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Modeling and Control Voltage of Wind Pumping Systems using a Self Excited Induction Generator

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Abstract: Self-excited induction generators (SEIG) are mostly exploited in isolated areas to generate electrical energy. However, an isolated induction generator should have a control system that keeps the DC bus voltage at a constant value when the speed of the rotor and load are varied. The control scheme has been presented to maintain the DC bus voltage constant to operate dc motor loaded with a centrifugal pump at its rated voltage under variable wind speed. It also shows the behavior of the pumping systems. The computer simulations are provided to verify the validity of the proposed control algorithm.

Keywords: Renewable energy, Self-excited induction Generator, .DC voltage control.

1. Introduction

Wind is a clean source of renewable energy that produces no air or water pollution. And besides this wind is free. This has spurred researchers attentions for renewable energy. The SEIG has become very popular for generating power from renewable energy sources, such as wind and small hydro. The utility of SEIG as standalone machine has started gaining importance when power engineers encountered difficult situations for installation of transmission and distribution lines in the remote areas due to difficult geographical conditions [4]. Moreover, it has distinct advantages like simplicity, low cost, ruggedness, little maintenance, absence of DC, brushless etc., as compared to the conventional synchronous generator.

However, its major disadvantage is the inability to control the voltage and frequency under change in load and speed in stand-alone system. [2]. To get around this problem, many researchers have proposed numerous control algorithms [4-5-6-8-12-13].Our proposed algorithm is based for keep the DC voltage of SIEG at constant level to provide the desired voltage and current required by the dc motor loaded with a centrifugal pump used in isolated areas under variable wind speed. Detailed Matlab/Simulink-based simulation studies are carried out to demonstrate the effectiveness of the scheme.

2. Description of the system

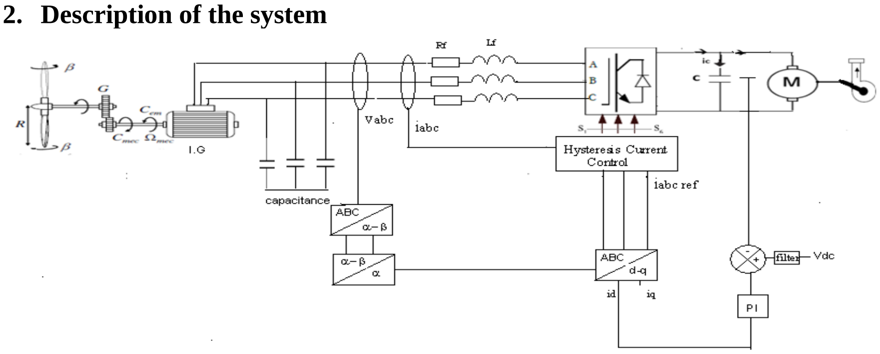

Figure 1. Block diagram of the proposed system.

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The self-excited induction generator using three phase AC capacitors can start its voltage buildup from a remnant magnetic flux in the core. This voltage buildup starts when the induction generator is driven at a given speed and an appropriate capacitance connected at its terminals. We introduce the voltage oriented control in order to operate dc motor loaded with a centrifugal pump at its rated voltage of 120 V under variable wind speed. Since this paper focuses on modeling and behavior of the electrical part of the system, the turbine is not taken into account. Rotor speed is taken as an independent and variable input into the model.

3. System Modeling

The following sections present the modeling of all subsystems of the wind pumping system. The main components are SIEG, PWM rectifier and DC motor loaded with a centrifugal pump as shown in Figure 1

A. Modeling of the SEIG

The equivalent circuit of self-excited induction generator is show in Figue 2[1]:

