorbs power from power network. When wind speed is high, the DFIG runs above synchronous speed and supplies power to the network through converter. Power is supplied to the network by stator only or power may be supplied to network by stator and rotor both. The direction of power flow is decided by speed of DFIG. The power supplied to rotor P_r is given by

$$P_r = s\, P_s$$

where P_s is power supplied by stator, s is slip and electrical power output P_e is given by

$$P_e = (1 \pm s)\, P_s$$

At all speeds, the frequency of rotor voltage is so adjusted that the total speed of rotor and speed of rotor flux is equal to synchronous speed of stator flux decided by frequency of grid. Hence power flows from stator to grid for all the speeds unlike conventional induction generator which supplies power at super synchronous speed only.

3.SIMPLE MODEL OF DFIG

A simple model of DFIG can be obtained from equivalent circuit which is used to represent conventional induction machine as indicated in Figure 2

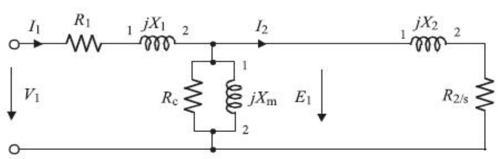


Figure 2 : Equivalent Circuit of Induction Machine

Where

Resistance of stator is given by R_1 and reactance of stator is given by X_1.

Resistance of rotor referred to stator is given by R_2 and reactance of rotor referred to stator is given X_2.

In DFIG, rotor is fed by converter and thus equivalent circuit of DFIG modifies to circuit as shown in Figure 3.

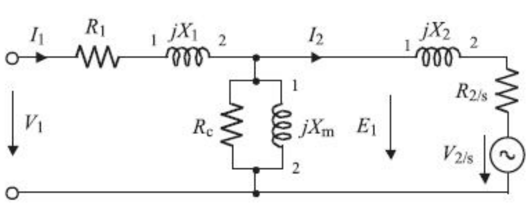


Figure 3: Model of DFIG

The equivalent circuit can be reduced to Thevenin's Equivalent network as shown in Figure 4

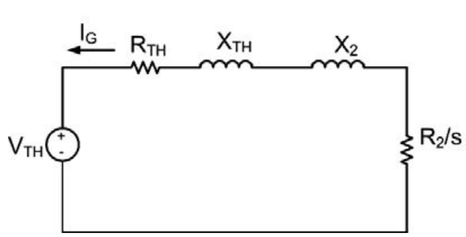


Figure 4: Thevenin's Equivalent Network

When wind speed changes, controller receives the signal and voltage of the rotor is changed by changing its magnitude and phase. With the help of Thevenin's network, output real power and reactive power can be calculated for a particular wind velocity. The real and reactive power can be calculated from the following expressions.

Real power is given by

$$Pg = \frac{V_{th}^{2}(R_{th} + \frac{R_2}{s})}{(R_{th} + \frac{R_2}{s})^2 + (X_{th} + X_{l2})^2}$$

And reactive power is given by

$$Qg = \frac{V_{th}^{2}(X_{th} + X_{l2})}{(R_{th} + \frac{R_2}{s})^2 + (X_{th} + X_{l2})^2}$$

4. SIMULATION RESULTS

In the analysis of DFIG unit, operational characteristics under variant wind condition are to be observed. Specific characteristic of a DFIG unit consists of real-reactive power with respect to wind speed variation. The real and reactive power of the DFIG unit is governed by V_d and V_q components. Hence, it is required to perform an analysis of V_q or V_d variation. The real power obtained through DFIG from the V_d variation from negative values to positive values keeping V_q fixed at positive value as shown in Figure 5.

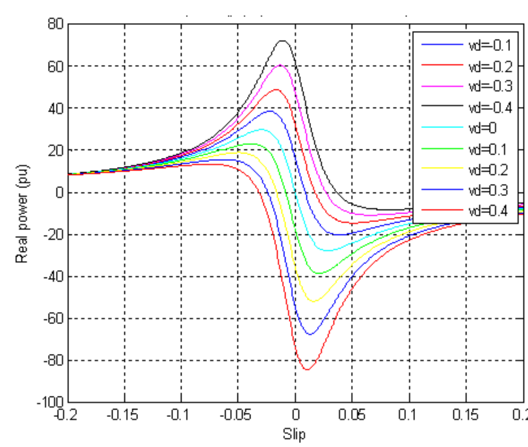


Figure 5: Real power at fixed V_q (=0.2 p.u.) and V_d changing from -0.1 p.u.to 0.4 p.u.

