Power factor Improvement of Combined Input Voltage and Slip Power Control of low power Wound Rotor Induction Generators

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***Abstract*—**
With growing application of wind energy conversion systems (WECSs), various technologies are developed to analyze the performance of WRIG based wind power generation systems. Input voltage control had been used for improvement of power factor in grid-connected induction generators. However, this method reduces the efficiency drastically due to high output current. Also the control range is limited. Slip control had also been used for wind power generation but it gives very low power factor. In the present paper, a simulation of combined input voltage control and slip control with capacitor has been proposed for improvement of power factor and maximizing the efficiency. A digital simulation model of the proposed scheme and its control system models are developed with MATLAB and a series of studies on power flow from induction generator to power system or grid are carried out with this model. The response characteristics of power flow under various wind conditions are discussed. Both power factor and efficiency are improved for a wide range of speed. Also the reactive power demand remains nearly constant throughout the range of operation. This scheme is useful for low power WECSs where wind speed varies over wide range as well as abruptly. Moreover, the proposed controller is simple and cheap.

Index Terms— Wind energy conversion systems (WECSs), Induction generator, Voltage control, Slip control, AC regulator, MATLAB.

I. 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. 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. With the priority status accorded to it in many countries, the share of wind power in relation to overall installed capacity has increased significantly and in some countries, the share of wind in relation to the overall installed capacity is already approaching the 50% mark [1].

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 [2-4]. The ac line regulates the frequency and output voltage of the induction generator, eliminating the need for expensive and complex electronic conversion equipment. Moreover, the operating speed of the induction generator is self-adjustable according to the variation in the input torque. This also reduces the wear and tear on the gearbox.

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. However, an electrical control is preferable and the easy option left especially at low wind speeds. However, 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. AC voltage controllers are widely used for soft starting, speed control and performance improvement of induction machine [5]. The use of an ac voltage controller improves the power factor but the efficiency dropped drastically. An ac regulator for soft switching is also necessary to reduce the extra wear on the gearbox at the time of cut-in of the generator. Slip control had also been used to improve the performance of WECSs but it gives very low power factor. Recently the performance of wound-rotor induction motor has been greatly enhanced by combination of input voltage control and slip power control simultaneously [6-8]. In the proposed work this technique is extended for induction generators with additional capacitor to improve both power factor and efficiency, over a wide range of speed.

II. Slip Power Control

In slip power control, the speed of the induction generator is controlled by varying the external resistance connected in the rotor circuit. This method enables fast response, since power electronics converters are used to vary external resistance. The drawback of this type of control is the substantial losses in the external resistor at high speed. This reduces the overall system efficiency [9]. Fig. 2 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. The use of a slip-power recovery induction generator is also called the static Kramer drive. However, the power flow can only occur from the rotor to the grid, due to the use of the diode bridge rectifier on the rotor side.

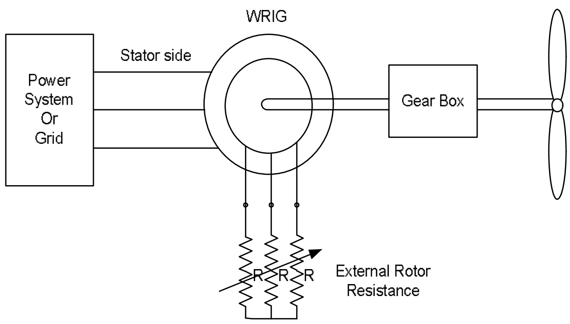

Fig. 2 Rotor resistance control of a wound rotor induction generator

The torque-speed characteristic of a wound rotor induction generator (WRIG) with slip power control is shown in Figure 3. The different operating points under different wind speeds are indicated by small bubbles.

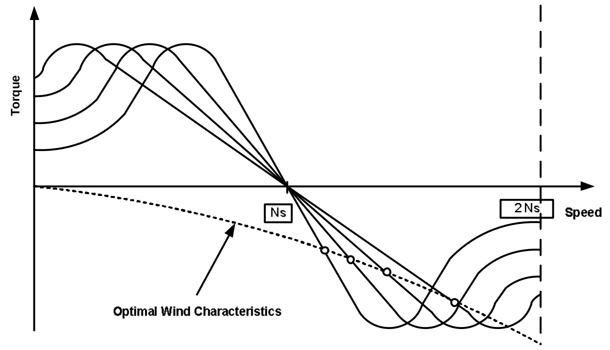

Fig. 3 Characteristics of a WRIG with rotor resistance control

III. Combined Input Voltage And Slip Power Control

In the combined input voltage and slip power control scheme, the characteristics of induction generators are matched with the characteristics of wind turbines by both input voltage control and slip power control. Figure 4 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 is controlled to match the characteristics of induction generator with the optimal characteristics of wind turbine. Now for any wind speed, a regulated input ac voltage is applied to the generator and a required external resistance is added in the rotor circuit to match both characteristics as shown in Fig. 5. Both efficiency and power factor improves for the whole range of control as compared to conventional rotor resistance method.

