Direct Torque Controlled Doubly Fed Induction Motor Supplied by WG and Based on ANN

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Abstract. Faced with a growing demand for energy and the exhaustion of fossil fuels in the more or less long term, various alternatives have been envisaged as renewable energies.

Renewable energy is a type source of energy that renews itself quickly enough to be considered inexhaustible on a human scale. Renewable energies come from regular or constant natural phenomena (sun, wind…).

Renewable sources of energy, allowing decentralized production of electricity, can help to solve the problem of electrification of isolated site where a large number of individuals are devoid of any energy supply, thus being unable to satisfy any need even minimal and improve its living conditions. Utilizing universally applicable, low maintenance energy sources, the wind solution most often represents the ideal economic and technological choice for the regions or isolated installations.

In this work, we will discuss the application of wind for pumping system based on the use artificial neural network to track the maximum power point and to control DC voltage, the simulation show the effectiveness the proposed method.

Keywords: DTC · DFIM · WIND generator · MPPT · DC/DC converter · ANN

1 Introduction

Wind energy is, for many reason, one of the most promising renewable energy sources [1]. Wind energy systems are the fastest growing technology. Among these wind technologies, many systems of different types have been designed and developed while extending an experiment in this area dating back several centuries. Nowadays, the most known and used form of wind technology is the wind turbine, a machine that gets energy from the wind to generate an electric current. The chain of conversion of wind

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energy into electrical energy integrates various electrical components. In order to maximize the efficiency of this energy conversion, many solutions have been discussed both at the level of the generator to be used and power electronics. Most devices use synchronous or asynchronous machines but studies are also carried out in order to develop special machines. The electronic power interface between the wind turbine and the load is generally intended to control the generator in order to extract a maximum of wind power. Agricultural watering needs are usually greatest [2]. Wind energy is used in various isolated site applications such as pumping. Its use in pumping has responded quickly especially in rural and Saharan regions. For wind power generation several structures are used with vertical or horizontal axes and several methods are available at fixed or variable speeds. While for the generator system, the researchers use the different electrical machines for energy conversion as permanent synchronous machine. In addition, induction motor is used more and more for pumping systems. The low cost of the engine, the low maintenance requirements [3]. However, lately the researchers are interested in the doubly fed asynchronous machine for pumping system.The introductions of new use of DTC control based on artificial techniques in the renewable domain are very promising. First i dea of direct torque control was developed in 1986. This method of controlling that has been progressed during past decade, provides a fast torque response and also it is robust against machine parameter variations [4–6]. Currently, artificial intelligence techniques are also widely used in many fields such as industrial process control, image processing, diagnostics, medicine, space technology, computer data management systems and pumping system. Among all intelligent techniques, Artificial Neural Networks (ANN) seems to have the greatest impact in the field of power electronics and in the control of electrical machines, which is evident from the large number of publications produced in Literature.

The main objective of this work is so to continue and improve the research in the framework of production by wind and wind energy. Develop control methods to improve the efficiency and production of electrical energy. We present and discuss the application of direct torque control on the doubly fed induction motor supplied with wind system, then to track the maximum power point and to regulate the DC voltage needed to feed our system, an artificial neural network controllers are used.

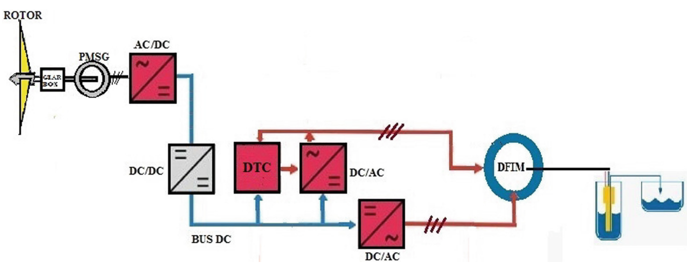

Fig. 1. Proposed intelligent pumping system

2 Wind Generator

A wind turbine is a device that transforms part of the kinetic energy of the wind (fluid in motion) into mechanical energy available on a transmission shaft and then into electrical energy via a generator. In this section, we are mainly interested in modeling and controlling the wind turbine. Where, an aerodynamic study of the turbine is presented, in order to know these main operating parameters, namely the power and torque coefficients, and the BETZ limit.

Artificial control strategies are described in the third and fourth section in order to control the turbine power of the turbine or to track the maximum power point. The last part of this section will be devoted to the control of the duty cycle of transistor to get the DC voltage (= 500 V).

