Microprocessor Closed Loop Control of Induction Generator

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Abstract

This paper presents a new simple approach for controlling the terminal voltage of capacitor self-excited induction generators. The method is based on switching ON or OFF certain extra capacitor banks that are connected with each phase of the induction generator. Only one leg consists of an IGBT and diode-bridge is required as a switch for each phase for three-phase self-excited induction generator. The advantages of this method are simple, powerful, effective and less expansive. Transient and steady state performances of induction generator terminal voltage are presented under different operating conditions. Simulation results for both open and closed loop system are presented in comparison with similar experimental results. A good agreement between simulation and experimental results were found.

Keywords

Control, Induction Generator, Integral Control

1. Introduction

In recent years, owing to increased emphasis on renewable resources, development of suitable isolated power generators driven by energy sources such as wind, small hydro-electric, biogas, etc. has assumed greater significance. Due to its reduced unit cost, brushless rotor construction, absence of separate source for excitation, raggedness, case of maintenance and self protection against severe over loads and short circuits, a capacitor self-excited induction generator (SEIG) has emerged as a suitable candidate of isolated power sources[1]. The importance of SEIG directed many researchers to investigate and analyze the system for many years. The primary advantages of SEIG are less maintenance cost, better transient performance, absence dc power supply for field excitation, brushless construction (squirrel-cage rotor), etc. Induction generators have been widely employed to operate as wind-turbine generators and small hydroelectric generators of isolated power systems [2]

A simple method for the calculation of the minimum capacitance required to start the self-excitation process in isolated induction generators has been described [3]. The method is based on the analysis of the complex impedance matrix of a loaded SEIG. Only one algebraic equation is solved iteratively to yield the value of the angular frequency and then C_{min} is computed. Poor voltage regulation is one of the major drawbacks of an isolated self-excited induction generator. The terminal voltage may be increase considerably due to a small increased in speed[4]

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A technique for optimizing the power generated ... introduced. The proposed control strategy ensures stable operation within a wide speed range without overheating the machine. The proposed scheme employed a controllable rectifier, a d.c. link, an inverter, and an isolating transformer in the rotor circuit. Variation of firing angles, overlap angle, voltages, and powers with speed are deduced [5]. Analysis of an isolated self-excited induction generator is described in two approaches for analysis of the operating frequency during isolated operation are presented : an analytical method based on eigen values analysis and simulation analysis using EMTP. The results obtained from the eigen values method are in good agreement with the simulation results [6].

2. Machine Model

Figure 1 shows the d-q axis equivalent circuit model for a no-load, three phase, symmetrical induction machine. The stator and rotor voltage equations using Krause transformation based on stationary reference frame are given as follows [7,8]:

$$V_{qs} = -r_s\, i_{qs} + \omega\lambda_{ds} + \rho\lambda_{qs} \quad (1)$$

$$V_{ds} = -r_s\, i_{ds} - \omega\lambda_{ds} + \rho\lambda_{ds} \quad (2)$$

$$V'_{qr} = r'_r\, i'_{qr} + (\omega-\omega_r)\, \lambda'_{dr} + \rho\, \lambda'_{qr} \quad (3)$$

$$V'_{dr} = r'_r\, i'_{dr} + (\omega-\omega_r)\, \lambda'_{qr} + \rho\, \lambda'_{dr} \quad (4)$$

where

$$\lambda_{qs} = -L_{ls}\, i_{qs} + M\,(i'_{qr} - i_{qs}) \quad (5)$$

$$\lambda_{ds} = -L_{ls}\, i_{ds} + M\,(i'_{dr} - i_{ds}) \quad (6)$$

$$\lambda'_{qr} = -L_{lr}\, i'_{qr} + M\,(i'_{qr} - i_{qs}) \quad (7)$$

$$\lambda'_{dr} = -L_{lr}\, i'_{dr} + M\,(i'_{dr} - i_{ds}) \quad (8)$$

$$V_g = \sqrt{\ }\,[(v'_{qr} - v_{qs})^2 + (v'_{dr} - v_{ds})^2] \quad (9)$$

The superscript ' in equations (1) - (9) denotes the transformed rotor quantities based on the stator. The value of magnetizing inductance M depends on the degree of magnetic saturation and it is nonlinear function of the air-gap open-circuit voltage (Vg). The relationship between M and Vg can be obtained by using synchronous speed test and it can be described by a set of linear piece wise approximate equations as below for the induction machine under consideration (appendix).

