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DOUBLY FED INDUCTION GENERATOR USING NEURAL NETWORK CONTROLLER

التحكم في المولد الحثي مزدوج التغذية باستخدام الشبكات العصبية

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الملخص:

يقدم هذا البحث النموذج العملي لمولد حثي مزدوج التغذية مدار بطاقة الرياح ويتم التحكم في كل من الجهد والتردد الخارجي باستخدام الشبكات العصبية لتحديد قيمة جهد وتردد الدخل الكهربائي للعضو الدوار اللازم لتوليد الطاقة الكهربائية على اطراف المولد. ويهدف هذا البحث الى دراسة كيفية ضبط قدرة المولد على انتاج جهد وتردد ثابتين برغم تغير كل من سرعة دوران المولد الناشئة عن تغير سرعة الرياح وكذلك تغير الحمل الخارجي.

Abstract - This paper presents the assessment and simulation of stand-alone wind driven doubly fed induction generator using neural network controller. The machine shows the ability to generate constant voltage with constant frequency irrespective of the machine speed or load variations.

I. INTRODUCTION.

The doubly fed induction generator (DFIG) can supply power at constant voltage and frequency, while the rotor speed varies. This make it suitable for variable speed wind energy application. Additionally, when a bidirectional AC-AC converter is used in the rotor circuit, the speed range can be extended above synchronous speed and power can be generated both from the stator and the rotor. An advantage of this type of (DFIG) drive is that the rotor converter need only to be rated for a fraction of the total output power, the fraction depends on the allowable sub and super synchronous speed range[1].

This paper presents the simulation results of a stand-alone wind driven doubly fed induction generator (DFIG) using classical constant *(V/f)* closed loop control scheme[2].The paper presents also the use of neural network to stand as a look up table to replace the classical constant *(V/f)* control scheme. The proposed neural network determines the required magnitude and frequency of the injected rotor voltage to maintain a constant stator voltage magnitude and frequency[3].

II. CLASSICAL CONSTANT *(V/f)* CONTROL

It is known that scalar control relates to the magnitude control of a variable only, while the command and feedback signals are dc quantities that are proportional to the respective variables. Provided that the main control strategy is based on regulating the machine flux level to be kept constant and closed to its nominal value, different control methods of varying degrees of complexity have been proposed and used for the scalar control of induction machine. The nature of application dictates the acceptance of particular method.

In order to operate at a constant flux level, the two controllable parameters, rotor supply voltage (v_r) and frequency (f_r) have to be adjusted for each operating condition. A closed loop for doubly fed induction generator (DFIG) control scheme, known as constant *(V/f)* control scheme, is shown in fig (1). The relation between the supply voltage and frequency is linear except at low speed. A voltage booster is provided at low speeds to compensate for the stator resistance drop. Below synchronous speed, the power is developed to the rotor. However, for super synchronous speeds, the power is delivered from both stator and rotor windings [2].

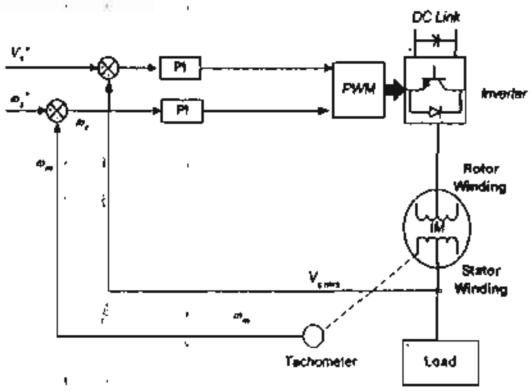

Fig 1. Closed loop Volts/Hertz stator voltage control of a doubly fed induction generator

III. PROPOSED NEURAL NETWORK CONTROLLER

In this section, the proposed method for controlling the stator voltage is introduced through the magnitude and frequency of the injected rotor voltage based upon the artificial neural network. The training epoch used as an input for the neural network is built depending on different machine speed and different loading conditions. The input data include the required rotor voltage and frequency to maintain a constant stator voltage of 220V, 50 Hz for different load impedance and different speeds[4].

The MATLAB function *newff* is used to create a three-layer tansig / tansig / purelin network with three inputs, namely the load resistance, load inductance and the machine speed, and two outputs, namely the rotor voltage and frequency. As this function finishes training at 500 epochs, fig (2) displays the following plot of errors[5 6 7 8].