The maximum available power of a site for a given wind speed is given by the following relation.

$$P_{\omega} = \frac{1}{2}\rho S V_{\omega}^{3} \tag{1}$$

With $S = \pi R^2$

The mechanical power recovered by the wind turbine can be written:

$$P_T = \frac{1}{2}\rho S V_{\omega}^{3} C_p(\lambda) \tag{2}$$

$$\lambda = \frac{R\Omega}{V_{\omega}} \tag{3}$$

$$T_T = \frac{1}{2}\rho R^3 V_{\omega}^{2} C_r(\lambda) \tag{4}$$

The wind torque depends to three variables: the wind speed, the rotation speed of the turbine shaft and wedge angle ß. [7]

$$T_g(V_{\omega}, \omega, \beta) = \frac{1}{2}\rho \pi R^3 V_{\omega}^{2} C_r(\lambda, \beta) \tag{5}$$

The development of magnetic materials has enabled the construction of synchronous machines with permanent magnets at costs that become competitive. Machines of this type have a large number of poles and make it possible to develop considerable mechanical torque. There are several concepts of synchronous machines with permanent magnets dedicated to wind turbine applications. As is shown in Fig. 1, the proposed intelligent pumping system, we use permanent magnet synchronous generator (PMSG).

3 Artificial Neural Network Control

3.1 MPPT Control

We propose in this part, a system of control of the output voltage of the wind system. Indeed, in most cases, such as wind pumping, for example our inverter (Fig. 4) must be powered by a constant voltage U_{dc}. The system comprises a wind generator, PMSG, a rectifier and DC-DC converter with its MPPT control, In this work, we propose an intelligent neuronal technique to control duty cycle of the switching transistor D1, as shown in Fig. 2.

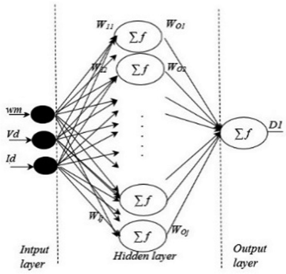

Fig. 2. Proposed intelligent MPPT appraoch

The caracteristic of the MPPT controller is presented as follow:

- Learning algorithm:**back-propagation algorithm**
- Input/hidden/output layer: **3/15/1**
- Input: three inputs presented by the current, voltage output of the rectifier connected to wind generator as presented in Fig. 2 and wind speed
- output: duty cycle of the switching transistor of DC-DC converter.
- activation functions: tansig for all neuron layers
- goal: the sum squared error falls under 2e−4 after 100 iterations.

3.2 DC Voltage Control

A static DC/DC converter equipped with an output voltage control system whose block diagram is shown in Fig. 4, this boost implements the regulation of the DC voltage on the DC bus. Thus, the DC bus is regulated to get a constant voltage value needed to supply our doubly fed induction motor (U_{dc}). We propose an artificial neural network ANN methods to control the output voltage

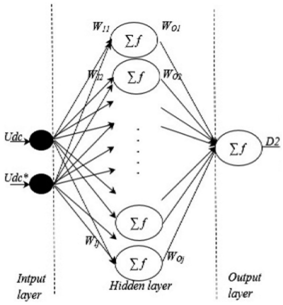

Fig. 3. Proposed neuro DC voltage regulator

The caracteristic of the DC voltage controller is presented as follow:

- Learning algorithm:**back-propagation algorithm**
- Input/hidden/output layer: **2/25/1**
- Input: two inputs presented by DC voltage (U_{dc} and U^{*}_{dc}) as presented in Fig. 3.
- output: duty cycle of the switching transistor of DC-DC converter
- activation functions: tansig for all neuron layers
- goal: the sum squared error falls under 5e−2 after 126 iterations.

