European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality (ICREPQ'11)
Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011

The Wind Energy apply to Water Pumping in Isolated Place

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Abstract. The stead-state analysis of Wind Energy Conversion Systems, consisting on windmill, synchronous generator, transmission line and induction motor driving a centrifugal pump is developed.

The performance of the system operating at variable speed with a flux control is examined using mathematical models and digital simulation. The control scheme is proposed and tested in laboratory and a test center to compare field results with simulation results.

Key words

AC-DC power converter, PWM rectifier, induction motor drive, synchronous generator.

Nomenclature

a - *Coefficient from laboratory*
b - *Constants coefficients*
E_1 - *Force electric driving*
f - *Frequency*
Kg - *Generator constant*
Ptot-motor - *Total motor power*
Pcobre rotor-motor - *Copper loss*
Ppump - *Power in the axis pump*
Pturbine - *Power in the turbine axis*
p - *Pole number*
q_1 - *Stator phase number*
Rturbine - *Turbine ray*
s - *Induction motor slip*
Tm - *Induction motor torque*
Tpump - *Pump torque*
Tturbine - *Wind turbine torque*
Vf - *Generator field voltage*
Vg - *Generator voltage*
Vm - *Induction-motor voltage*
vs - *Synchronous velocity*
vr - *Asynchronous velocity*
Vv - *Wind velocity*
Φ - *Magnetic flux*
λ - *Velocity relation*
u - *Wind speed value subject to the disturbance*
u_0 - *Average wind speed*
n - *Is the kind of the mechanical eigenswing excited in the rotating wind turbine*
A_n - *Magnitude of the eigenswing n*
ω_n - *Eigenfrequency of the eigenswing n*
Ve - *Sinal no circuito de disparo dos scr's.*
α - *thyristor firing angle*

1. Introduction

In this paper is shown a work developed in the Federal Paraiba University in Campina Grande City in Brazil as reference to master thesis.

This work is the stead-state analysis of a Wind Energy Conversion Systems, consisting of a windmill, synchronous generator, transmission line and induction motor driving a centrifugal pump where the performance of the system in variable speed was examined across mathematical models and digital simulation when a flux control was used

The control scheme was proposed and tested in laboratory and a test center was used to compare with simulation results.

2. Proposed System

The proposed system of "wind energy applied for water pumping in isolated place" had the first one objective make an analysis of wind energy system where was developed an automatic voltage device to control the field current of a generator to keep the maximum power transfer to electric motor pump.

This requires that the generator output voltage divided by line frequency is constant, V_g/f. Through this control was achieved the maximum transfer of power in this study pumping of the water.

The methodology was begun by construction of mathematical model of the seven subsystem involved, after that construction mathematical model, a FORTRAN program was realized to all sub-systems, the next step was the development of voltage control system of generator field. The test field began with installation of the turbine and all her components and finished with final test. In the final test the values necessary to analysis of system they were obtained from the measures equipment. The field data and simulation data were compared.

Finally these results were recorded. Note who in this model was used a conventional model to induction motor from of book "Electric Machinery", the same was made for the synchronous generator, but the model used was smooth pole. [3]

3. Control Strategy

The control strategy follows the steps: As there is only one variable to be controlled who is the V_f to keep of V_g /f constant. As the velocity of axis generator depend of wind velocity this velocity will influence all systems variables, then the control is made across of the knowledge who there is a linear relation enter E_g and I_f, where the frequency f is function of wind velocity, this relation linear is limited by range for iron saturation [1]. So, this system will operate only in the range of 5 to 10 m/s of wind velocity, out this range the system is turning off automatically.

The feedback control system is composed by: a frequency sensor, a frequency to voltage converters, synchronized ramp circuit (SRC), voltage comparator integrated circuits, a gate circuit to fire the thyristor (SCR) and finally a semi-controlled rectifier, see the block diagram in figure 1.

The Strategy is that the signals from the voltage and frequency of the generator terminals, these are converted into a DC signal through of converting but with variable amplitude.

This signal is compared with the Reference signal result in an error who see figure 1 signal.

The SRC is synchronized with the frequency network f and has as output a ramp signal.

The second comparator circuits receive the signals from the first comparator and also the output signal from of SRC, produce an signal *Ve*.

This *Ve* signal is processed to firing the angle α of SCR's.

4. Modelling

A. Wind Speed

The wind speed usually varies considerably and has a stochastic character. The wind speed variation can be modeled as a sum of harmonics with the frequency range 0.1–10 Hz [8]:

$$u = u_0 \left[1 + \sum_n A_n \sin(\omega_n t) \right] \qquad (1)$$

Hence, the physical wind turbine model is subjected to the disturbance.

B. Electric System

The electrical model used here, both for engine and generator, can be found in the book Electric Machinery [2]. In the case of the synchronous generator model was used machines with not-salient poles.

