Simulation for Performance Analysis of Grid-connected Induction Generators with Input Voltage Control

Farhad Ilahi Bakhsh
(Student Member, IEEE)
Dept. of Electrical Engg.,
Aligarh Muslim University,
Aligarh, India.

Shirazul Islam
(Student Member, IEEE)
Dept. of Electrical Engg.,
Teerthankar Mahavir University,
India.

Sayeed Ahmad
Dept. of Electronics Engg.,
Aligarh Muslim University,
Aligarh, India.

***Abstract*—With the increasing application of wind energy, various technologies are developed for analyzing the performance of grid-connected induction generator (GIG) based wind energy conversion systems (WECSs). Input voltage control is one among them. In the paper, a simulation of input voltage control is done for analyzing the performance of grid-connected induction generators (GIGs). A digital simulation model of the input voltage control and its control system models are developed with MATLAB. An optimum value of input voltage is obtained using the simulation model such that maximum power is fed from induction generator to grid for a particular input mechanical torque and a series of studies on power flow from induction generator to power system or grid is carried out with this model. The improvement in power factor, efficiency and stator current are realized over a limited range of input mechanical torque (or wind speed). Also, the response characteristics of power flow under various wind conditions are also discussed.**

Keywords—grid-connected induction generators (GIGs); wind energy conversion systems (WECSs); input voltage control; performance analysis; MATLAB.

I. INTRODUCTION

Energy is the key factor for any development. However, due to continuous depletion of primary energy sources and concern about the global warming, the importance of locally available natural sources i.e. renewable energy sources has 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 important issue.

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]. 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% [11]. To achieve maximum conversion, the turbine must necessarily operate at an optimum tip speed ratio, which to a very large extent depends on the variation of the power coefficient with respect to the tip speed ratio, a relationship that can only be determined experimentally [12-13]. 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. Slip power control had been used to improve the performance of WECSs but it gives very low power factor [14-15].The use of an ac voltage controller improves the power factor but the efficiency dropped drastically [14-17]. In the paper, a simulation of input voltage control is done for analyzing the performance of GIGs. A digital simulation model of the input voltage control and its control system models are developed with MATLAB. An optimum value of input voltage is obtained using the simulation model such that maximum power is fed from induction generator to grid for a particular input mechanical torque and a series of studies on power flow from induction generator to power system or grid is carried out with this model. The improvement in power factor, efficiency and stator current are realized over a limited range of input mechanical torque (or wind speed).

II. INPUT VOLTAGE CONTROL

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 [16-17], 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

978-0-7695-4941-5/13 $26.00 © 2013 IEEE
DOI 10.1109/ACCT.2013.73

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 [18]. Here, this method is extended for the induction generators. Figure 1 shows the input voltage control scheme for a GIG. The equivalent circuit of a GIG with an auto transformer is shown in Fig. 2.

$$Is = \left[\left(a\,\mathrm{Im}\right)^2 + \left(\frac{Ir'}{a}\right)^2 \right]^{\frac{1}{2}} \qquad (1)$$

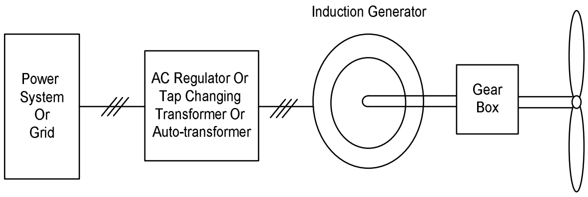

Figure 1. Input voltage control of a GIG.

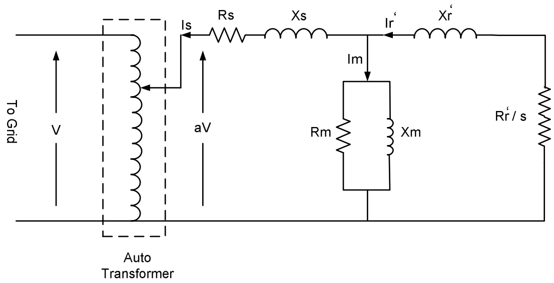

Figure 2. The equivalent circuit of a GIG with an auto transformer.