4 Dual Star Induction Motor

Currently, the asynchronous motor is increasingly used in pumping systems. This type of engine is appreciated for its robustness, its low cost of purchase and maintenance. His order is more difficult than for other machines especially those with direct current. In addition, the efficiency of wind pumping systems makes the latter more interesting, even with the additional cost of the inverter. In recent years, the appearance of the inverter to control the speed of these motors has allowed their use in wind pumping applications. $(\sigma = 1 - \frac{M_{sr}^2}{L_s L_r})$

$$\begin{array}{l} \frac{dI_s}{dt} = \frac{R_s}{\sigma L_s} I_s + \frac{M_{sr} R_r}{\sigma L_s L_r} I_r + \frac{1}{\sigma L_s} V_s - \frac{M_{sr}}{\sigma L_s L_r} V_r \\ \frac{dI_r}{dt} = \frac{R_r}{\sigma L_r} I_r + \frac{M_{sr} R_s}{\sigma L_s L_r} I_r + \frac{1}{\sigma L_r} V_r - \frac{M_{sr}}{\sigma L_s L_r} V_s \end{array} \quad (6)$$

5 Direct Torque Control

In order to have an adjustable flow rate of the pump, it is necessary to have an asynchronous motor control system. The vector control by orientation of the rotor flow has the disadvantage of being relatively sensitive to variations in the parameters of the machine, which is why in the mid-1980s, a direct control strategy of the torque of the asynchronous machine appeared under the name of DTC (Direct Torque Control), this method was proposed by Takahashi and Depenbrock. The principle of the DTC control consists of the voltage vectors selection among the eight vectors delivered by the voltage inverter to control the torque and the stator flux after the determination of the components of the stator flux vector,

$$\phi_s = \int_0^t (V_s - Ri_s)dt \tag{7}$$

$$V_s(S_a, S_b, S_c) = \frac{2}{3}U_{dc}(S_a + S_b e^{\frac{j2\pi}{3}} + S_c e^{\frac{j4\pi}{3}}) \tag{8}$$

Subsequently, the instantaneous torque error is calculated and applied to a dual band hysteresis regulator which will generate at its output a three-level variable (−1.0, 1), to define the desired direction of evolution for the electromagnetic torque (as shown in Fig. 4). Regarding the stator flux, its module is calculated from the values of its coordinates, and then its error will be applied to a single band hysteresis regulator that will provide a binary variable, defining the evolution of the desired flux.

S_a, S_b, S_c, represent the state of the three phase legs 0 meaning that the phase is connected to the negative and 1 meaning that the phase is connected to the positive leg [7–10].

The stator current space vector is calculated from measured currents i_a, i_b, i_c:

$$i_s = \frac{2}{3}(i_a + i_b e^{\frac{j2\pi}{3}} + i_c e^{\frac{j4\pi}{3}}) \tag{9}$$

The component α and β of vector φ_s can be obtained

$$\begin{aligned} \phi_{s\alpha} &= \int_0^t (V_{s\alpha} - Ri_{s\alpha})dt \\ \phi_{s\beta} &= \int_0^t (V_s - Ri_{s\beta})dt \end{aligned} \tag{10}$$

Stator Flux amplitude and phase angle are calculated in expression:

$$\begin{aligned} \phi_s &= \sqrt{\phi_{s\alpha}^2 + \phi_{s\beta}^2} \\ \angle\phi_s &= arctg\frac{\phi_{s\beta}}{\phi_{s\alpha}} \end{aligned} \tag{11}$$

The DTC command has the advantage of having a simple implementation without resorting to mechanical sensors and fast dynamic response, however it presents problems for low speeds and the need to have stator flux estimators and electromagnetic torque

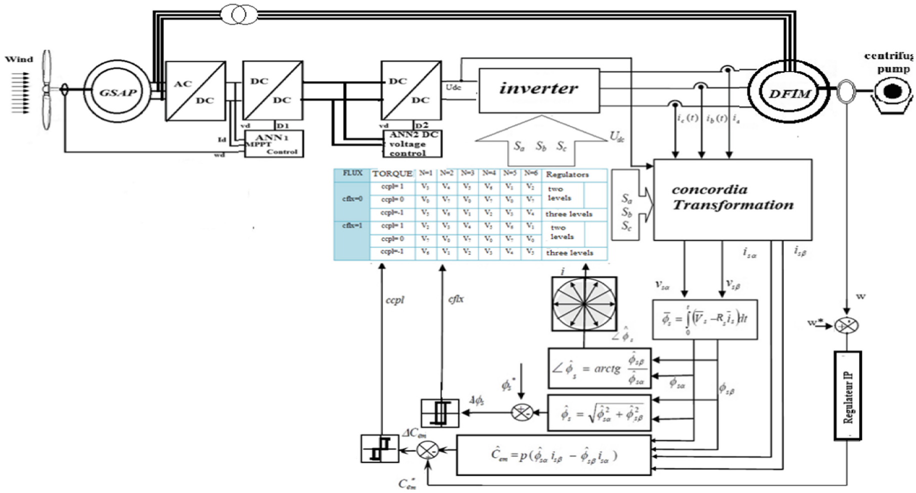

Fig. 4. Schematic diagram of DTC-DFIM supplied by wind generator

6 Simulation Results

The wind pumping system studied consists of a wind generator, PMSG, rectifier, a DC-DC boost converter with its MPPT control, a DC-DC adapter, an inverter and a centrifugal pump driven by DFIM as shown below and to confirm the effectiveness of this proposed system, simulations are performed in this section by using MATLAB/SIMULINK.