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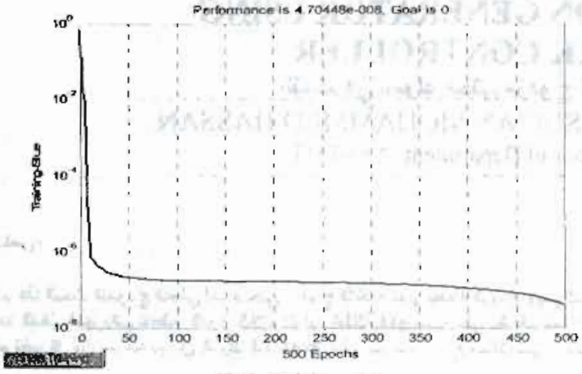

Fig 2. Training error

IV. EXPERIMENTAL SETUP

The experimental setup used to verify the previous control scheme is shown in fig (3). The inverter used to inject a variable voltage, variable frequency, AC supply in the rotor circuit is emulated by a synchronous machine driven by a DC machine. The speed of the DC machine is used to change the frequency, while the field current of the synchronous machine is used to control the voltage magnitude. The output voltage of the synchronous generator is applied to the rotor circuit of the induction generator. The wind energy is emulated using another DC machine to drive the induction generator. An extend speed range is obtained by varying the speed of the DC machine used to drive the induction machine from sub-synchronous to super-synchronous speed.

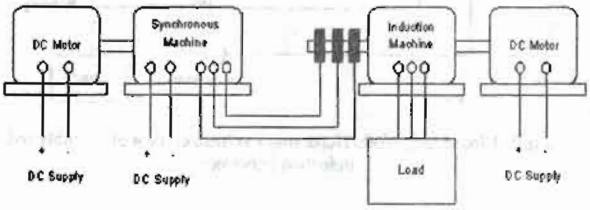

Fig 3. Experimental Setup for doubly fed induction generator

V. SIMULATION RESLUTS

The proposed control scheme is simulated using SIMULNK. Wind speed variation is simulated by varying the machine speed from sub-synchronous to super-synchronous speed. The desired rms output voltage is set to 220V at a constant frequency of 50Hz.

The generator is driven at a constant speed of 1500 r.pm. The machine is simulated for two different load impedances. The first impedance is of 100Ω resistance and 0.1H inductance, while the second impedance is of 200Ω resistance and 0.2H inductance. The machine output rms voltage for the two different loads is shown in fig (4). The output phase voltage is stable at 50Hz, 220V rms irrespective load impedance. Fig (5) illustrates also the stator flux linkage which is kept constant. This ensures that the internal generated emf is kept constant irrespective of the load or machine speed variations. The rotor phase voltages are illustrated in fig 5. The rotor voltage is a DC for this speed. It is noted that the rotor voltage increases as the load current increases. Also, the voltage magnitude matches with that of the input epoch used for neural network training.

The same previous case is simulated when generator is driven at a constant speed of 1400 r.p.m. The machine is simulated for the same two different load impedances. The machine output rms voltage for the two different loads is shown in fig (6). The output phase voltage is stable at 50Hz, 220V rms irrespective of load impedance. Fig (7) illustrates also the stator flux linkage which is also kept constant.

The rotor phase voltages are illustrated in fig (7). The rotor voltage is an AC of frequency of 3.333Hz for this speed. It is noted that the rotor voltage is still proportional to the load current. Also, the voltage magnitude matches with the neural network training

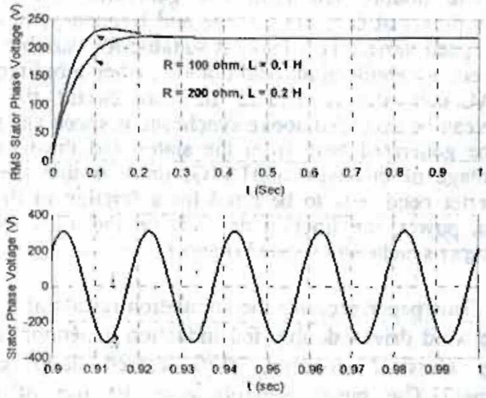

Fig 4. Stator phase voltage for different load impedances at 1500r.p.m

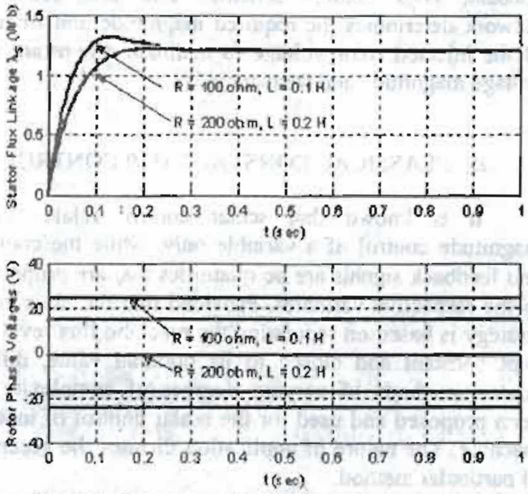

Fig 5. Stator flux linkage and the rotor phase voltages for different load impedances