III. Digital Simulation

A. *MATLAB Simulation Model*

For MATLAB, here induction generator is simulated with the asynchronous machine SI units in Simulink. The power system is simulated with three phase voltage source as shown in Fig. 3. The three phase voltage source is connected to the stator side of induction generator. Thus, it forms a GIG. The torque is applied to the GIG 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 Fig. 3, is used to find the optimum value of input voltage such that maximum power is fed from induction generator to grid for different values of input mechanical torque.

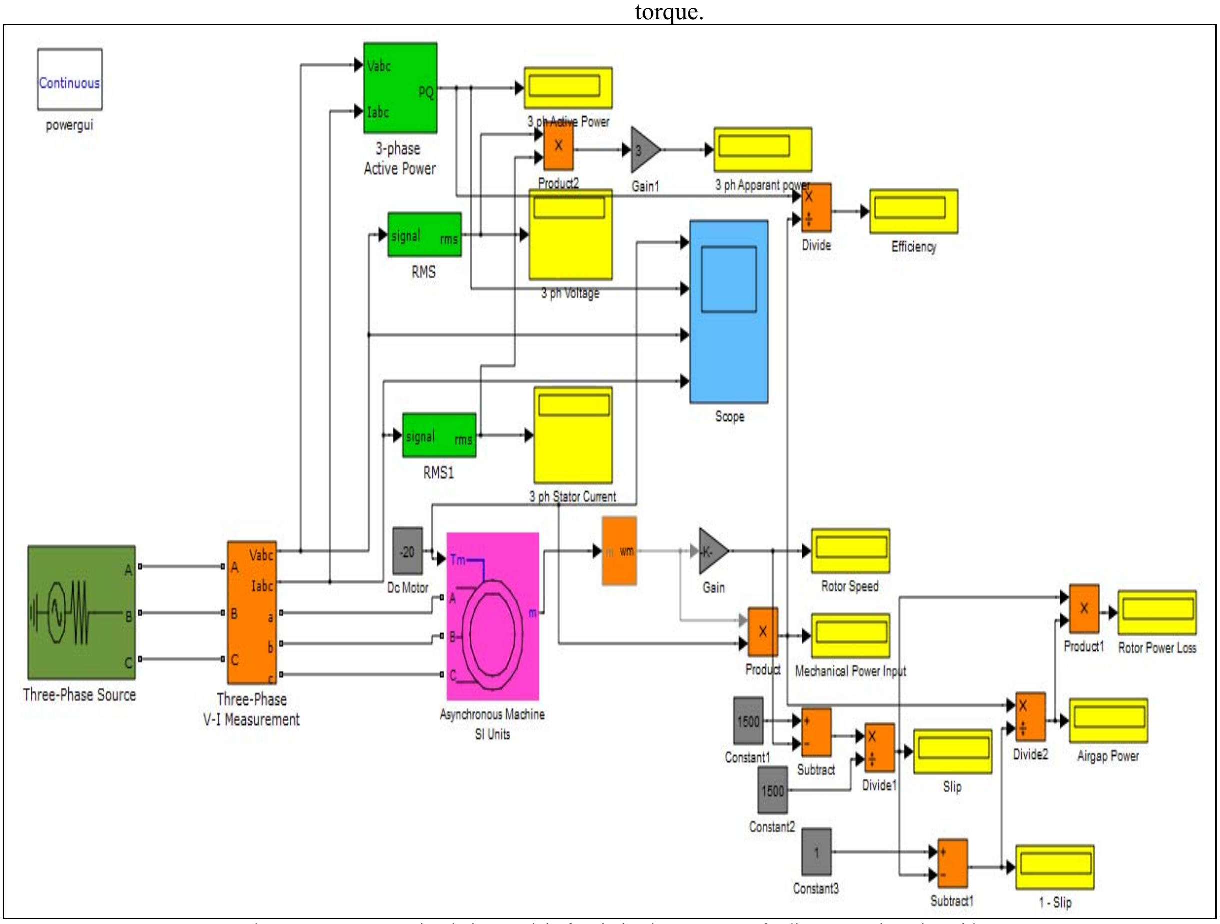

Figure 3. MATLAB Simulation model of an induction generator feeding power into the grid.