On V_d set to 0.2, varying V_q from 0 to 0.4p.u., the real power generation is illustrated in Figure 6.

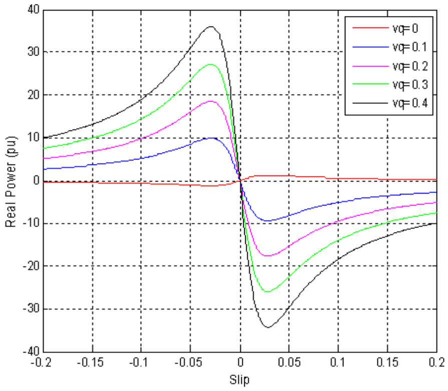


Figure 6: Real power for constant V_d=0.2 p.u, varying V_q

The results of simulation obtained are summarized as,

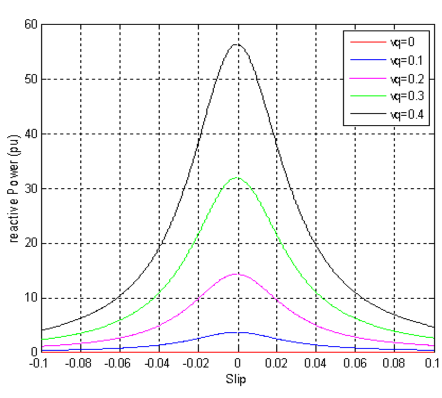
1) When the real and reactive part of voltage of rotor changes on positive side the characteristics of real power shifts towards speeds which are below synchronous speeds.

2) With positive increase in V_q or $V_{d,}$ the DFIG power of pushover also increases. This increase in power implies enhancement in stability and capability of generating power of DFIG and

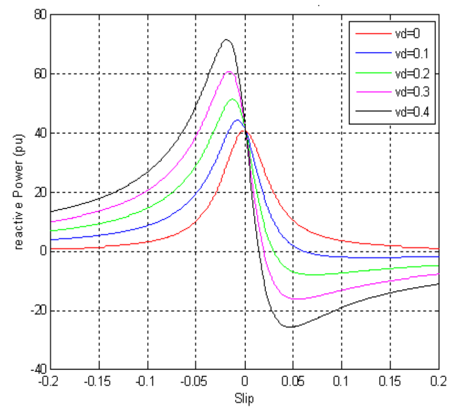
3) With change in values of V_d from positive to negative, active power of DFIG sweeps slowly from flowing out (generating) to flowing into (motoring) the induction machine.

For a traditional fixed speed induction machine when speed of the motor changes below or above synchronous speed to run either as motor or generator, the machine needs reactive power for magnetization and to take care of leakage flux. This reactive power is drawn from the supply. But such is not the case for DFIG due to converter which injects voltage in the rotor circuit.

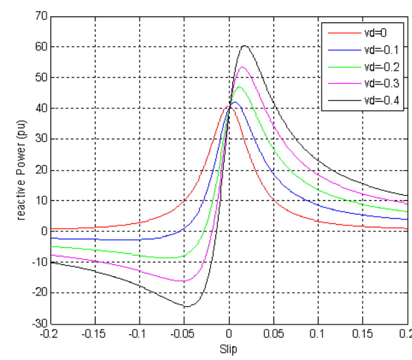
Figure 7 shows the characteristics of reactive power of DFIG for same conditions as that of Figure 5 and Figure 6.



(a)



(b)



(c)

Figure: 7 Reactive power for a) fixed Vd (=0) and varying Vq, b) fixed Vq(=0.2) Vd varying positive and c) fixed Vq(=0.2) with Vd varying negative.

The analysis of reactive and real power shows that

1) When V_q is increased in the generation mode of DFIG the characteristics of real power expands and DFIG asks for more reactive power too.