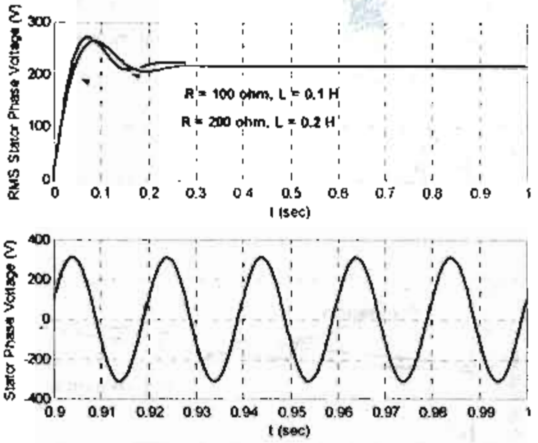

Fig 6. Stator phase voltage for different load impedances at 1400r.p.m

The effect of instantaneous speed variations is also simulated. The generator is firstly driven at a constant speed of 1500 r.p.m then the speed is changed to 1450 r.p.m after 1 sec. The machine speed is shown in fig (8). The load impedance is assumed constant with resistance of 100Ω and inductance of 0.1H. The machine output rms voltage is shown in fig (8). The output phase voltage is stable at 50Hz, 220V rms irrespective of machine speed. It is noted that the voltage transients are high because the method of constant *(V/f)* control suffers high transients. Fig (9) illustrates also the stator flux linkage which is kept constant. This ensures that the internal generated emf is kept constant irrespective of the load or machine speed variations. The rotor phase voltages are illustrated in fig (9). The rotor voltage is DC when the speed is 1500 r.p.m. When the speed is changed to 1450 r.p.m the rotor voltage is AC with frequency of 1.667Hz. It is noted that the rotor voltage increases as the load current increases. Also, the voltage magnitude matches with that of the input epoch used for neural network training.

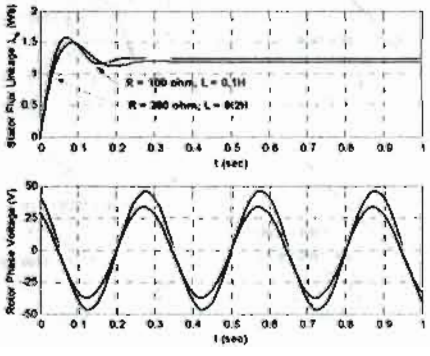

Fig 7. Stator flux linkage and the rotor phase voltages for different load impedances

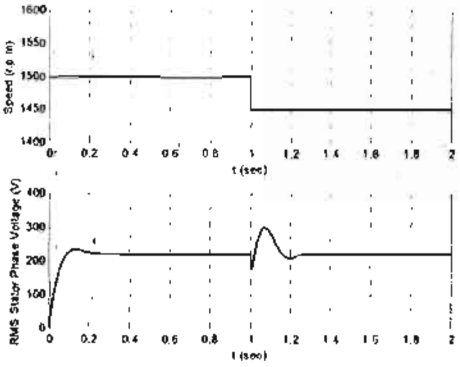

Fig 8. Machine speed variations and the rms stator phase voltage

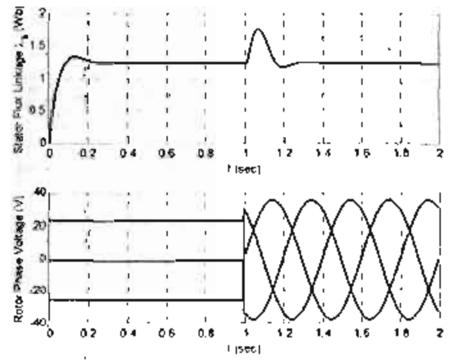

Fig 9. Stator flux linkage and the rotor phase voltages for different load impedances

The effect of load variations is also simulated. The generator is driven at a constant speed of 1500 r.p.m. The machine is firstly connected to an impedance of 200Ω resistance and 0.2H inductance then the load impedance is changed to an impedance of 100Ω and 0.1H inductance after 1 sec. The machine output rms voltage is shown in fig (10). The output phase voltage is kept stable at 50Hz, 220V rms irrespective of the load variation. It is noted that the voltage transients due to load variations are smaller than that due to speed variations. Fig (10) illustrates also the stator flux linkage which is kept constant. This ensures that the internal generated emf is kept constant irrespective of the load or machine speed variations.

