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# Performance Analysis of Grid-connected WRIG using Combined Input Voltage Control and Slip Power Control Schemes

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**Abstract**

With the increasing application of wind power based energy conversion systems, various technologies are developed for analyzing the performance of grid-connected wound rotor induction generator (GWRIG). Input voltage control scheme and slip power control scheme are among them. In the paper, the digital simulation of input voltage control scheme and slip power control scheme using rotor resistance method has been used for performance analysis of GWRIG. A digital simulation model of the GWRIG and its control system are developed with MATLAB Simulink. An optimum value of input voltage is obtained using simulation model such that maximum power is fed from wound rotor induction generator (WRIG) to power system or grid at a particular wind speed. Then the performance of the same WRIG is analyzed by slip power control scheme using rotor resistance method (at same wind speed). A series of studies on power flow from WRIG to power system or grid using input voltage control scheme and slip power control scheme are carried out with this model. Finally, the comparison of efficiency, power factor, stator current and power fed to grid under different wind speeds using both control strategy are discussed.

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## I.INTRODUCTION

With the energy requirement, continuous depletion of primary energy sources and concern about the global warming, the importance renewable energy sources have been increased. Wind power has proved to be the most promising renewable energy source over the past decades, which can overcome the concern of energy shortage in future because of its environment friendliness and sufficient availability [1-6]. With the priority status accorded to it in many countries, the share of wind power in relation to overall installed capacity has increased significantly. It is predicted that by 2020 up to 12% of the world's electricity would be supplied from wind power [2]. Therefore, efficient and stable utilization of wind energy has been an importantissue.

For utilizing the power of wind, the induction generators and synchronous generators are used in wind energy conversion systems (WECSs). The grid-connected induction generators are preferred over synchronous generators due to their low unit cost, ruggedness and less maintenance requirements [7-10]. Usually, the wind energy is explored tremendously in grid-connected applications using wound rotor induction generators [11-18]. Normally, the gearbox of a wind turbine has single gear ratio between the rotation of the rotor and the induction generator. Therefore, either the control has to be applied on the generator itself or by pitching the rotor blades out marginally or fully as required.

Only a fraction of the power available in the wind is converted to useful power by a wind turbine. This fraction, which is theoretically limited by the so-called Betz limit (about 58%), is known, as the power coefficient is primarily a function of the tip speed ratio and is usually less than a certain peak value, which is about 45% [19]. To achieve maximum conversion, the turbine must necessarily operate at an optimum tip speed ratio, which to a very large extent

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depends on the variation of the power coefficient with respect to the tip speed ratio, a relationship that can only be determined experimentally [20-21]. However, an electrical control is preferable and the easy option left, especially at low wind speeds. But the electrical control also suffers from certain drawbacks. The main demerit of this system is its very low power factor. Moreover, the efficiency at low wind speeds becomes very poor. At low wind speeds the energy content available to be harvested is low; a low efficiency power generation would lead to a drastic reduction in the output power. Moreover, the power factor becomes poor and the reactive power demand varies widely with the wind speed.

Various techniques had been used to improve the performance of WECSs. The use of an ac voltage controller improves the power factor but the efficiency dropped drastically [22-25]. Slip power control had also been used to improve the performance of WECSs but it gives very low power factor [24-25]. In the paper, the digital simulation of input voltage control scheme and slip power control scheme using rotor resistance method has been used for performance analysis of GWRIG. An optimum value of input voltage is obtained using simulation model such that maximum power is fed from wound rotor induction generator (WRIG) to power systemorgri data particular wind speed. Then the performance of the same WRIG is analyzed by slip power control scheme using rotor resistance method (at same wind speed). A series of studies on power flow from WRIG to power system or grid using both control schemes are discussed.

## II. INPUT VOLTAGECONTROL

In input voltage control scheme, the speed of the induction motor is controlled by varying the input voltage of induction motor, which is done using ac regulator [22- 23], tap changing transformer or auto transformer. Induction motors are efficient at rated load but as the load is decreased (voltage remaining constant) the iron losses contributes a greater percentage of output which results in reduction of efficiency at part loads. When the input voltage is reduced the iron loss of motor will reduce. Moreover, at reduced voltage the motor will draw an increased active component of current to supply the same output. The reactive current component will come down since applied voltage has reduced. Thus, the total stator current which is phasor sum of active and reactive current will decrease depending upon the amount of input voltage reduction. Hence, this will result in reduced copper loss. Thus, the motor will operate at better power factor and better efficiency condition [26]. Here, this method is extended for the induction generators. Figure 1 shows the input voltage control scheme for an induction generator. The torque-speed characteristic of an induction machine with input voltage control is shown in Fig. 2.