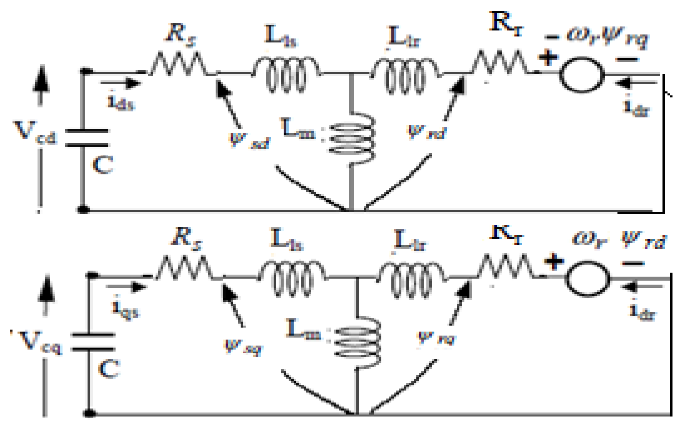

Figure 2. d-q model of SEIG at no load

Including initial conditions, i.e. initial voltage in the capacitors and remnant magnetic flux in the core, one can obtain the following differential equation [1]:

$$\mathrm{PI} = AI + B$$

$$I = \begin{bmatrix} i_{qs} \\ i_{sd} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

$$B = \begin{bmatrix} L_m K_q - L_r V_{cq} \\ L_m K_d - L_r V_{cd} \\ L_m V_{cq} - L_s K_q \\ L_m V_{cd} - L_s K_d \end{bmatrix}$$

$$A = \frac{1}{L} \begin{bmatrix} -L_r R_s & -L_m^2 w_r & L_m R_r & -L_m w_r\ L_r \\ L_m^2 w_r & -L_s R_s & L_m w_r\ L_r & L_m R_r \\ L_m R_s & L_s w_r\ L_m & -L_s R_r & -L_s w_r\ L_r \\ -L_s w_r\ L_r & L_m R_s & -L_s w_r\ L_r & -L_s R_r \end{bmatrix} \quad (1)$$

Where L= $L_r\, L_s - L_m^2$
The excitation system model:

$$V_{cq} = 1/c\int \; i_{qs} - icq\; dt \quad (2)$$

$$V_{cd} = 1/c\int \; i_{ds} - icd\; dt \quad (3)$$

B. Modeling of dc motor

The modeling of DC motor and its load are represented by the following equations with constant coefficients [5]:

$$V_a = R_a I_a + L_a \frac{dI_a}{dt} + Kw \quad (4)$$

$$KI_a = A_1 + Bw + J_a \frac{dw}{dt} + T_L \quad (5)$$

The load torque here is the mechanical torque of the pump which is a nonlinear function of the motor speed:

$$T_L = A_2 + \varepsilon\, w^{1.8} \quad (6)$$

B. Modeling of the control scheme

The topology of the voltage source AC/DC converter connected to the self excited induction generator is presented in Figure 3 [3]. The following equations describe the dynamic model of the PWM rectifier in natural (A, B, C) coordinates. Sa, Sb and Sc represent states [1,0] of power switches in respective converter legs.

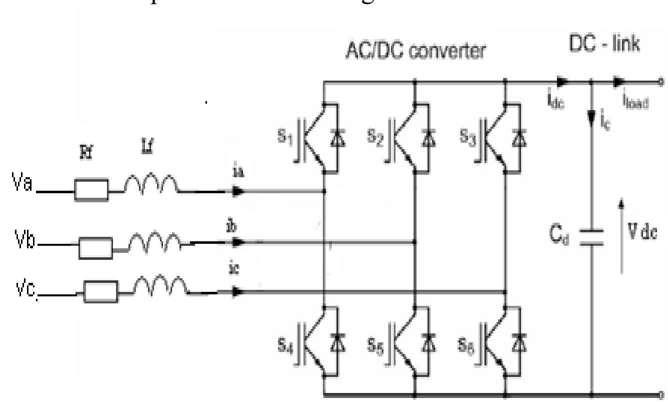

Figure 3. Voltage source AC/DC line-side converter.