2) When V_d is increased in positive direction in the generation mode of DFIG the characteristics of real power expends reducing its demand of reactive power changing inductive power to capacitive also, and

3) When V_d is increased in negative direction in the generation mode the characteristics of real power contract and asks for more reactive power. The above analysis helps to conclude that the proper coordination between V_q and V_d components of voltage that is injected in rotor is required for optimum performance of DFIG as far as real and reactive power characteristics are concerned.

Considering the power of rotor now, it consists of rotor loss and reactive and real power. This power is passed to power grid via converters. Figure 8 shows the characteristics of real power for different conditions of Vd and Vq.

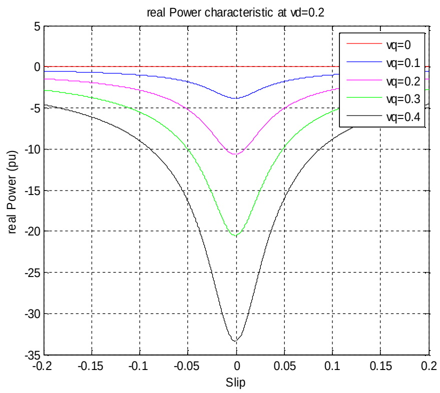


Figure: 8(a) Real power analysis for V_d = 0.2 p.u.

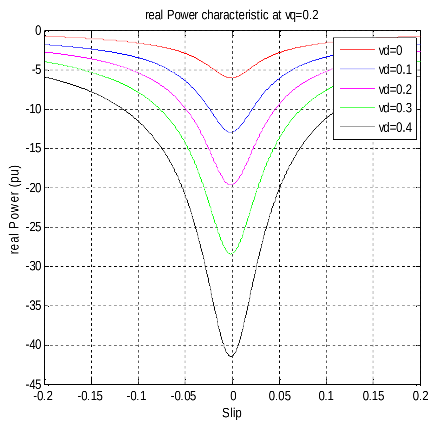


Figure:8(b) Real power analysis for Vq=0.2 p.u.

From the results obtained in the simulation it can be concluded that

1)The additional real power is sent by DFIG rotor to grid.

2) The power sent through rotor is decided by amount of voltage that is injected into the rotor.

3) When the magnitude of rotor injected voltage is high, the real power delivered is maximum at synchronous speed. At this speed rotor acts as a short circuit and in this case also to limit the rotor current Vd and Vq are to be properly controlled. Figure 9 gives stator and rotor real power.

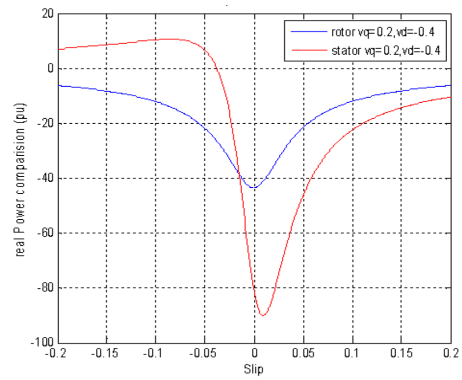
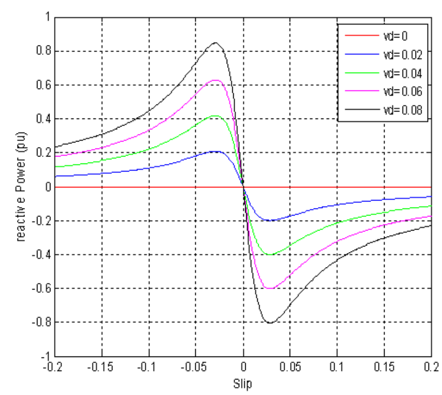


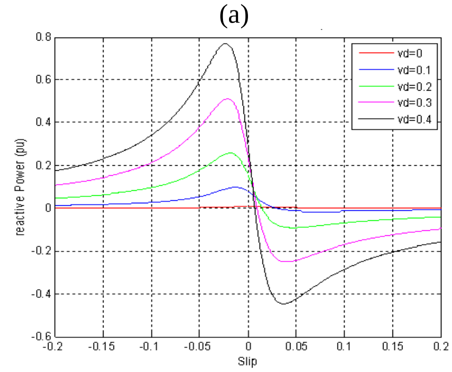
Figure: 9: Comparison between stator and rotor real power

If stator and rotor real powers shown in figure are compared, it is seen that power of rotor is smaller than the power of stator. The Vq and Vd along with slip decide the difference between the two.