Figure 5 presents the speed, electromagnetic torque, current and flux obtained while starting up the induction motor initially under no load then connecting the nominal load. The speed reaches quickly its reference value without overshoot, however when the nominal load is applied at 0.2–0.4 s a little overtaking is noticed and the command reject rapidly the disturbance.

The results obtained from the closed-loop drive using the ANN controller to provide the maximum power point and also to track the U_{dc} voltage signal are shown in Fig. 5. Random step changes in the speed reference are applied. The response for a drive run-up is shown in Fig. 6. These results show that satisfactory closed-loop performance is obtained.

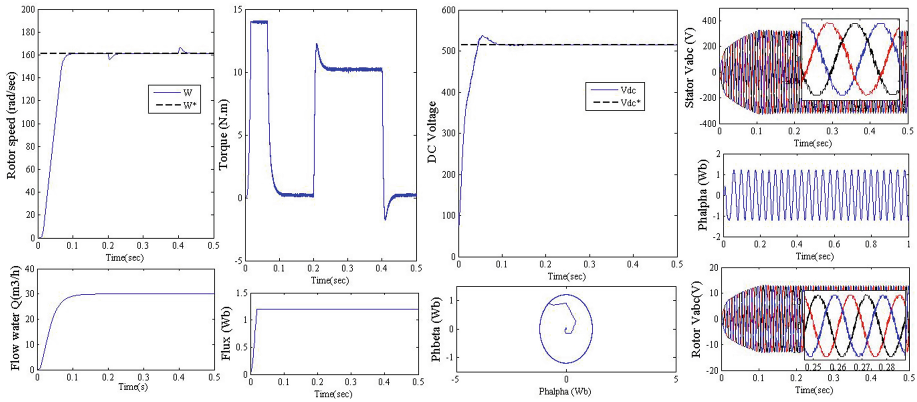

Fig. 5. Torque, flux, DC volatge, current and rotor speed responses using DTC-DFIM supplied by wind gnerator

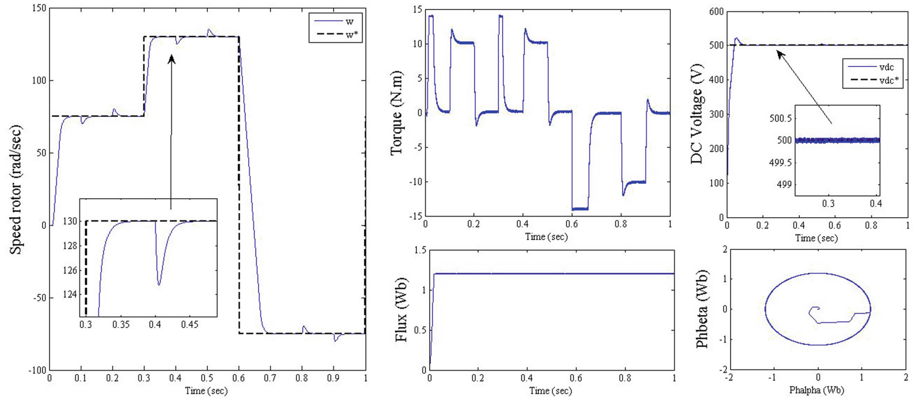

Fig. 6. Torque and rotor speed responses using DTC-DFIM supplied by wind gnerator (with speed and electromagnetic variation)

7 Conclusion

For an isolated and windy site, the use of wind energy for pumping water can be indispensable and highly competitive with other energy sources. We presented in this work a method of electric wind pumping from a wind turbine. So from current waveforms responses obtained from wind generator, it can be possible to power and to feed the AC motor and maintained the output voltage at a predetermined value. To get better performance, this paper proposes and discusses the application of one the most known artificial neural network named neural network, so the obtained results were very successful and confirm the validity of proposed technique

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