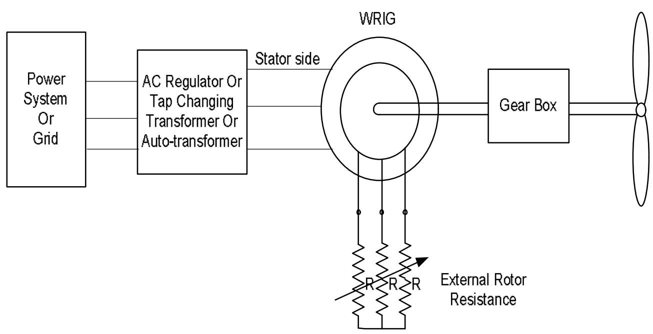

Fig. 4 Circuit topology of the combined input voltage and slip power control scheme

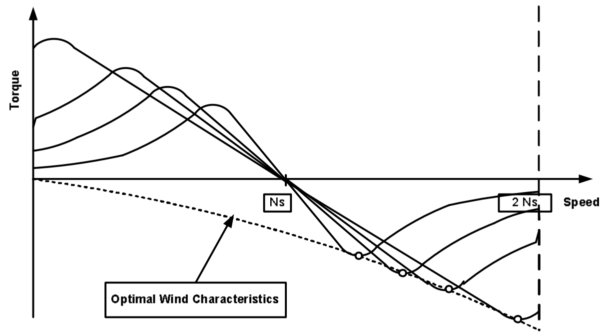

Fig. 5 Characteristics of a WRIG with rotor resistance as well as stator voltage control

IV. PROPOSED SCHEME

In the proposed scheme, capacitor is added in the

combined input voltage and slip power control method. The capacitor is connected across the external resistance as shown in Fig. 6. Here efficiency and power factor is further improved for the whole range of control as compared to combined input voltage and slip power control.

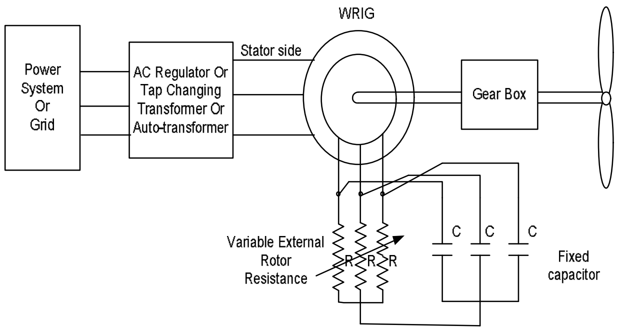

Fig. 6 Circuit topology of the proposed scheme

V. DIGITAL SIMULATION

A. 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 three phase voltage source as shown in Figure 6. 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 block. To simulate various power transmission or power flow functions, other blocks are also used. Then this simulated model, as shown in Figure 7, is used to solve the system shown in Figure 6.

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 8.

