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Advanced Control of Wind Electric Pumping System for Isolated Areas Application

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ABSTRACT

The supply water in remote areas of windy region is one of most attractive application of wind energy conversion. This paper proposes an advanced controller suitable for wind-electric pump in isolated applications in order to have a desired debit from variation of reference speed of the pump also the control scheme of DC voltage of SIEG for feed the pump are presented under step change in wind speed. The simulation results showed a good performance of the global proposed control system.

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1. INTRODUCTION

The climate change is a complex global challenge its impacts on the environment and human health are now more understood requiring real solutions to reduce greenhouse gas emissions and accelerate the transition to a low-carbon future.Eventually, the world will run out of fossil fuels, or it will become too expensive to retrieve those that remain. Fossil fuels also causes air, water and soil pollution, and produce greenhouse gases that contribute to global warming.

In recent years, wind has become an increasingly attractive source of renewable energy. While wind power helps the environment by producing electricity without producing pollution, great resource to generate energy in remote locations, Efficient and reliable and they will never run out.

The wind energy can be used for pumping water and are particularly useful in remote locations where access to electrical utilities would be costly, different types of wind water pumps. Some are straight wind water pumps, such as the Aermotor windmill, while others are wind-electric pumps. In this case, the spinning of the wind turbine creates electricity that is used to power a water pump. Although mechanical windmills still provide a sensible, low-cost option for pumping water in low-wind areas, wind-electric pumping systems is an emerging technology that combines modern high-reliability small wind turbines and standard electric centrifugal pumps to provide a reliable and they can pump. In addition, mechanical windmills must be placed directly above the well, which may not take the best advantage of available wind resources. Wind-electric pumping systems can be placed where the wind resource is the best and connected to the pump motor with an electric cable and possibility to control the pumping system [24].

An overview of complete mechanical and electrical wind pumping systems is presented in Figure 1 and Figure 2.

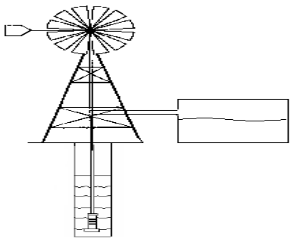


Figure 1. Mechanical Wind Pump

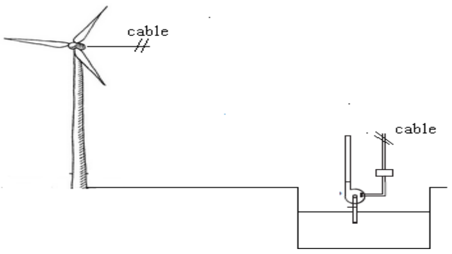


Figure 2. Wind electric pump systems

In this context our application aims to make good use of the wind electric pump system, including a good control of the pumping speed, and of course ensuring a control of the voltage source of the generator.

The induction machine is a very popular generator used wind turbine systems in isolated areas to generate electrical energy also for motor application because of its low price, mechanical simplicity, robust structure, as compared to other machine. However, the major draw back of the SIEG (Self Excited Induction Generator). A poor voltage regulation under change in load and speed in stand-alone system. In literature many researchers have proposed numerous control for regulating the terminal voltage [1]-[2], [4]-[5], [8], [10], [12]-[13].

Since the aims of the proposed system consists of a SEIG driven by an unregulated rotor speed supplies induction motor loaded with a centrifugal pump (non linear load). The proposed control should have keeps the DC bus voltage at a constant value for supplied inverter when the speed of the wind change and the application of pump, based in this regulation then we are more interested towards a desired state while varying the debit from the variation of the reference speed of the pump.

The indirect vector control using rotor flux orientation for two controls with fuzzy logic regulation applied in order to carry out DC voltage of SIEG and speed of the pump. Detailed Matlab/Simulink-based simulation studies are carried out to demonstrate the effectiveness of the proposed scheme.

2. SYSTEM DESCRIPTION AND CONTROL SCHEME

A self-excited induction generator using three phase AC capacitors can start its voltage buildup only from a remnant magnetic flux in the core, the voltage buildup starts when the induction generator is driven at a given speed and an appropriate capacitance connected at its terminals, However, for a system with a single DC capacitor as proposed in this paper it cannot start the voltage buildup from the remnant flux in the core [2]. The proposed system starts its excitation process from a charging circuit an external battery. 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. The main components of the proposed system are shown in Figure 3.