The stator phase current is illustrated in fig (11) which is shown to be increased when the load impedance is reduced after 1 sec while speed is kept constant at 1500 r.p.m. The rotor phase voltages are also illustrated in fig (11). It is noted that the rotor voltage increases as the load current increases. That correlates with the neural network training output.

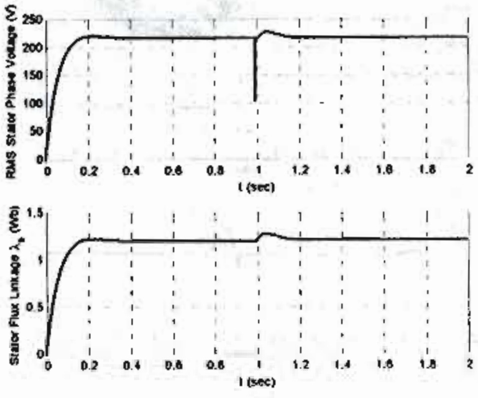

Fig 10. Stator phase voltage and stator flux linkage

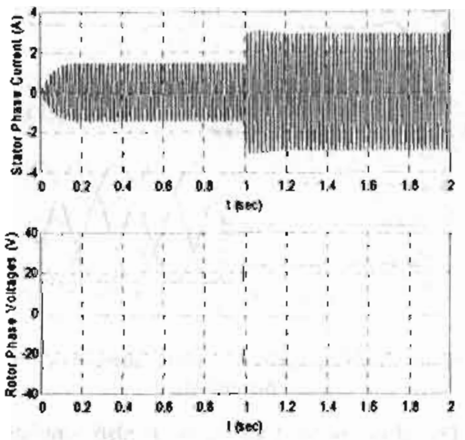

Fig 11. Stator phase current and rotor phase voltages

VI. COMPARISON BETWEEN EXPERIMENTAL AND SIMULATION RESLUTS

The experimental results for the system described in section IV are compared with their corresponding simulation result in this section. The synchronous machine is driven at a constant speed of 400 r.p.m, while its field current is adjusted to control the injected voltage to the induction generator rotor circuit. The corresponding output frequency from the synchronous generator at this speed is 13.33 Hz. Moreover, the induction machine is driven at a constant speed of 1100 r.p.m to ensure that the stator frequency is 50Hz. The stator output is connected to a three phase pure load resistance of 200Ω. The rotor voltage is adjusted to control the output stator voltage at some selected values. The rotor voltage and current are also measured and compared with their corresponding simulation results. Fig (12) illustrates the comparison between both experimental and simulation results which are shown to be very close to each other.

The system efficiency is calculated as the ratio between the output power which represents the stator output power (P_s) and the input powers. The input powers to the system are the mechanical power (P_{mech}) and the injected rotor power (P_r).

$$\eta = \frac{P_s}{P_r + P_{mech}} \qquad (1)$$

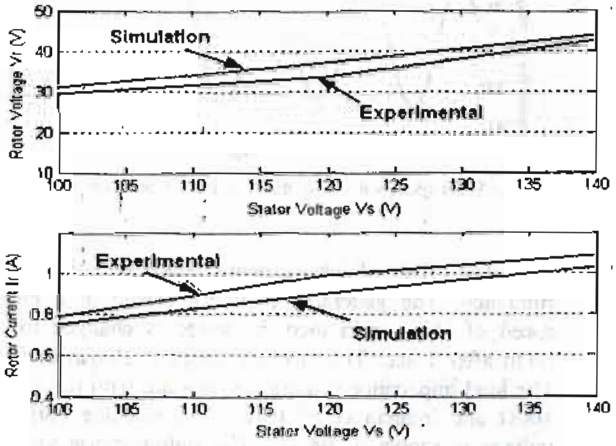

Fig 12 Comparison between experimental and simulation results.

VII. CHARACTERISTIC CURVES

The effect of loading on rotor quantities, namely the rotor injected power and rotor power factor, rotor current, rotor voltage, are illustrated in fig (13).