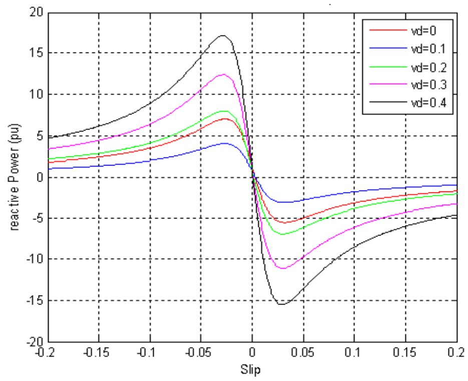
Fig. 10 (a) shows the characteristics of reactive power of rotor and speed when Vq is fixed at 0 p.u. and Vd is changed by a very small amount. In the absence of rotor injected voltage, no power is transferred from rotor to converter. When there is slight increase in voltage injected in rotor, reactive power pass through rotor to converter as shown in Figure 10(b) which is obtained by keeping Vq=0 p.u fixed and varying V_d. Fig. 10 (c) shows reactive power for Vq= 0.2 p.u. fixed and V_d allowed to vary.



(a)



(b)



(c)

Figure 10: Reactive power for a) V_d marginal variation, b) Vq is fixed (=0) p.u, c) Vq is fixed (=0.2) p.u.

The operational characteristic of the power generation under the wind strength variation is shown in Figure 11 and figure 12. From the results obtained, as wind speed increases there is rise in active power and generation can be maintained by controlling V_d and Vq components.

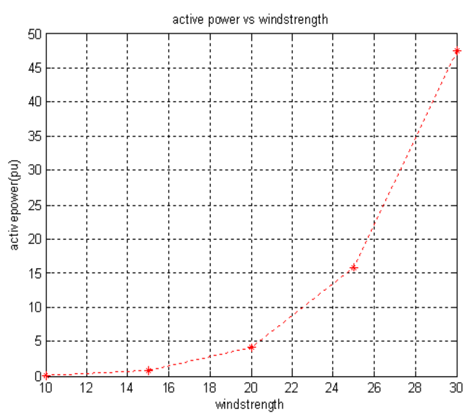


Figure 11: DFIG Active power with the wind strength variation

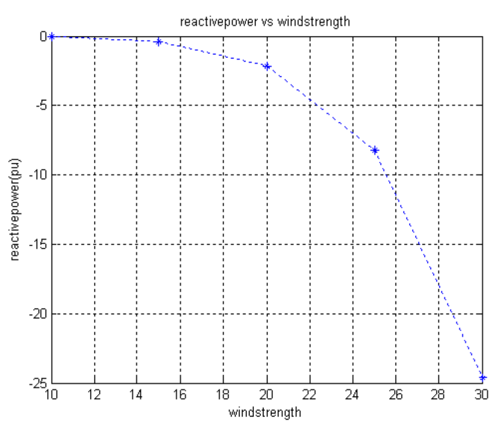


Figure12: DFIG Reactive power with wind strength variation

5. CONCLUSION

In this paper with the help of simple model, operation and control of DFIG is validated. The injected voltage in the rotor has an impact over DFIG operation and it changes its operational characteristics with change in magnitude and phase of the voltage. In this paper, with electrical modeling of DFIG, its characteristic validation under different direct (V_d) and quadrature (Vq) voltage is done. The real and reactive power generation for a DFIG unit under wind variation is analyzed. The operational mode of a DFIG unit under a sub-synchronous and super-synchronous level is evaluated. The design of DFIG unit with the control operation by injected voltage gives a suitability of providing a stable generation in wind farm application. Designed DFIG in future can be fixed onto a distributed wind farm interface where injected voltage can be governed to control the generation capacity and terminal switching for load compensation.

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