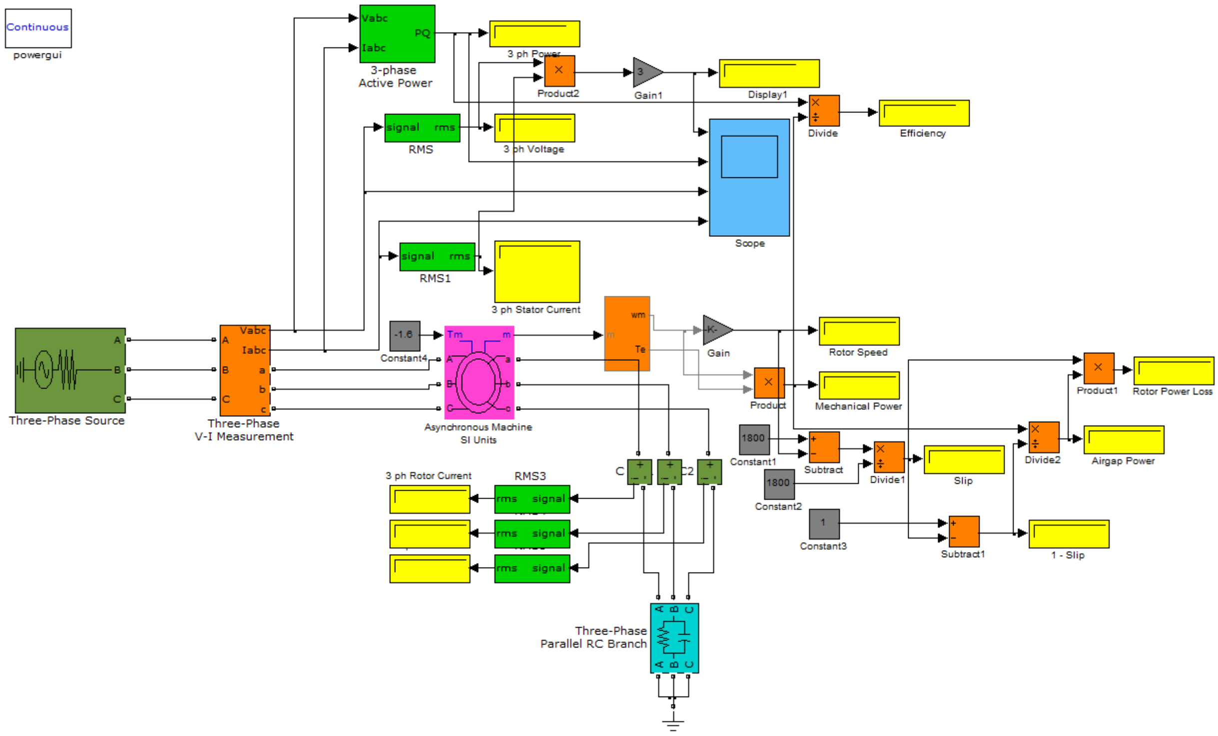

Fig.7 MATLAB Simulation model of WRIG feeding power to grid

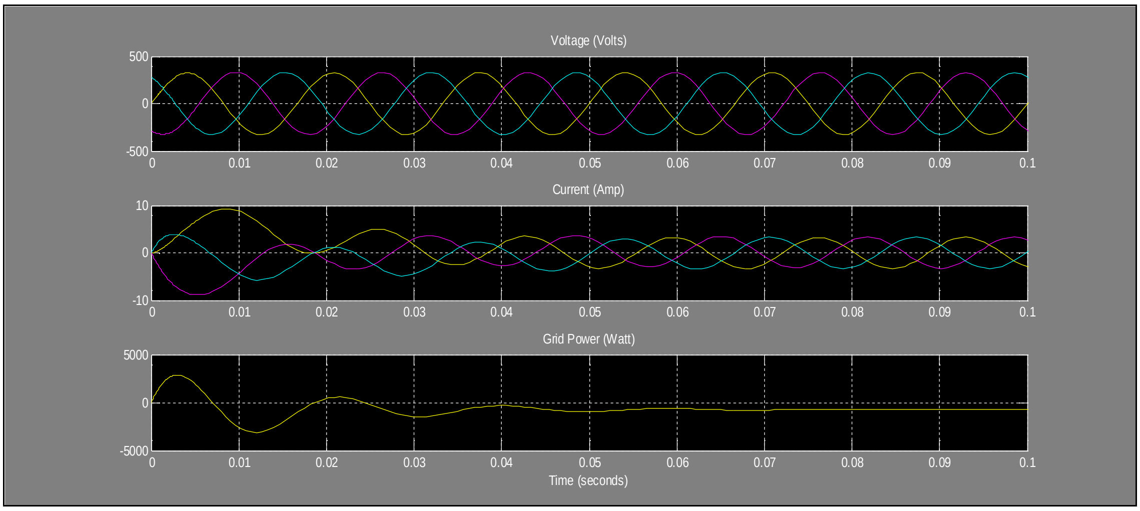

Fig.8 Waveform showing stator voltage, stator current and power flow capability

B. MATLAB Simulation Results

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

TABLE I: SIMULATION RESULT OF COMBINED INPUT VOLTAGE AND SLIP CONTROL WITHOUT CAPACITOR

Speed rpm	Efficiency (%)	Power Factor	Stator Current Per Phase (Ampere)	Power to grid (Watt)
1918	83.31	0.34	1.67	374.6
1973	82.68	0.38	1.97	491.6
2026	81.88	0.40	2.072	560.6
2080	80.84	0.43	2.167	681.07
2130	80.32	0.46	2.255	720.5
2180	79.59	0.47	2.312	755.13
2230	79.04	0.48	2.382	798.9

