International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Performance of Low Power Wind-Driven Wound Rotor Induction Generators using Matlab

Abhilash Ghosh[Ȧ*] and Vinay Kumar Tripathi[Ȧ]

[Ȧ]Electrical Engineering Department, SHIATS Deemed University, Allahabad, U.P., India

Accepted 04 July 2014, Available online 01 Aug2014, **Vol.4, No.4 (Aug 2014)**

Abstract

Various techniques have been employed to optimize the performance of wound rotor induction generator (WRIG) based wind power generation systems. Input voltage control was used for the improvement of power factor in grid-connected induction generators. However, here, efficiency reduces drastically because of high output current. Moreover, the control range is limited. The conventional rotor resistance control had also been used for wind-driven WRIG. But, the input power factor becomes very poor. In this paper, a new control method is analyzed where both input voltage and slip power control are used together to achieve better performance. For each operating point an optimum input voltage is set and slip is controlled by rotor resistance such that the maximum efficiency is obtained. Moreover, both power factor and efficiency are improved for a wide range of speed variations. Also the reactive power demand is reduced throughout the range of effective speed which is compensated by optimum fixed capacitors. This scheme is useful for low power wind energy conversion system (WECS) where wind speed varies over wide range. Simulation model for the proposed schemes are developed using MATLAB and the performance of the induction generator under various wind conditions are studied with this model. Also the performance characteristics of the schemes are experimentally verified. The new control schemes are cheap.

Keywords: *Combined input voltage and slip power control, Wound Rotor Induction generator (WRIG), MATLAB, Slip power control, Renewable energy sources (RES), Wind energy conversion system (WECS).*

1. Introduction

With the decrease in primary energy sources and concern for environment due to excessive use of fossil fuels have led to the remarkable energy effort in harnessing renewable energy sources. During the last decade of the twentieth century, worldwide wind capacity doubled every three years and the cost of electricity from wind power has fallen to about one sixth of the cost in the early 1980s (S. Engelhardt, I. Erlich, C. Feltes, J. Kretschmann, and F. Shewarega, 2011). And the trend seems to continue. The cumulative capacity is growing worldwide by about 25% per year. By the end of 2003, around 74% was installed in Europe (28706 MW), a further 18% in North America (6677 MW) and 8% in Asia and the Pacific (3034 MW). Wind energy technology itself also moved very fast in new dimensions. In 1989 a 300kW wind turbine with a 30 meters rotor diameter was in use and now 5MW wind turbines (128 meters rotor diameter) have already been tested. Thus, the penetration of wind power in the power systems is higher.

An important step for installation of wind energy system is selection of the turbine rating, the generator, and the distribution system. In general, the output characteristics of the wind turbine power do not follow exactly those of the generator power; so they have to be matched in the best way possible. Based on the maximum speed expected for the turbine and taking into account the cubic relationship between the wind speed and the generated power, the designer must select the generator and the gearbox so as to match these limits. The most sensitive point here is the correct selection of the rated speed for the generator. If it is too low, the high speed of the primary source wind will be wasted; if it is too high, the power factor will be harmed (R. C. Bansal, T. S. Bhatti and D. P. Kothari, 2003).

Variable speed wind turbine has the advantages of maximum energy capture and reduction of the aerodynamic noise levels produced by wind turbines which is more significant in low wind speeds (B. Singh, Taylor & Francis, 1993) (S. Engelhardt, I. Erlich, C. Feltes, J. Kretschmann, and F. Shewarega, 2011). The gearbox of a wind turbine has single gear ratio between the rotation of the rotor (turbine) and the induction generator (S. N. Bhadra, D. Kastha, and S. Banerjee, 2006). The conventional rotor resistance control had been used with WRIG for wind power generation. (A. Petersson, T. Thiringer, and L. Harnefors 2004) But, the main demerit of this system is its very low input power factor. The efficiency also becomes poor (N. Mohan, 1980).

Recently the performance of wound-rotor induction motor had been greatly enhanced by the combination of input voltage control and slip power control (H. Ashfaq, S.

*Corresponding author: **AbhilashGhosh**

A. Nahvi and M. S. JamilAsghar, 2006) (H. Ashfaq and M. S. JamilAsghar, 2003). In this paper this technique is analyzed for wind-driven WRIGs to improve both efficiency and power factor, over a wide range of low speeds and compared with another scheme in which fixed capacitors are connected in parallel with the rotor external resistances to compensate the reactive power demand of the induction generator.