B. MATLAB Simulation Results

The results obtained using MATLAB simulation model of a GIG feeding power into the grid, are given in Tables I, II, III, IV, V, and VI.

TABLE I: SIMULATION RESULT OF GIG WITHOUT INPUT VOLTAGE

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
5	400	82.64	0.2188	4.305	654.9
10	400	88.76	0.4243	4.780	1416
15	400	90.84	0.5724	5.454	2189
20	400	90.70	0.6656	6.260	2932
25	400	90.46	0.7294	7.134	3678

TABLE II: SIMULATION RESULT OF GIG WITH INPUT VOLTAGE CONTROL AT TM = -5NM.

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
5	340	84.11	0.299	3.775	668.1
5	330	84.07	0.315	3.692	668.2
5	320	84.30	0.333	3.613	670.5
5	310	83.52	0.348	3.534	664.7
5	**300**	**84.34**	**0.371**	**3.459**	**671.7**
5	290	84.21	0.391	3.388	671.1
5	280	83.57	0.411	3.321	666.6

TABLE III: SIMULATION RESULT OF GIG WITH INPUT VOLTAGE CONTROL AT TM = -10NM.

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
10	380	88.81	0.4857	4.659	1419
10	370	89.34	0.4797	4.607	1429
10	360	89.01	0.4970	4.555	1425
10	350	89.04	0.5165	4.509	1426
10	**340**	**89.48**	**0.5390**	**4.473**	**1435**
10	330	89.40	0.559	4.438	1435
10	320	89.34	0.5806	4.408	1434

TABLE IV: SIMULATION RESULT OF GIG WITH INPUT VOLTAGE CONTROL AT TM = -15NM.

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
15	390	89.91	0.58	5.431	2169
15	385	90.56	0.60	5.421	2190
15	380	90.47	0.60	5.415	2183
15	**375**	**90.69**	**0.62**	**5.405**	**2191**
15	370	90.07	0.62	5.398	2177
15	365	90.38	0.63	5.399	2186

TABLE V: SIMULATION RESULT OF GIG WITH INPUT VOLTAGE CONTROL AT TM = -20NM.

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
20	395	90.20	0.67	6.269	2918
20	390	90.57	0.68	6.274	2932
20	385	90.42	0.69	6.285	2929
20	380	90.44	0.70	6.291	2932
20	**383**	**90.71**	**0.69**	**6.282**	**2939**
20	382	90.70	0.69	6.284	2939
20	378	90.38	0.70	6.299	2931

TABLE VI: SIMULATION RESULT OF GIG WITH INPUT VOLTAGE CONTROL AT TM = -25NM.

Input mechanical torque (-ve), Tm (Nm)	Input voltage (Volt)	Efficiency (%)	Power factor	Stator current per phase (Ampere)	Power fed to grid (Watt)
25	392	90.21	0.74	7.178	3672
25	390	90.24	0.74	7.186	3675
25	389	90.20	0.74	7.192	3674
25	**388**	**90.30**	**0.74**	**7.195**	**3678**
25	387	90.24	0.75	7.201	3676
25	386	90.28	0.75	7.205	3678
25	384	89.97	0.75	7.223	3667

The comparision of the obtained simulation results are shown in Figures. 4 – 7.