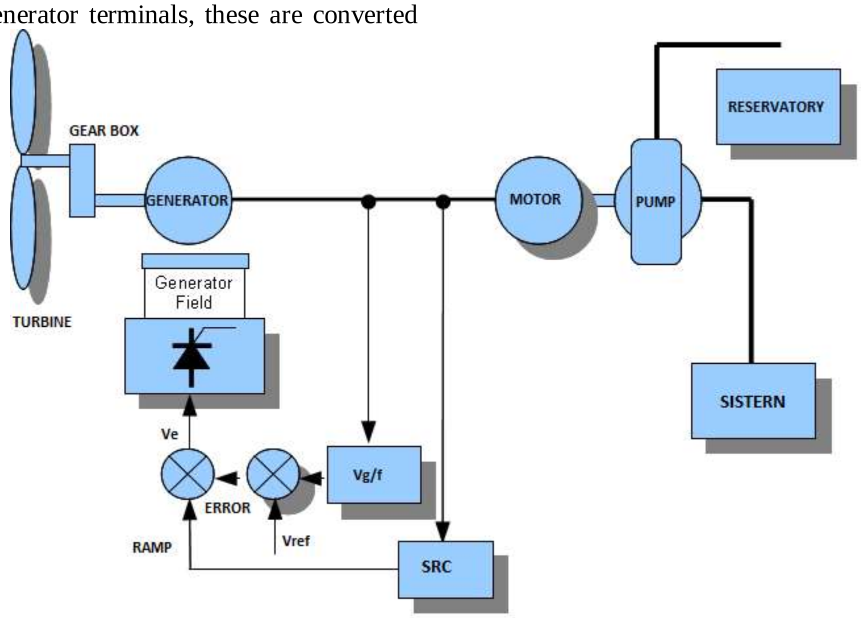

Fig.1. Block diagram of SCEE

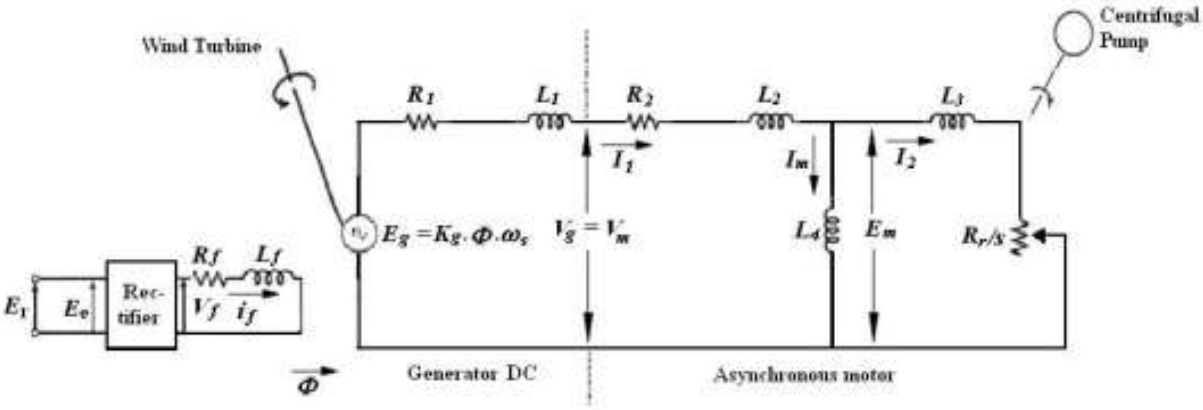

Fig. 2 – Electric circuit model

Is important the development of the transfer function E_m/E_g, to obtaining the total torque T who will supply the lost in the copper and will supply the mechanic torque T_m.

$$H = \frac{L_4\,(W_S\,L_3 + R_r)}{R_e + \mathrm{j}\,I_m} \qquad (2)$$

$$Re = L_1R_r + L_2R_r + L_3R_1 + L_3R_2 + L_4R_1 + L_4R_r \qquad (3)$$

$$Im = W_sL_1L_3 + W_sL_1L_4 + W_sL_2L_3 + W_sL_2L_4 + W_sL_3L_4 - \frac{R_1R_r}{W_s} - \frac{R_2R_r}{W_s} \qquad (4)$$

$$H_m = \frac{E_m}{E_g} \qquad (5)$$

$$V_S = \frac{2\ f\ 60}{P} \quad [\text{rpm}] \qquad (6)$$

$$W_S = 2\ \pi\ V_S \quad [\text{rad/s}] \qquad (7)$$

$$V_r = (1 - S)\ V_S \quad [\text{rpm}] \qquad (8)$$

$$E_g = K_g\,\phi\,W_S \quad [\text{v}] \qquad (9)$$

$$P_{tot\text{-}motor} = q_1\,I_2^{\,2}\,\frac{Rr}{s} \quad [\text{w}] \qquad (10)$$

$$P_{cobre\ rotor\text{-}motor} = q_1\,I_2^{\,2}\,R_r \quad [\text{w}] \qquad (11)$$