2. Conventional Slip Power Control Scheme

In slip power control, the speed of the induction generator is controlled by varying the resistance which is connected externally to the rotor circuit. The drawback of this type of control is the substantial losses in the external resistor at high speed. This reduces the overall system efficiency . Fig. 1 shows the slip power control scheme for induction generator. The drawback of slip power control can be removed by feeding the rotor power back into grid by placing diode bridge rectifier on the rotor side.. However, the power flow can only occur from the rotor to the grid.

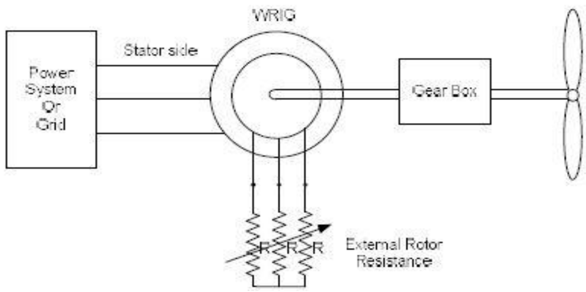

Fig. 1 Rotor resistance control of a wound rotor induction generator

The torque-speed characteristic of a wound rotor induction generator (WRIG) with slip power control is shown in Figure 2. The different operating points under different wind speeds are indicated by small bubbles.

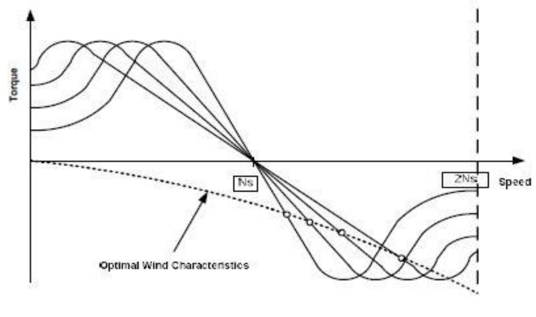

Fig. 2 Characteristics of a WRIG with rotor resistance control

3. Combined Input Voltage and Slip Power Control Scheme

In the combined input voltage and slip power control scheme, the characteristics of the induction generator are matched with the characteristics of wind turbine by both input voltage control and slip power control.

Figure 3 shows the circuit topology of the combined input voltage and slip power control scheme. Here, rotor power is controlled by varying external rotor resistance. The input voltage is controlled by using ac regulator or tap changing transformer or auto transformer. In this scheme, both external rotor resistance and input voltage are controlled to match the characteristics of the induction generator with the optimal characteristics of the wind turbine. Both efficiency and power factor improves for the whole range of control as compared to conventional rotor resistance method.

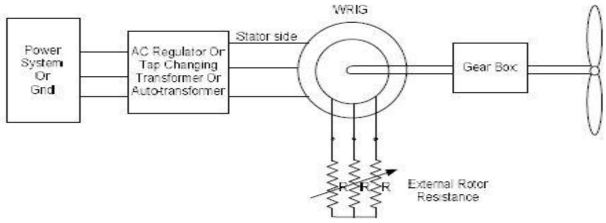

Fig. 3 Circuit topology of the combined input voltage and slip power control scheme

The torque-speed characteristic of a wound rotor induction generator (WRIG) with combined input voltage and slip power control is shown in Figure 4.

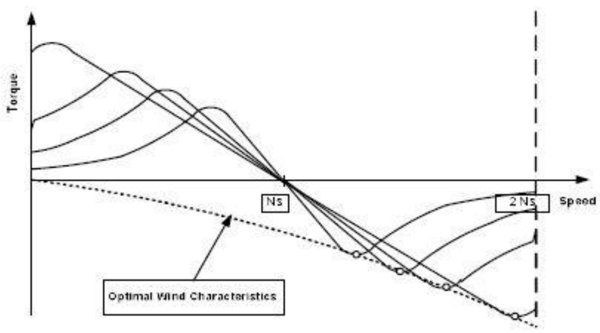

Fig. 4 Characteristics of a WRIG with rotor resistance as well as stator voltage control

4. Combined Input Voltage and Slip Power Control with Fixed Capacitor Scheme

In this scheme, capacitor is added in the combined input voltage and slip power control method.