$$\frac{di_a}{dt} = \frac{1}{Lf}\left[V_a - Rf \cdot i_a - \frac{1}{3} V_{dc}(2S_a - S_b - S_c)\right] \quad (7)$$

$$\frac{di_b}{dt} = \frac{1}{Lf}\left[V_b - Rf \cdot i_b - \frac{1}{3} V_{dc}(2S_b - S_c - S_a)\right] \quad (8)$$

$$\frac{di_c}{dt} = \frac{1}{Lf}\left[V_c - Rf \cdot i_c - \frac{1}{3} V_{dc}(2S_c - S_a - S_b)\right] \quad (9)$$

By considering a DC motor connected to the dc link and assuming the inverter as an ideal current source that transfers energy between the dc-link and the induction generator, the dc-link can be represented by the following equation:

$$\frac{d}{dt}V_{dc} = \frac{1}{C}(S_a i_a + S_b i_b + S_c i_c - i_{load}) \quad (10)$$

Where C is the dc-link capacitance and i_{load} is the load current. The Hysteresis current control is based on feedback loops with hysteresis comparators, which directly produce the switching signals for the converter power devices when the error between the reference and the actual value exceeds an assigned tolerance band. The error between the reference and actual capacitor voltages is processed by the PI controller.

4. Simulation results and discussion

MATLAB/Simulink® modelling is used to observe the proposed control. The residual magnetism in the machine is taken into account in simulation process without which it is not possible for the generator to self excite. The relationship between magnetizing inductance (Lm) and phase voltage for induction machine was obtained experimentally taken from reference[1]:

$$1.56e\text{-}11.\ v^4+2.44e\text{-}8.\ v^3-1.19e\text{-}5.\ v^2+1.42e\text{-}3.\ v\ +0.245$$

The dc motor loaded with a centrifugal pump is connected at t=3 sec and the variation of rotor speed is between 1700rpm , 1500rpm, 1800rpm ,and 1600 rpm respectively at 0s, 8s, 12s and 16s as shown in Figure 4.

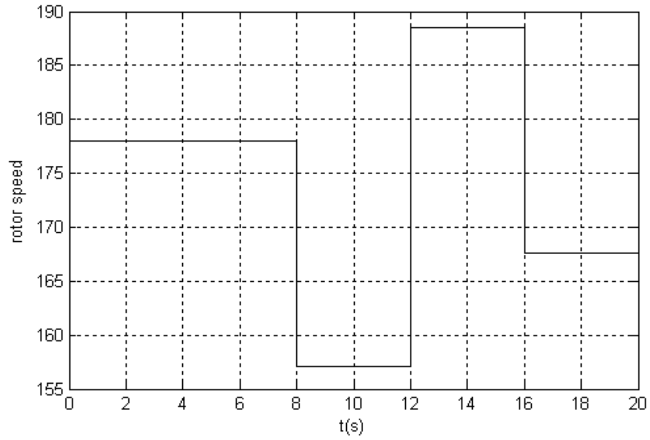

Figure 4. Variation of rotor speed (rad/s)