$$P_{mec\text{-}motor} = (1 - S)\ P_{tot} \quad [\text{w}] \qquad (12)$$

$$T_m = \frac{P_{tot\text{-}motor}}{W_S} \quad [\text{N.m}] \qquad (13)$$

C. Wind Turbine

The model mathematic of the turbine was obtained across laboratory test [6]. The turbine torque is:

$$T_{turbine} = \frac{P_{ex}}{W_t} \quad [\text{N.m}] \qquad (14)$$

$$P_{turbine} = \rho_{ar}\,A\,V_v^{\,3}\ .\ Cp \quad [\text{N.m}] \qquad (15)$$

$$A = \pi\ r^2 \quad [\text{m}^2] \qquad (16)$$

$$C_p(\lambda) = b_0\lambda + b_1\lambda^{3/2} + b_2\lambda^2 + b_3\lambda^{5/2} + b_4\lambda^3 \qquad (17)$$

$$b(i) = a_0 + a_1\beta + a_2\,\beta^2 \qquad (18)$$

D. Centrifugal Pump

The centrifugal pump model obtained from laboratory was the same calculated by expressions [7].

$$T_{pump} = \frac{P_{pump}}{Wr} \quad [\text{N.m}] \qquad (19)$$

$$P_{mec\text{-}motor} = P_{pump} = q_1\,R_r\,I_2^{\,2}\,\frac{(1 - S)}{S} \quad [\text{w}] \qquad (20)$$

E. Semi Controlled Rectifier

The mathematical model of semi-controlled rectifier is shown in equation 21, according to figure 1 it is powered by the generator output *Vg*, and its output voltage is controlled by the input signal in the activate circuit of scr's *Ve*.

$$V_f = \frac{3}{\sqrt{2}} Ve(1 + Cos \propto) \quad [v] \qquad (21)$$

5. Field results

Note that the error found between the theoretical values and electric measurement values were around two percent [5].

Table I show the input dates used in the simulation, which are the same values used in field testing of the electric system.

Table I. Data input

Variable	Value
R1 [Ohms]	0.4000
R2 [Ohms]	0.4400
Rr [Ohms]	0.7080
L1 [H]	0.0089
L2 [H]	0.0890
L3 [H]	0.0089
L4 [H]	0.0067

Table II shows the values of power flow through the system of converting wind energy, referring to the slip *S* values of the induction motor.

Table II. Power in function to slip *S*

S	Pturbine [w]	Ptot-motor [w]	Ppump [w]
0.2540	2708.82	1921.05	1916.86
0.2450	2350.02	1680.47	1673.56
0.2330	1989.45	1436.09	1435.84
0.2220	1667.41	1215.67	1210.67
0.2090	1381.14	1017.15	1013.69
0.1950	1120.76	839. 98	837.24
0.1790	908.00	682.97	682.39
0.1620	716.69	545.02	543.91
0.1420	552.62	425.31	424.47
0.1170	412.74	321.96	321.60
0.0990	295.72	234.21	223.60

The table III is showed the generator voltage V_g as function of wire frequency *f*.

This relation give an idea of value of *Vg(f)* in the range of frequency *f*.

Table III. Generator voltage and frequency *f*

f [hz]	Vg [Volts]
101.00	307.00
96.03	287.00
90.48	265.00
84.92	243.77
79.33	222.77
73.70	202.17
68.02	181.97
62.27	162.12
56.42	142.60
50.36	123.08
44.07	103.67

The table IV show us the conjugate of the pump *Tpump* as function of slip *S*, is important say that these values *Tpump(s)*, is repeated for an range of frequency *f* where these values are shown in the table III.

Table IV. Pump torque in function to slip *S*

S	Tpump [N.m]
0.2540	4.05
0.2450	3.67
0.2330	3.29
0.2220	2.92
0.2090	2.57
0.1950	2.25
0.1790	1.94
0.1620	1.66
0.1420	1.40
0.1170	1.15
0.0990	0.90

Table V. *Vg/f* in function to slip *S*

S	Vg/f
0.2540	3.04
0.2450	2.99
0.2330	2.93
0.2220	2.87
0.2090	2.81
0.1950	2.74
0.1790	2.68
0.1620	2.60
0.1420	2.53
0.1170	2.44
0.0990	2.35

Table V shows the value of the output signal of frequency converter *Vg/f* as a function of the network frequency *f*.

4. Conclusion

This work was part of the Master's program at the Federal University of Paraíba in Brazil and was funded by CAPES - Coordination for the Improvement of Higher Education.

The proposed work is completed and included: development of mathematical models, computer simulation, and data collection from the test center.

Important is to say that many other studies were performed using as base as this research work [3] and [4].

This work was presented as part of the graduate program in Electrical Engineering of Paraíba Federal University in Brazil and was implemented on its campus.

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