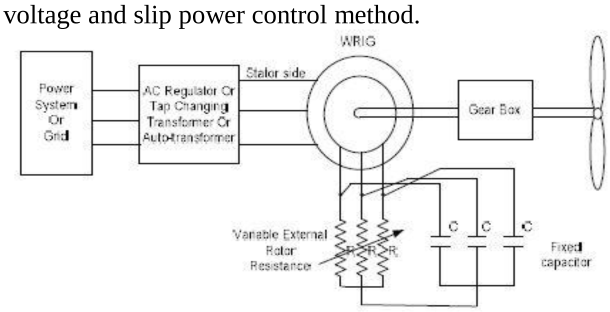

Fig. 5 Circuit topology of the combined input voltage and slip power control with fixed capacitor scheme

The capacitor is connected across the external resistance as shown in Figure 5. Here efficiency and power factor is further improved as compared to combined input voltage and slip power control and it also compensates the reactive power required by the system,. However, it is found that the performance improves only for an optimum value of the capacitance for a particular system.

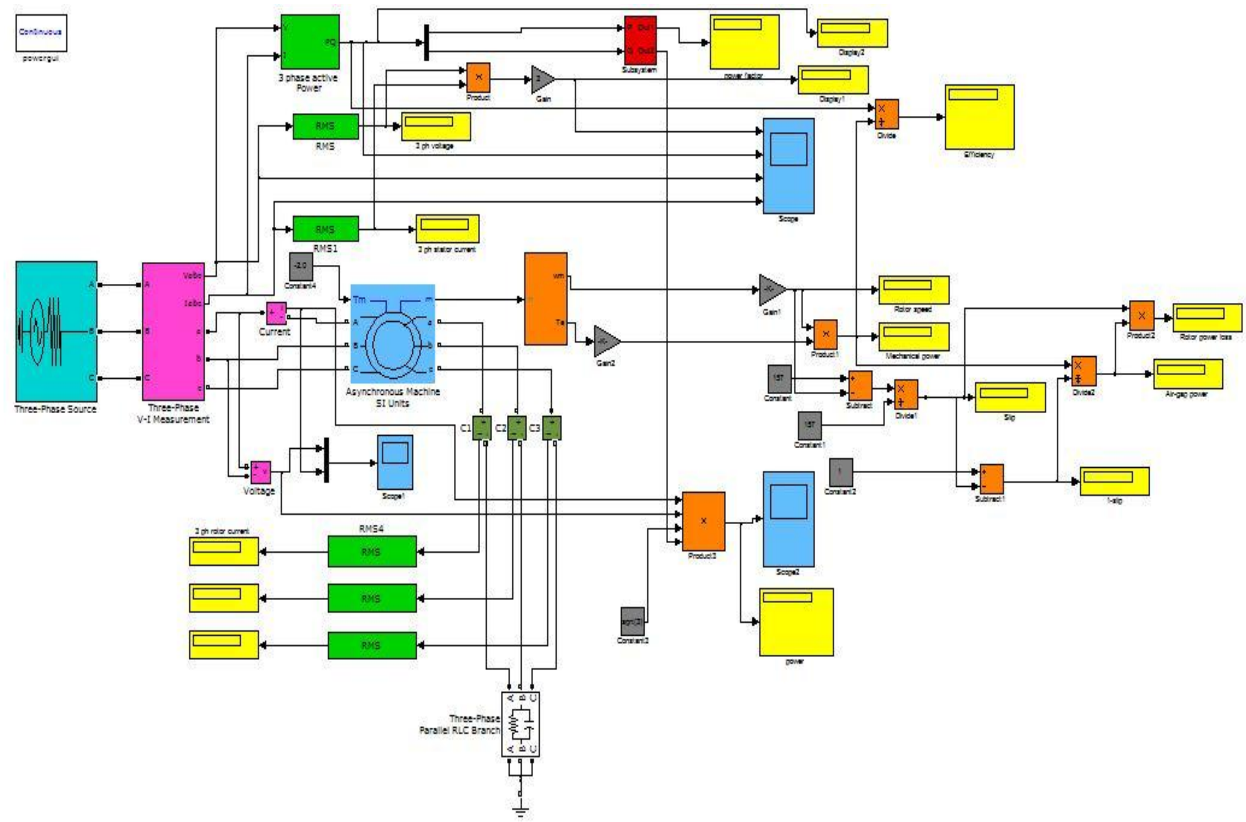

Fig.6 MATLAB Simulation model of WRIG feeding power to grid

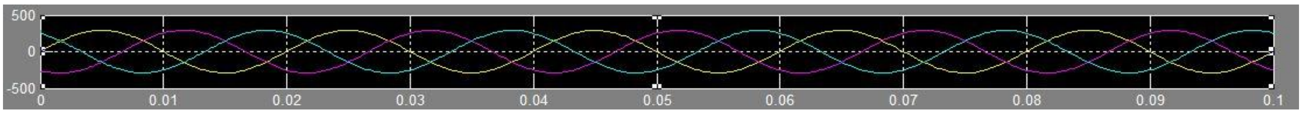

Fig.7 Waveform showing stator voltage

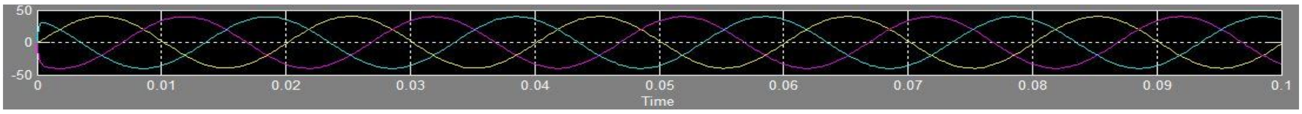

Fig.8 Waveform showing stator current

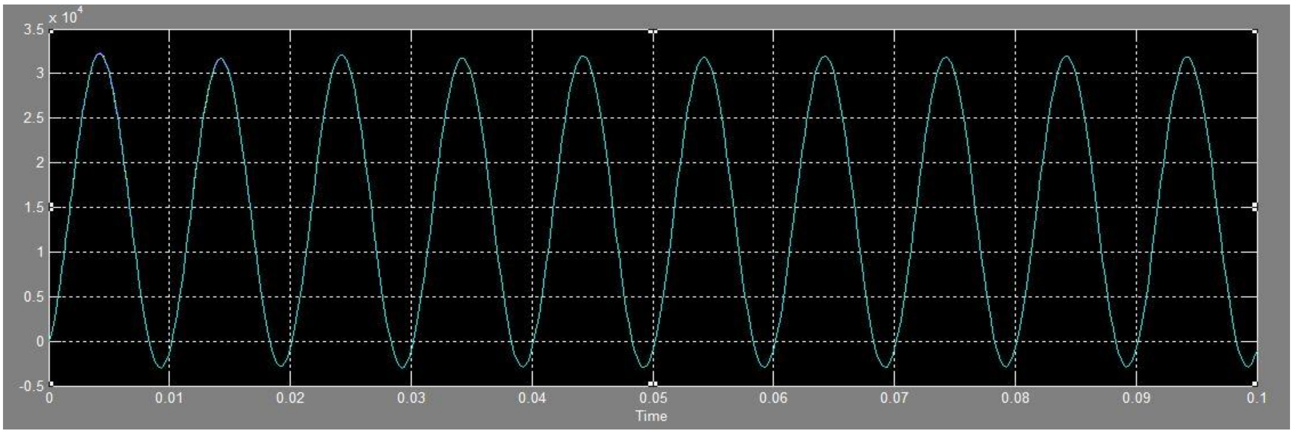

Fig.9 Waveform showing power flow capability

5. Digital Simulation

5.1. MATLAB Simulation Model

For MATLAB, here wound rotor induction generator (WRIG) is simulated with the asynchronous machine SI units in simulink. The power system is simulated with