$$M = \begin{cases} 0.6 & V_g \le 66\ \text{V} \\ 0.5 & 66 < V_g \le 132 \\ 0.3 & 132 < V_g \le 220 \\ 0.2 & V_g > 220 \end{cases} \quad (10)$$

The voltage-current equations of the excitation capacitor can be transformed from three-phase quantities into d-q axis ones by using Krause transformation. The transformed results are as below:

$$i_{dc} = C\rho\, V_{qs} + \omega\, C\, V_{ds} \quad (11)$$

$$i_{qc} = C\, \rho\, V_{ds} - \omega\, C\, V_{qs} \quad (12)$$

where idc and iqc are respectively the d-axis and q-axis components of the current flowing into excitation capacitor. The expression for the electromagnetic torque can be written as:

$$T_e = P\,(\lambda_{ds}\, i_{qs} - \lambda_{qs}\, i_{ds}) \qquad (13)$$

The dynamic equation of motion can be written as:

$$T_m = T_L + K\omega + J\, d\omega/dt \qquad (14)$$

and $T_e = T_m$ (15)

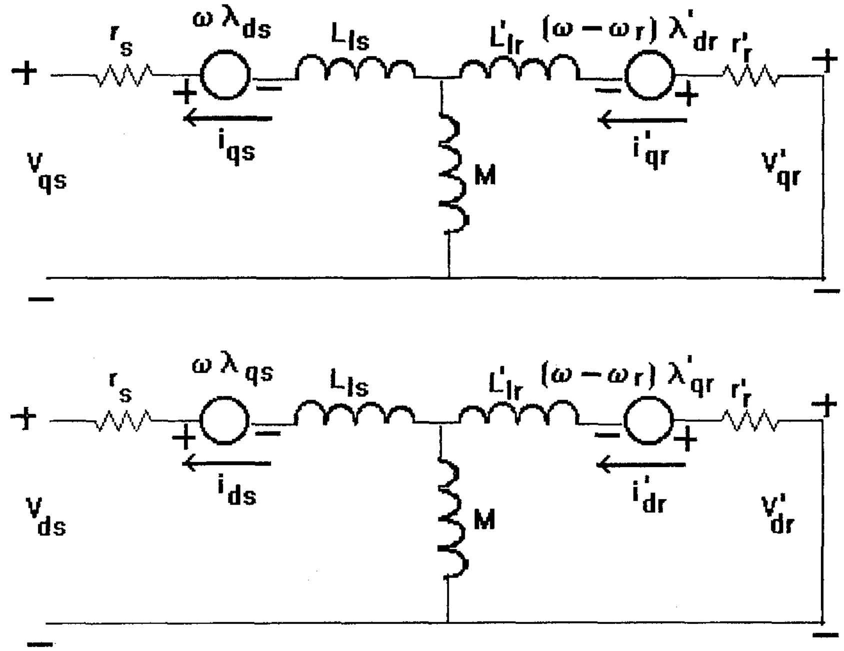

Figure (1) d-q equivalent circuit of an induction generator

3. Description of a proposed control system

A schematic diagram of a proposed system is shown in Figure (2). It consists of an induction generator, three branches; each of them consists of banks of fixed capacitors, auxiliary capacitance. and an IGBT; each of them connected in series on each phase of the induction generator. A minimum value of capacitance was taken into account for choosing a fixed capacitance. For a certain terminal voltage; a feedback value of one phase voltage of a balanced induction generator is stepped down by a transformer. Output voltage of the transformer is rectified then compared with a reference voltage corresponding to a required terminal induction phase voltage, error voltage equals to reference voltage minus feedback signal of phase voltage fed to microprocessor through an A/D converter. An assembly program is designed to achieve the error voltage and according to integral control; output pulses from a microprocessor deliver the gates of the three IGBTs (IGBT1, IGBT2 and IGBT3) through the driver circuit and respecting the following rules:

As Reference voltage ≥ feedback signal voltage   Turn on IGBTs

otherwise Reference voltage < feedback signal voltage   Turn off IGBTs

The auxiliary capacitances are connected in parallel of the three induction generator phases as IGBTs are turn on. On the other hand, the auxiliary capacitances are disconnected from the this system for inserting or outing the auxiliary capacitoances, and this will affect of the terminal voltage of the induction generator.

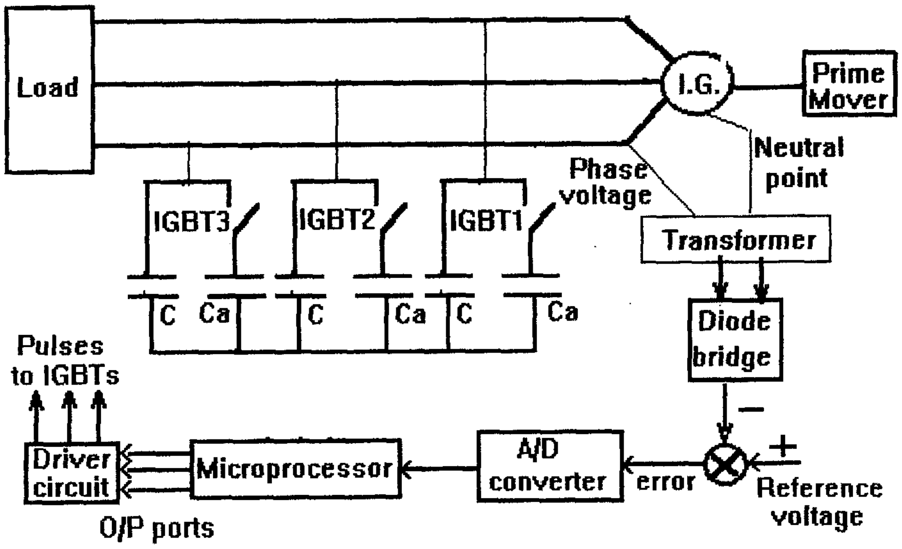

Figure (2) Schematic diagram of a proposed system

4. Simulation and Experimental Results

In this section, dynamic simulated results will be compared with the experimental results under different operating conditions. A FORTRAN program is designed and written to solve Equations 1-12, using Rung-Kutta technique. Dynamic performance is calculated using an integration step of time (0.0001 sec). Figure(3) shows the simulation of terminal voltage simulation response of a loaded induction generator during start-up and steady state periods. An induction generator is used in the laboratory to test for onset of self-excitation. The speed of the test machine is varied using a dc motor, and the minimum value of capacitance for the onset of self-excitation, at each speed, is established. An experimental results of the dynamic performance of induction generator is shown in Figure(4). Simulation and experimental results are in good agreement.

Terminal voltage perturbation due to sudden reference voltage change are shown in Figures 5,7 simulation and 6,8 Experimental. It may be observed that the proposed controller is capable for controlling the terminal voltage of unloaded induction generator by inserting or outing the auxiliary bank of capacitances. Also, the comparison between the simulation and corresponding experimental results gives another pointer of the accuracy of the simulation program. From this point, studying the terminal voltage perturbation due to sudden load change is obtained. The results are shown in Figures 9 and 10 . The results show that the terminal voltage of the induction generator voltage is decreased when the load is connected without controller. So, from this point it is very important to maintain the terminal voltage under different conditions. An integral controller is used for inserting or outing the capacitor to achieve that. Figures 11,12 show simulation and experimental results of load voltage and load current in case of generator is loaded and reference voltage is stepped up for 500 m.sec. In the other hand, Figure13,14 show the terminal voltage of the induction generator as the load is varied from 67 watt to 74 watt. From these results, it is impossible to keep the terminal voltage of induction generator at the value of no-load during the variation of load current by the proposed controller, but the decrease in load voltage is acceptable.