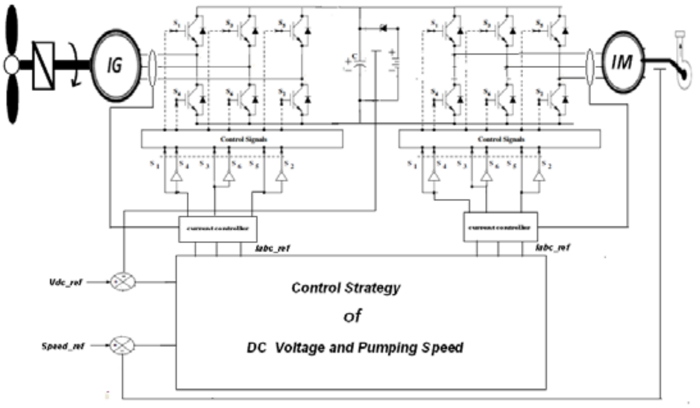


Figure 3. Control structure proposed

The components are Induction Generator, PWM rectifier PWM inverter, and Induction Motor coupled with a centrifugal pump those modelling are explained below.

2.1. Mathematical Model of Induction Machine

The following equations describe model of the squirrel-cage induction machine the stationary dq reference frame:

$$V_{sd} = R_s.i_{sd} + \frac{d\psi_{sd}}{dt} - \frac{d\theta_s}{dt}\psi_{sq} \qquad (1)$$

$$V_{sq} = R_s.i_{sq} + \frac{d\psi_{sq}}{dt} + \frac{d\theta_s}{dt}\psi_{sd} \qquad (2)$$

$$\psi_{rd} = L_r.i_{rd} + M.i_{sd} \qquad (3)$$

$$\psi_{rq} = L_r.i_{rq} + M.i_{sq} \qquad (4)$$

$$V_{rd} = R_r.i_{rd} + \frac{d\psi_{rd}}{dt} - \frac{d\theta_r}{dt}\psi_{rq} \qquad (5)$$

$$V_{rq} = R_r.i_{rq} + \frac{d\psi_{rq}}{dt} + \frac{d\theta_r}{dt}\psi_{rd} \qquad (6)$$

Electromagnetic torque is expressed as:

$$C_e = P\frac{M}{L_r}(\psi_{rd}.i_{sq} - \psi_{rq}i_{sq}) \qquad (7)$$

2.2. Mathematical Modeling of the control scheme for induction generator

In order to model any field oriented control system, it is necessary to choose the synchronously rotating reference frame (d, q) In the RFO control system, the rotor flux vector is aligned with the d-axis Figure 4, which means:

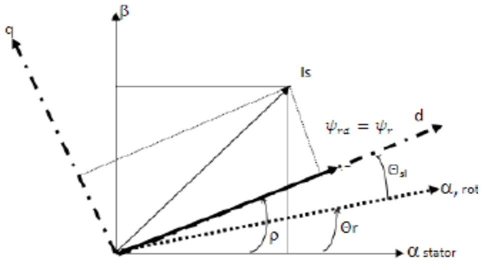


Figure 4. dq and alpha beta frame

$$\psi_{rd} = \psi_r \qquad (8)$$

$$\psi_{rq} = 0 \qquad (9)$$

From the desired value of the DC voltage, it is possible to express that the reference power by:

$$V_{dc\_ref}.i_{dc} = P_{ref} \qquad (10)$$

The electromagnetic torque:

$$C_{em} = \frac{P_{ref}}{\Omega} \tag{11}$$

The control voltage V_{dc} can be done via the electromagnetic torque control, the derivative of rotor flux can be written as:

$$\frac{d\psi_r}{dt} = \frac{M}{\tau_r} i_{sd} - \frac{1}{\tau_r} \psi_r \tag{12}$$

The slip frequency can be written as:

$$\omega_r = \frac{M}{\tau_r} \frac{i_{sd}}{\psi_r} \tag{13}$$

And,

$$\omega_s = \omega + \omega_r \tag{14}$$

Then,

$$\omega_s = \omega + \frac{M}{\tau_r} \frac{i_{sd}}{\psi_r} \tag{15}$$

The field angle is calculated as:

$$\theta_s = \int \omega_s dt \tag{16}$$

The electromagnetic torque is expressed from the current i_{sq} by:

$$C_e = p.\frac{M}{L_r}.\psi_r.i_{sq} \tag{17}$$

The flux controlled by i_{sd} and electromagnetic torque controlled by i_{sq}.

$$\psi_r = p.\frac{M}{1 + p\tau_r}.i_{sd} \tag{18}$$

The several studies carried out shows that the fuzzy logic control provides good results for contributions to conventional regulation that was introduced for this type of regulator in order to have a good performance in our application.