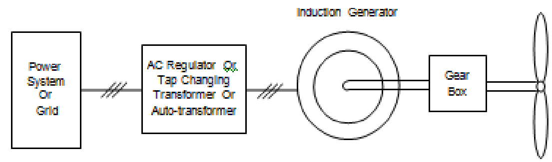


Fig. 1 Input voltage control of an induction generator.

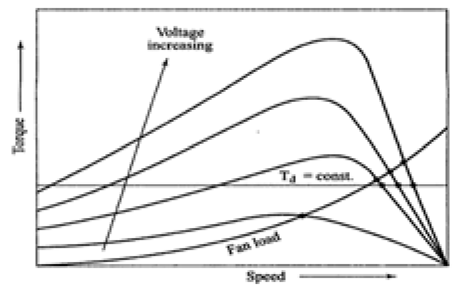


Fig. 2 Characteristics of an induction machine with input voltage control.

WRIM). However, in this type of control, there is substantial losses in the external resistor which reduces the overall efficiency of the system [27]. Here, this method is extended for the wound rotor induction generator (WRIG). The torque-speed characteristic of a wind power based WRIG with slip power control is shown in Fig. 4. The different operating points of WRIG under different wind speeds are indicated by small bubbles.

## III. SLIP POWERCONTROL

In slip power control scheme using rotor resistance method, the speed of the induction machine is controlled by varying the external resistance, which is inserted in the rotor circuit. Figure 3 shows the slip power control scheme using rotor resistance method for an induction machine.

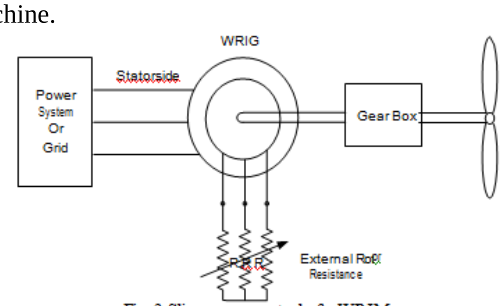


Fig. 3 Slip power control of a WRIM.

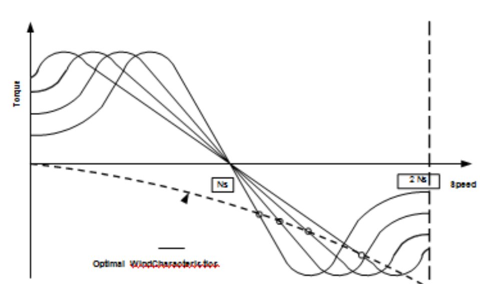


Fig. 4 Characteristics of a WRIG with slip power control.

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## IV. DIGITALSIMULATION

### *A. MATLAB SimulationModel*

For MATLAB, here wound rotor induction generator (WRIG) is simulated with the asynchronous machine SI units in Simulink. The power system is simulated with three phase voltage source. Then the three phase voltage source is connected to the stator side of WRIG. The torque is applied to the WRIG as input mechanical torque ‘$T_m$’ through a dc motor block. The three phase external rotor resistor is simulated with three phase parallel RLC branch. To simulate various power transmission or power flow functions, other blocks are also used. Then this simulated model, as shown in Fig. 3, is used to find the optimum value input voltage. An optimum value of input voltage is achieved such that maximum power is fed from WRIG to power system or grid at a particular wind speed. Then the performance of the WRIG is analyzed by slip power control scheme using rotor resistance method (at same wind speed). A series of studies on power flow from WRIG to power system or grid using both control schemes are analyzed with the simulation model as shown in Fig.5.