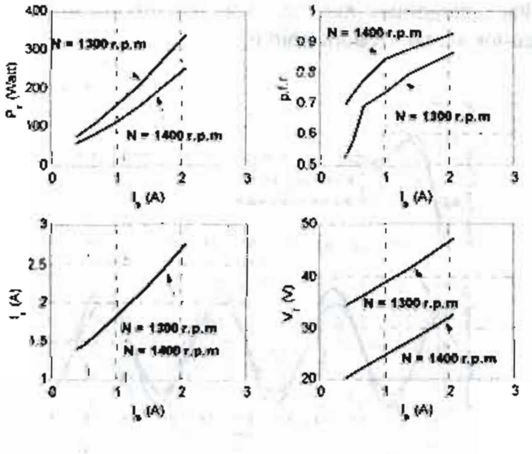

Fig 13. Effect of loading on rotor quantities at constant speed 1400 r.p.m, 1300r.p.m

The generator power gain, which is the ratio between the stator output power and the injected rotor power, is illustrated in fig (14) for two different speeds. It is obvious that as the load increases the power gain increases to an optimum value then it decreases again. Also, the power gain increases as the speed increases.

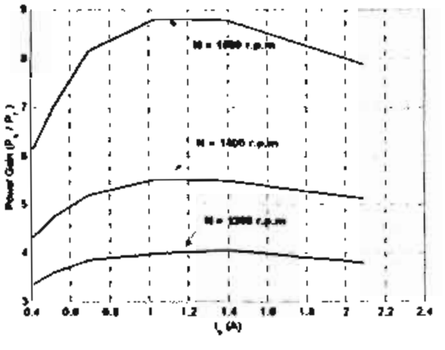

Fig 14. Effect of loading on generator power gain

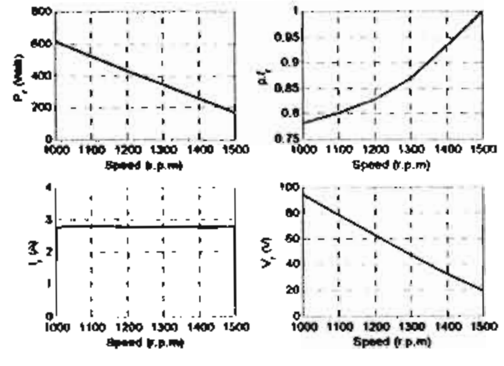

Fig 15. Effect of speed on rotor quantities with the generator connected to a load of 100Ω and 0.1H inductance.

The speed effect on the same rotor quantities is also illustrated in fig (15). Also, the effect of speed on power gain is illustrated in fig (16). It is noted that as the speed increases the generator power gain increases for the same output stator load. This means that the required injected rotor power to maintain a constant output stator power is reduced as the speed increases which improves the generator power gain.

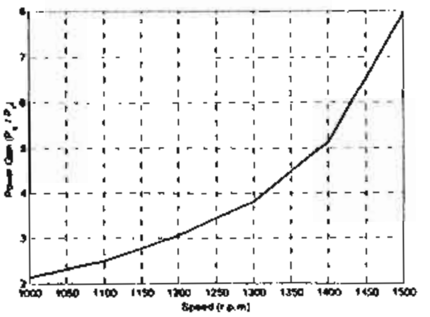

Fig 16. Effect of speed on the generator power gain

VIII:CONCLUSION

The Experimental and simulation study of the doubly fed induction machine performance in the generation mode shows the ability to control the magnitude and frequency of the stator winding voltage through the rotor winding irrespective of the load or machine speed. A theoretical and simulation study of the DFIG dynamic performance shows that the proposed system is able to produce a constant output voltage with constant frequency irrespective of load or rotor speed variations. This makes it suitable for variable speed wind energy applications.

The experimental and simulation results of a stand-alone wind driven doubly fed induction generator (DFIG) using classical constant (*V/f*) closed loop control scheme was investigated. The experimental results was found to be matched with the simulation results

The neural network was used to stand as a look up table that determines the required magnitude and frequency of the injected rotor voltage to maintain a constant stator voltage magnitude and frequency. The neural network is trained using different speeds and different load conditions. The simulation to this control scheme reveals that the output voltage can be maintained constant irrespective of machine speed or load variations.

APPENDIX

Induction machine data

The induction machine has the following parameters referred to the stator side

$R_s = 2.08\ \Omega$, $X_{ls} = 5.48\Omega$, $R_r = 7.15\ \Omega$, $X_{ls} = 5.48\Omega$,

$X_m = 179.96\Omega$

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