5. Conclusion

The voltage regulation of induction generator to be constant has been achieved using a bank of capacitors controlled by an IGBT as a switch over a wide range of operating condition with induction generator constant speed prime mover. An integral closed loop control with microprocessor is sensitive to improve the terminal voltage of a loaded induction generator. The system presented a highly integrated unit requiring small values of passive components. The effect of a smooth control represent the advantages of the proposed technique. The proposed method can be effectively applied to control the terminal of induction generator over a wide range of operating conditions. The good agreement simulation and experimental results substantiate the techniques and analysis presented in the paper

6. Appendix

Induction generator parameters:
3-phase, 4 poles, 50 Hz, 220 v, 0.5 amp., Rs = 4.7 ohm/ph Rr = 4.1 ohm/ph Lls = 0.34 mH, Llr = 0.34 mH, ωr = 105 rad/sec and C = 60 μF

7. Symbols

C:	Per phase fixed excitation capacitance.
Ca:	Auxiliary phase controlled capacitance.
J:	Moment of inertia constant.
K:	Friction constant.
ids:, iqs:	D- and q-axis machine stator currents.
idr:, iqr:	D- and q-axis machine rotor currents.
Lls, Llr:	Phase leakage inductance of stator and rotor.
λ_{ds},λ_{qs}:	Direct and quadrature stator flux linkage.
λ_{dr},λ_{qr}:	Direct and quadrature rotor flux linkage.
M:	Magnetization inductance per phase.
ρ:	Differential operator with respect to time t.
r_s, r_r :	Per phase resistances of stator and rotor.
Te:	Electromagnetic torque.
Tm:	Mechanical torque.
Tl:	Load torque.
Vds, Vqs:	Stator voltage components in d- and q-axis.
Vdr, Vqr:	Rotor voltage components in d- and q-axis.
ωr:	Mduction generator rotor speed
ω:	Angular frequency of the self-excitation voltage, rad/sec.

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التحكم بالدائرة المغلقة بإستخدام الميكروبروسيسور للمولد التأثيـــرى

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ملخص البحث :

يتضمن هذا البحث طريقة مبسطة وجديدة للتحكم فى جهد الاطراف للمكثفات الموصله بالمولدات التأثيرية ، وهذه الطريقة تعتمد على أساس التحكم فى الفتح والغلق لمجموعة معينة من المكثفات الزائدة المتصله مع كل وجه للمولد التأثيرى ، وكل طرف يتكون من مفتاح من نوع الترانزستور الثنائى ذو البوابة المعزولة IGBT وقنطرة موحدات وذلك كمفتاح لكل وجه من الثلاثة أوجه للمولد التأثيرى ، وذلك للتحكم فى توصيل المكثفات بالدائرة المغلقة بإستخدام الميكروبروسيسور.

ومن مميزات هذه الطريقة هى البساطة والفعالية والتأثير المباشر لتغيير الجهد وأيضا تقليل التكاليف.

ويشمل هذا البحث خواص المولد فى حالة الاستقرار وفى الحالة العابرة لجهد الاطراف عند حالات تشغيل مختلفة .

وتم فى هذا البحث مقارنة بين نتائج التمثيل العددى لكل من نظام الدائرة المفتوحة والمغلقة ووجد أن هناك إتفاق كبير بينهما مما يؤكد صحة الدراسة النظرية لمثل هذا النظام.