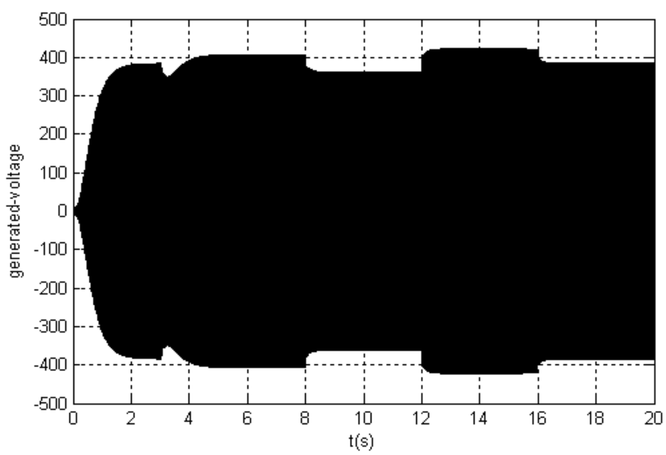

Figure 5. Terminal stator voltage (ia) of the sieg

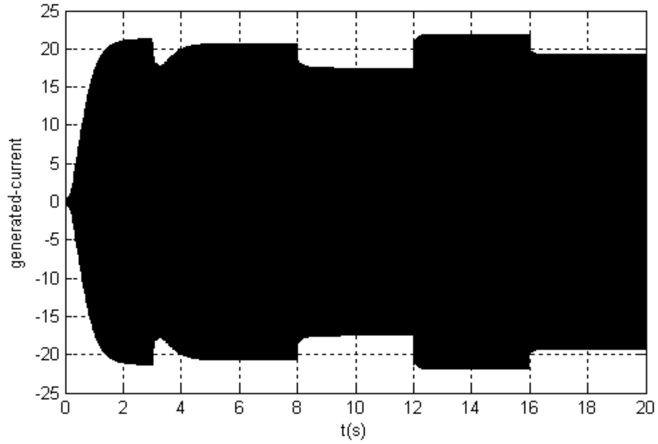

Figure 6. Stator line current (ia) of the sieg

It is observed that any variation in rotor speed of the SEIG or application of pumping system is directly indicated by the variation in the terminal stator voltage and current of the generator as shown in Figure 5 and Figure 6.

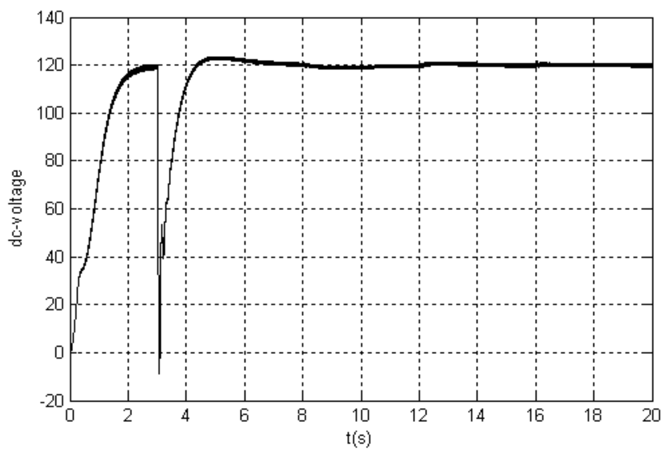

Figure 7. dc link voltage

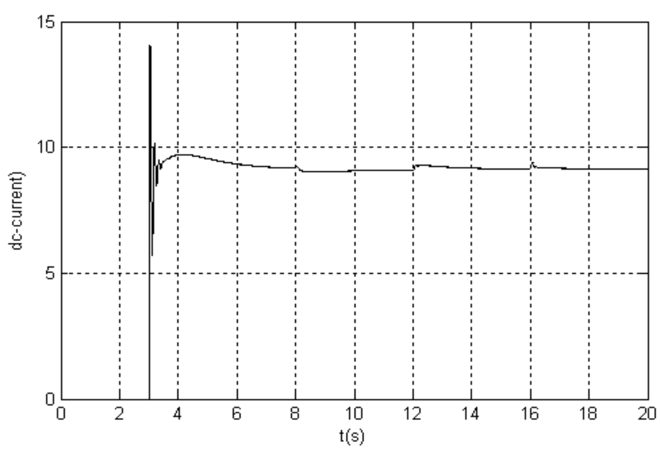

Figure 8. dc current motor (A)

Figure 7 shows the simulation results of the control constant DC voltage technique. The DC motor loaded with a centrifugal pump. suddenly is applied at t=3s A large peaks in the DC bus voltage is observed, but it recovers quickly due to the corrective action of the PI controller it is observed too that the value of the DC bus voltage is maintained at a constant value even if the rotor speed changes.

In order to provide the effectiveness of our proposed control Fig 8, Fig 9, Fig 10 shows the behavior of transient and steady-state operation of dc-current, dc motor speed, and pumping torque, during step change in wind speed.