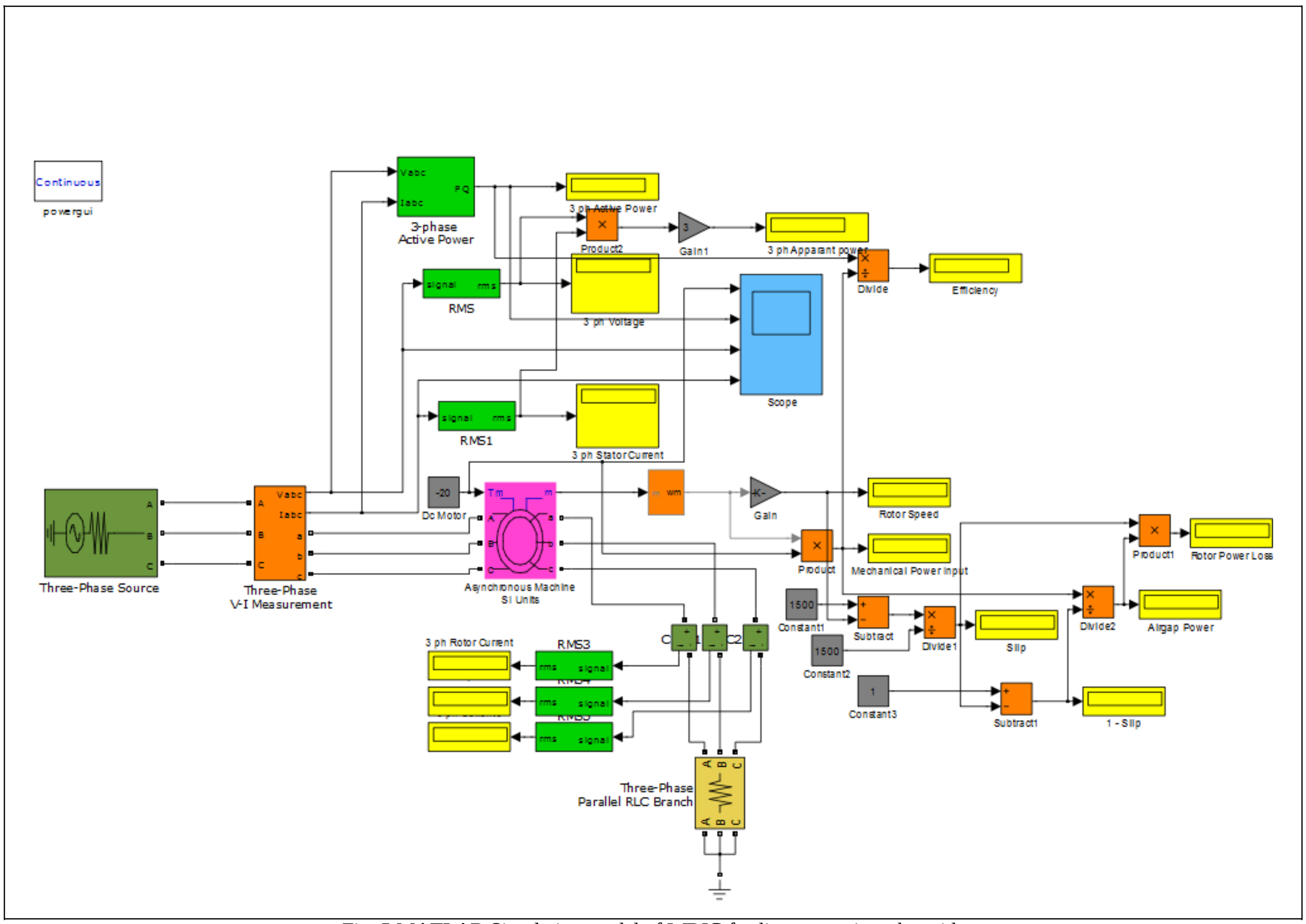


Fig. 5 MATLAB Simulation model of WRIG feeding power into the grid.

### *B. MATLAB SimulationResults*

The results obtained using MATLAB simulation model of WRIG feeding power into the grid, are given in Table I and Table II.

TABLE I: SIMULATION RESULT OF GWRIG WITH INPUT VOLTAGE CONTROL SCHEME

| Speed (rpm) | Efficiency (%) | Power Factor | Stator Current (Ampere) | Power fed to grid (Watt) |
|---|---|---|---|---|
| 1521 | 84.34 | 0.37 | 3.459 | 671.7 |
| 1531 | 89.48 | 0.54 | 4.473 | 1435 |
| 1538 | 90.69 | 0.62 | 5.405 | 2191 |
| 1547 | 90.71 | 0.69 | 6.282 | 2939 |
| 1556 | 90.3 | 0.74 | 7.195 | 3678 |

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TABLE II: SIMULATION RESULT OF GWRIG WITH SLIP POWER CONTROL SCHEME

| Speed (rpm) | Efficiency (%) | Power Factor | Stator Current (Ampere) | Power fed to grid (Watt) |
|---|---|---|---|---|
| 1521 | 82.19 | 0.22 | 4.302 | 654.5 |
| 1531 | 89.21 | 0.43 | 4.776 | 1430 |
| 1538 | 90.44 | 0.57 | 5.455 | 2186 |
| 1547 | 90.79 | 0.67 | 6.257 | 2941 |
| 1556 | 90.50 | 0.73 | 7.135 | 3685 |

The comparision of the obtained simulation results are shown in Figs. 6 – 9.