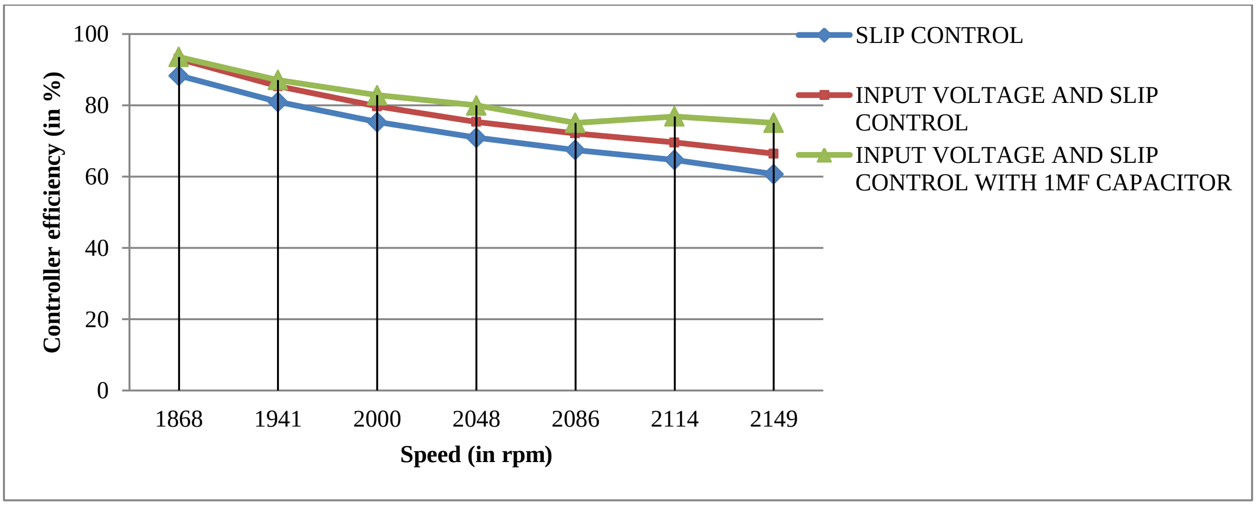

Fig.10 Efficiency versus speed

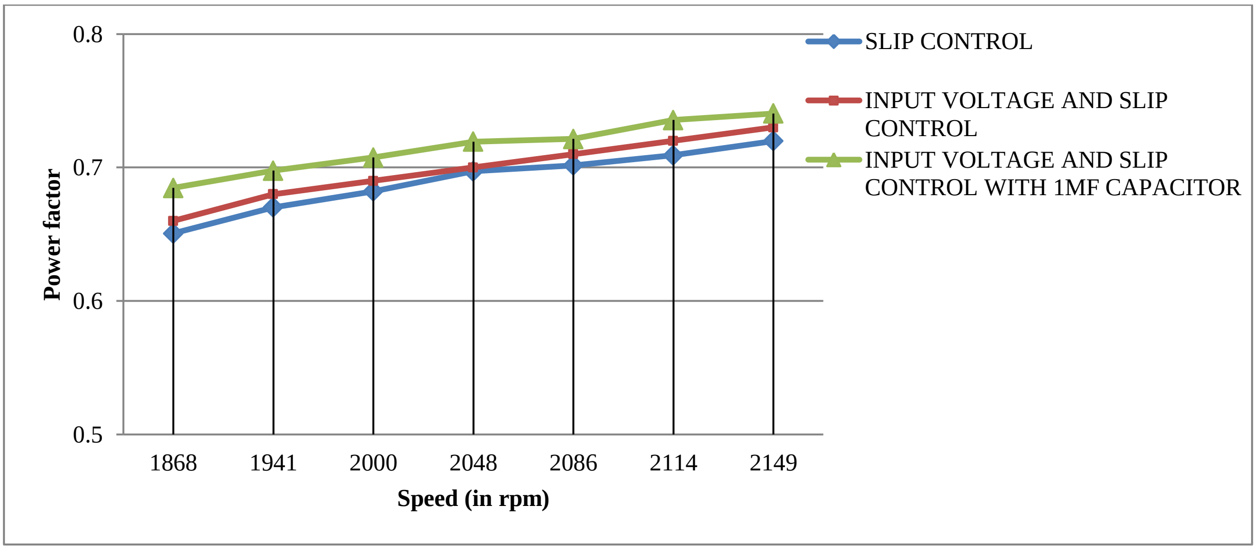

Fig.11 Power factor versus speed

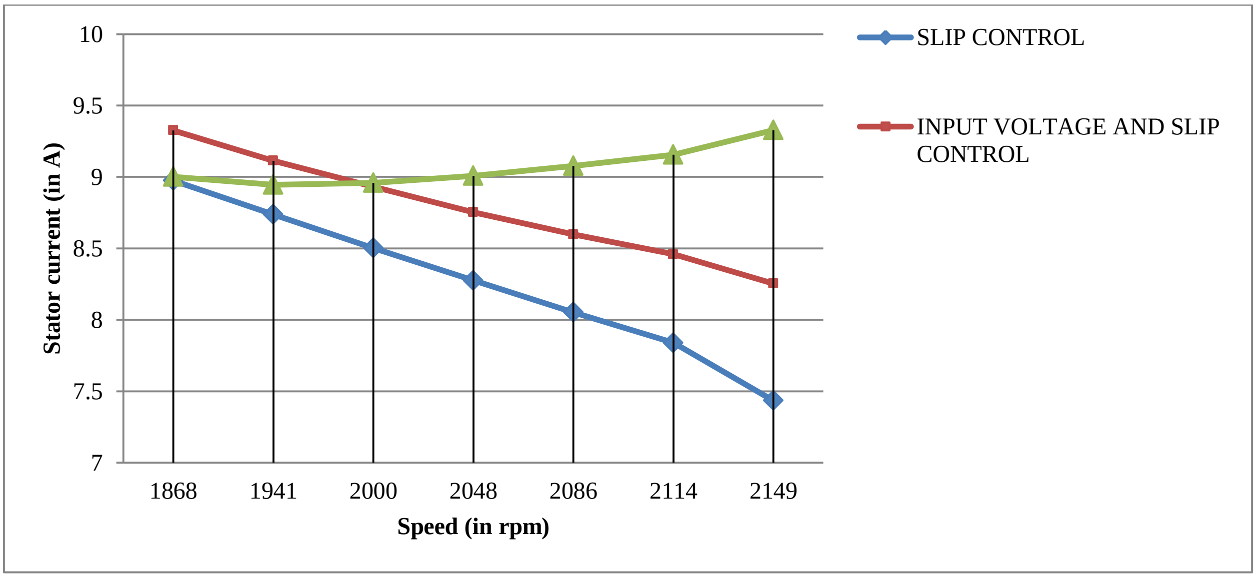

Fig.12 Stator current versus speed

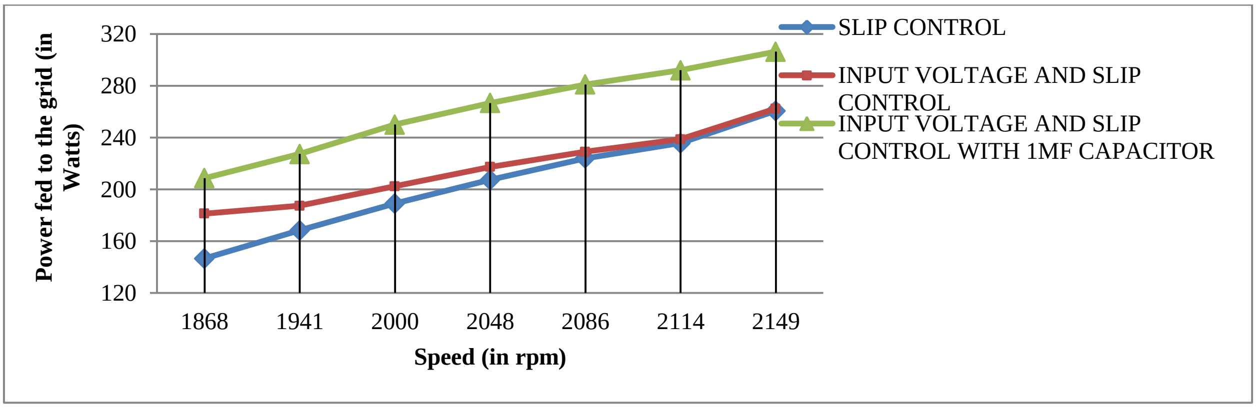

Fig.13 Power fed into grid versus speed

three phase voltage source as shown in Figure 5. The three phase voltage source is connected to the stator side of WRIG. The torque is applied to the WRIG as input mechanical torque ‘Tm’ through a block. To simulate various power transmission or power flow functions, other blocks are also used. Then this simulated model, as shown in Figure 6, is used to solve the system shown in Figure 5. Under different torque conditions, the power transferred from the WRIG to the power system is simulated. The simulated results of waveforms of stator voltage, stator current, and power flow are obtained, which are shown in Figure 7, 8 and 9.

5.2 MATLAB Simulation Results

The results obtained using MATLAB simulation model of WRIG feeding power to the grid, are given in Table 1, Table 2 and Table 3.