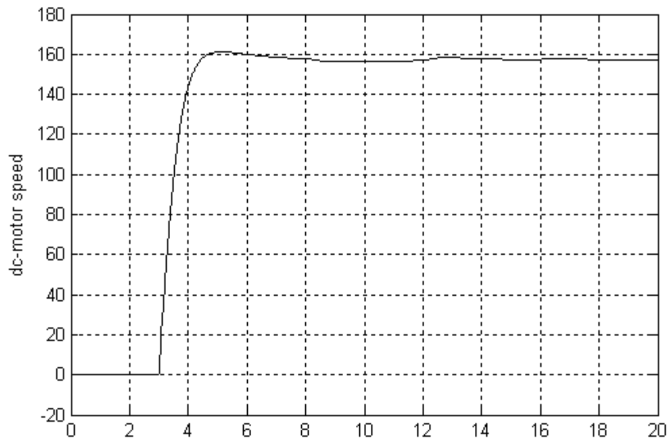

Figure 9. dc motor speed (rad/s)

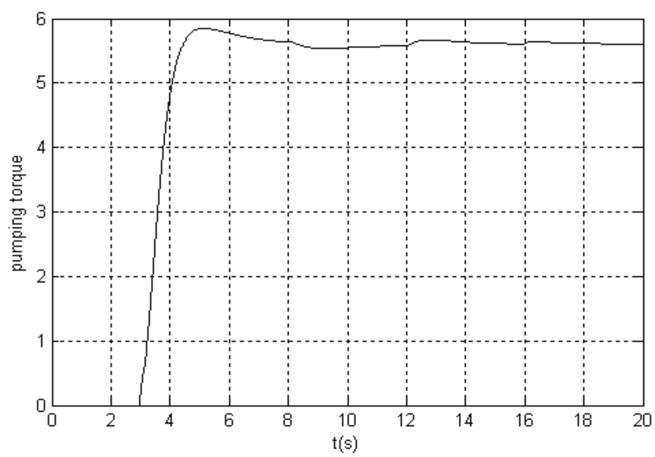

Figure 10. Pumping torque (N.m)

As already shown the pumping system applied at time 3 sec and from these figures, it is observed that the behavior of the pump system operates at its nominal state despite change of wind speed. As show in Figure 8, Figure 9, and Figure 10.

Conclusion

The objective of this work is to contribute to the development of control and the application of self excited induction generator used in isolated areas. Since this study is focused on the modeling and simulation of wind pumping systems controlled by the voltage oriented control under variable rotor speed. The voltage regulation of SEIG remains within the tolerable limits, thus enhancing the capability of machine to supply pumping system in its nominal operating.

Appendix

The data of the SIEG are indicated as follows:

3.6kW, Voltage =415V, F=50Hz

P = 4 poles; Rs = 1.66Ω; ls = 11.4 mH; Rr = 2.74Ω; lr = 11.4mH; Lm= 0.18H; C=3000e-6 F;

Rf=25Ω; Lf=3e-3 H

The data of the DC Motor & Pumps are as follows:

Va=120 volt, Ia = 9.2 A; w= 1500 rpm ; Ja = 0.02365 Kg.m2; Ra =1.5 Ω; La=0.2 H,

K = 0.67609 Nm.A-1; A1 = 0.2 Nm; A2 = 0.3 Nm; B =0.002387 Nm.s.rad-1

ξ = 0.00059 Nm.s.rad-1.

Nomenclature

R_s: Stator Resistance

R_r: Rotor Resistance

l_s: Stator leakage Inductance

l_r: Rotor leakage Inductance

L_m: Mutual inductance

$V_{cd}, V_{cq,}$: are the direct and quadrature axes stator.

i_{ds} , i_{qs}, i_{dr} , i_{qr}: are the direct and quadrature axes stator and rotor current

C: dc-link capacitance

c: ac capacitance

icd, icq: are inverter currents in d-q axis.

R_F, L_F: resistance and inductance of the AC side filter of the PWM converter

P: Number of poles.

Kd, Kq: are constants which represent the initial induced voltages along the d-axis and q-axis respectively due to remnant magnetic flux in the core.

K: Torque & back emf constant

A1: Motor friction

B: damping

ε : Load torque constant

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