TABLE II: SIMULATION RESULT OF COMBINED INPUT VOLTAGE AND SLIP CONTROL WITH CAPACITOR

a) C = 1mF

Speed rpm	Efficiency (%)	Power Factor	Stator Current Per Phase (Ampere)	Power to grid (Watt)
1918	83.38	0.4309	1.401	264.5
1973	82.81	0.4532	1.428	281.3
2026	82.43	0.4124	1.48	298
2080	82.11	0.4206	1.489	316.6
2130	81.96	0.4165	1.515	333.1
2180	81.96	0.4647	1.491	354
2230	81.74	0.5078	1.487	372.6

b) C = 10mF

Speed rpm	Efficiency (%)	Power Factor	Stator Current Per phase (Ampere)	Power to grid (Watt)
1918	83.73	0.438	1.381	265.1
1973	84.06	0.4784	1.369	284.7
2026	85.19	0.4602	1.356	304.6
2080	86.03	0.4831	1.328	324.5
2130	86.37	0.4832	1.346	343.7
2180	86.67	0.534	1.33	363.1
2230	86.67	0.5796	1.336	382.1

The comparision of these results obtained are shown in Figs. 9 – 12.

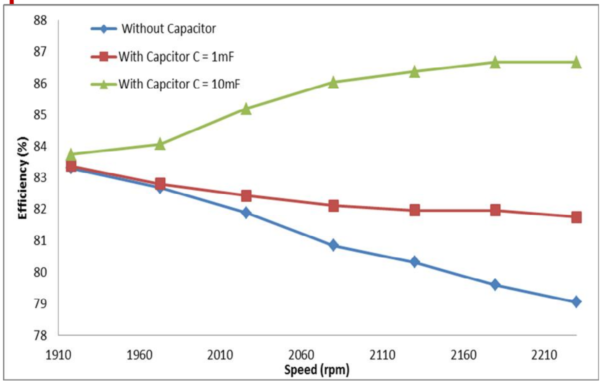

Fig.9 Efficiency versus speed

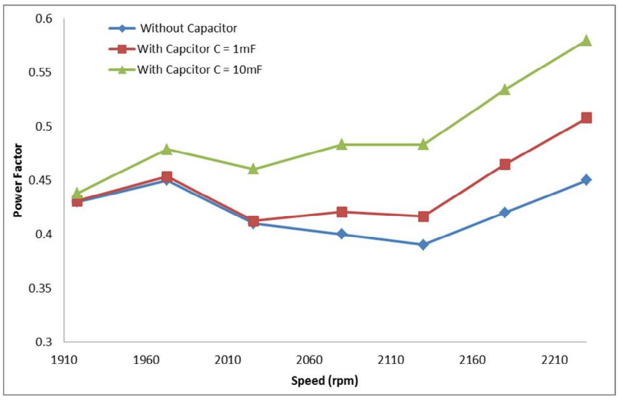

Fig.10 Power factor versus speed

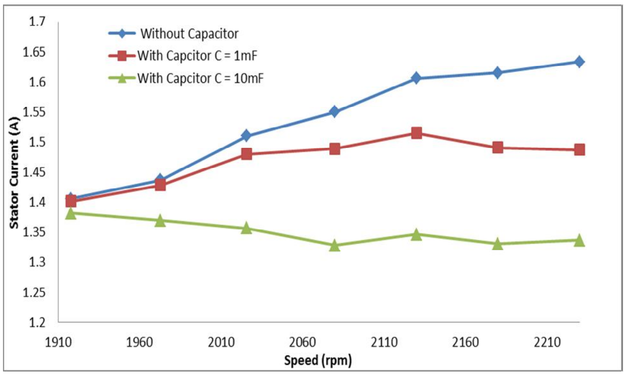

Fig.11 Stator current versus speed

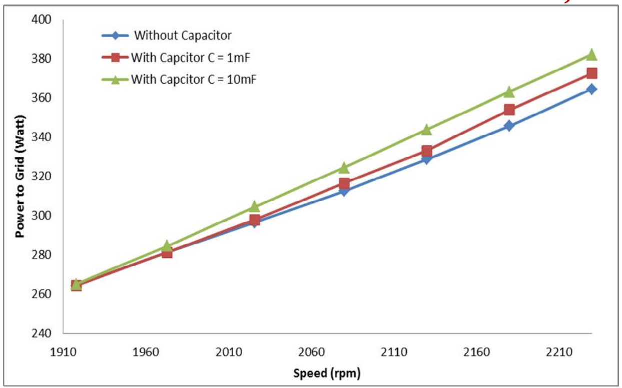

Fig.12 Power fed into grid versus speed

VI. 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, 1750rpm, star connected, R_1 = 6.28 Ω, X_1 = 15.9Ω, R_2 = 1.5 Ω, X2 =3.6 Ω and X_m = 118.01Ω.

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