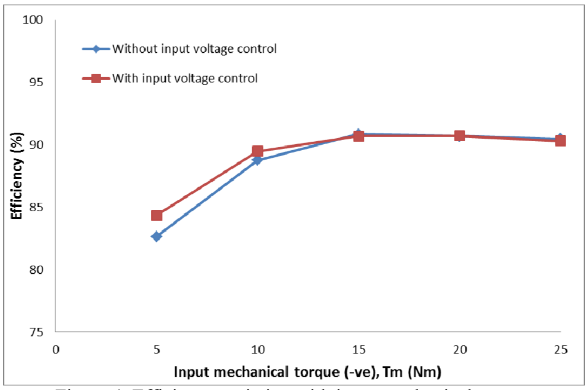

Figure 4. Efficiency variation with input mechanical torque.

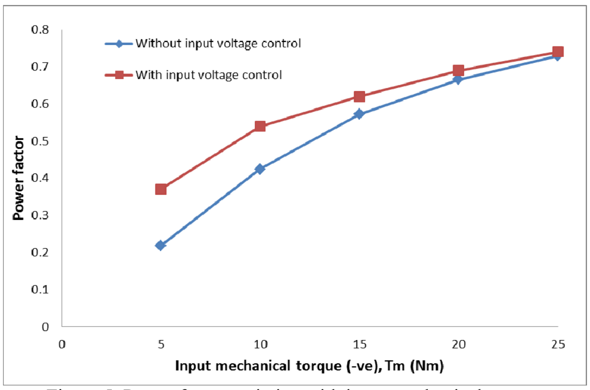

Figure 5. Power factor variation with input mechanical torque.

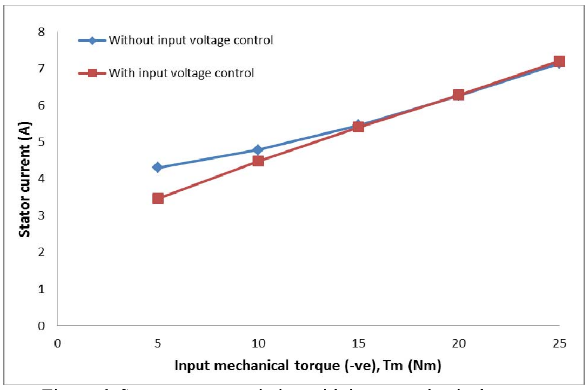

Figure 6. Stator current variation with input mechanical torque.

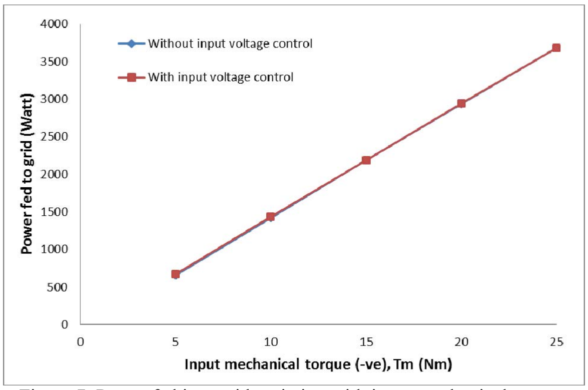

Figure 7. Power fed into grid variation with input mechanical torque.

IV. CONCLUSION

In the paper, input voltage control scheme is analyzed for grid-connected induction generators (GIGs). It is evident from the simulated results that the input voltage control scheme is quiet effective for GIGs at low value of input mechanical torque (or low wind speed). Here, an optimum value of the input voltage is obtained such that maximum power is fed from induction generator to grid for each value of input mechanical torque. Then at the optimum input voltage the performance of grid-connected induction generator (GIG) is analyzed. Both efficiency and stator current of an induction generator based wind energy conversion system have been improved significantly at low value of input mechanical torque (or low wind speed). Further, there is an improvement in power factor over the whole range. Thus, the scheme is useful for low wind speed based wind energy conversion systems (WECSs).

APPENDIX

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

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