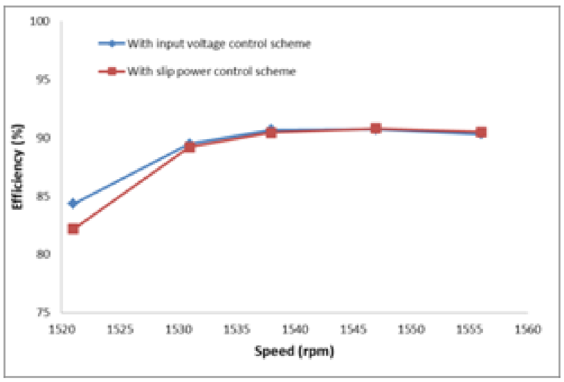


Fig. 6 Efficiency variation with input mechanical torque.

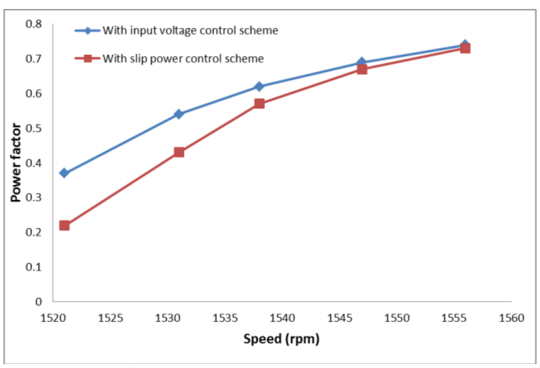


Fig.7Powerfactorvariationwithinputmechanicaltorque.

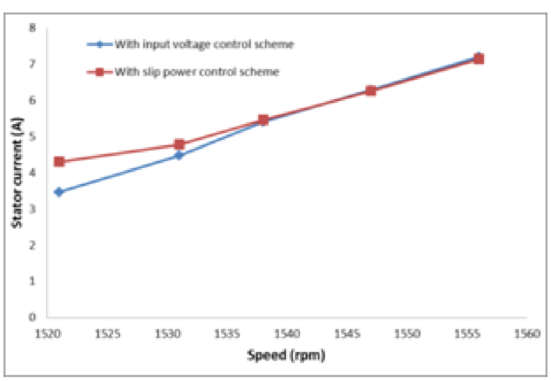


Fig.8Statorcurrentvariationwithinputmechanicaltorque.

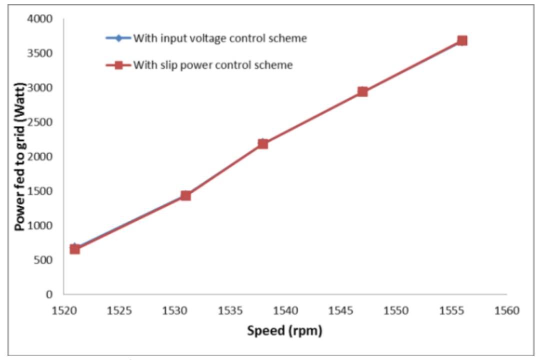


Fig. 9 Power fed into grid variation with input mechanical torque.

## I. CONCLUSION

In the paper, input voltage control scheme and slip power control scheme is analyzed for grid-connected wound rotor induction generators. It is evident from the simulated results that the input voltage control scheme is quite effective at low wind speed and slip power control scheme is effective at high wind speed for grid-connected induction generators. Here, an optimum value of the input voltage is found such that maximum power is fed from wound rotor induction generator (WRIG) to power system or grid at a particular wind speed. Then for this value of input voltage the performance of grid-connected WRI Gisanalyzed. Both efficiency and power factor of a wind energy conversion system have been improved in comparison to a slip power control scheme at low wind speed. Further, there is a significant reduction of the line current and increase in the active power supplied to the grid at low wind speed. Thus, the input voltage scheme is useful for low wind speed based energy conversion systems and the slip power control scheme is useful for high wind speed based energy conversionsystems.

## APPENDIX

Wound Rotor Induction Generator Data: 4kW, 3phase, 400V, 50Hz, 1430rpm, star connected (all values referred to stator): Stator resistance, $R_1 = 1.405\Omega$, Stator reactance, $X_1 = 1.834\ \Omega$, Rotor resistance, $R_2' = 1.395\Omega$, Rotor reactance, $X_2' = 1.834\ \Omega$, and Mutual reactance, $X_m = 54.098\Omega$

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