Table 1: Simulation Result of Slip Control

Speed (in rpm)	Controller Efficiency (in %)	Power Factor	Stator Current (in Ampere)	Power fed to the grid (in watts)
1868	92.98	0.66	9.326	181.33
1941	85.32	0.68	9.114	187.33
2000	79.70	0.69	8.931	202.33
2048	75.34	0.70	8.753	217.33
2086	72.11	0.71	8.598	229.00
2114	69.57	0.72	8.459	238.66
2149	66.40	0.73	8.254	262.66

Table 2: Simulation Result of Combined Input Voltage and Slip Power Control

Speed (in rpm)	Controller Efficiency (in %)	Power Factor	Stator Current (in Ampere)	Power fed to the grid (in watts)
1868	92.98	0.66	9.326	181.33
1941	85.32	0.68	9.114	187.33
2000	79.70	0.69	8.931	202.33
2048	75.34	0.70	8.753	217.33
2086	72.11	0.71	8.598	229.00
2114	69.57	0.72	8.459	238.66
2149	66.40	0.73	8.254	262.66

Table 3: Simulation Result of Combined Input Voltage and Slip Power Control with 1mf Capacitor

Speed (in rpm)	Controller Efficiency (in %)	Power Factor	Stator Current (in Ampere)	Power fed to the grid (in watts)
1868	93.55	0.6847	9.002	208.66
1941	87.06	0.6976	8.946	227.33
2000	82.84	0.7075	8.959	250.00
2048	79.97	0.7194	9.008	266.66
2086	78.02	0.7214	9.078	281.00
2114	76.86	0.7355	9.156	292.00
2149	75.05	0.7405	9.328	306.33

The comparison of these results obtained are shown in Figs. 10 – 13.

6. Conclusion

The combined input voltage and slip control scheme with capacitor is found quite effective control scheme for grid connected induction generators. In this scheme both efficiency and power factor of a gird connected induction generator has been improved, in comparison to the simple input voltage control method, the slip power control method or the combined input voltage and slip power control method. The improvement in efficiency and power factor is achieved with better line current throughout the operating range. Also an optimum value of the capacitor is found by simulation for reactive power compensation which remains nearly constant throughout the range of operation. This scheme is cheap and useful for low power wind energy conversion systems where the wind speed varies abruptly as well as over wide range.

Appendix

Wound Rotor Induction Generator Data: 1kW, 3phase, 400V, 60Hz, 1800rpm, star connected, R1 = 6.28 Ω, X1

= 15.9Ω, R2 = 1.5 Ω, X2 =3.6 Ω and Xm = 118.01Ω.

References

S. Engelhardt, I. Erlich, C. Feltes, J. Kretschmann, and F. Shewarega (2011), Reactive power capability of wind turbines based on doubly fed induction generators, *IEEE Trans. on Energy conversion,* Vol. 26, No. 1, pp. 364-372.

S. N. Bhadra, D. Kastha, and S. Banerjee (2006), Wind Electrical Systems, *Oxford University Press*, New Delhi.

R. C. Bansal, T. S. Bhatti and D. P. Kothari (2003), Bibliography on the application of induction generators in non-conventional energy systems, *IEEE Trans.OnEnergy conversion,* Vol. 18, No. 3, pp. 433-439.

B. Singh, Taylor & Francis, “Induction generators–a prospective (1993), *Electric Machines and Power Systems*, Vol.23, pp. 163-177.

N. Mohan (1980), Improvement in energy efficiency of induction motor by means of voltage control, *IEEETrans. on PAS*, Vol. PAS-99, pp.1466-1471.

H. Ashfaq, S. A. Nahvi and M. S. JamilAsghar (2006), A personal-computer based controller for performance improvement of grid-connected wound rotor induction generators, *International Power & Energy Conference(PECON)*, Putrajaya, Malaysia, pp. 432-436.

H. Ashfaq and M. S. JamilAsghar (2003), Speed control of wound rotor induction motors by ac regulator based optimum voltage control, *International conference onPower Electronics and Drivepp. 1037-1040.*

H. Ashfaq and M.S. JamilAsghar (2005), Optimum input voltampere control of three-phase induction motors connected to distributed generating systems, *IEEE International Conference on Power Electronics and Drive Systems (PEDS)*, Kuala Lumpur, Malaysia, pp. 486-488.

A. Petersson, T. Thiringer, and L. Harnefors (2004), Flicker Reduction of Stall-Controlled Wind Turbines using Variable Rotor Resistances, in *Proc. Nordic Wind Power Conference*, G¨oteborg, Sweden.