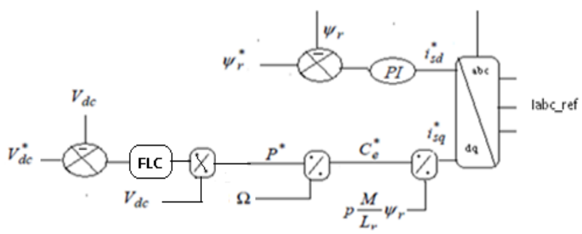


Figure 5. Block diagram control scheme of SIEG

3. FUZZY LOGIC CONTROL

The FLC consists of four major blocks, Fuzzification, knowledge base, inference engine and defuzzification.

There are two inputs, the voltage error *e(k)* and the change of voltage error *ce(k)*. The two input variables are calculated at every sampling time as:

$$e(k) = V_{dc}(k)^{*} - V_{dc}(k) \quad (19)$$

$$ce(k) = V_{dc}(k)^{*} - V_{dc}(k-1) \quad (20)$$

Where $V_{dc}{}^{*}(k)$ denotes the reference speed, $V_{dc}(k)$ is the actual speed and $e(k-1)$ is the value of error at previous sampling time.

3.1. Fuzzification

The crisp input variables are *e(k)* and *ce(k)* are transformed into fuzzy variables referred to as linguistic labels. The membership functions associated to each label have been chosen with triangular shapes. The following fuzzy sets are used, *NL* (Negative Large), *NM* (Negative Medium), *NS* (Negative Small), *ZE* (Zero), *PS* (Positive Small), *PM* (positive Medium), and *PL* (Positive Large). The universe of discourse is set between – 1 and 1. The membership functions of these variables are shown in Figures 6, 7 and 8.

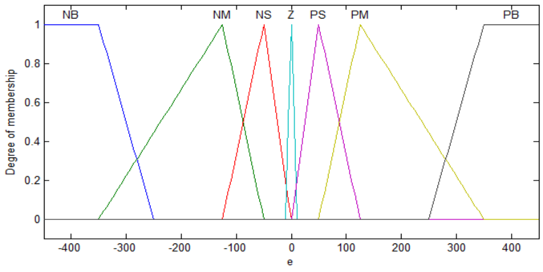


Figure 6. Membership function for input e

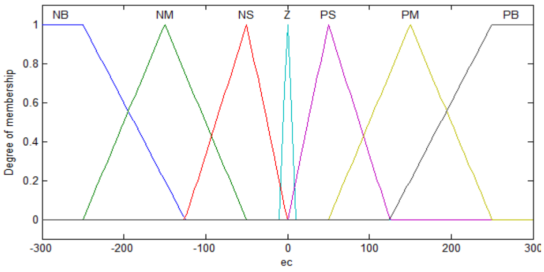


Figure 7. Membership function for input ce

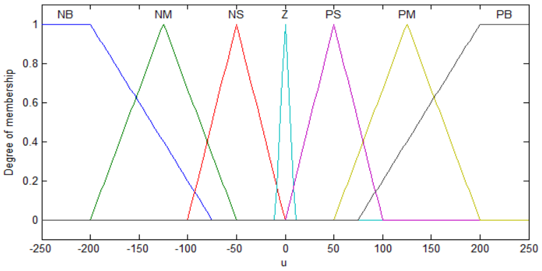


Figure 8. Membership function for output u

3.2. Knowledge Base and Inference Engine

The knowledge base consists of the data base and the rule base. The data base provides the information which is used to define the linguistic control rules and the fuzzy data in the fuzzy logic controller. The rule base specifies the control goal actions by means of a set of linguistic control rules [19]. The inference engine evaluates the set of IF-THEN and executes 7*7 rules as shown in Table 1. The linguistic rules take the form as in the following example:

IF e is NL AND ce is NL THEN u is NL

Table 1. Fuzzy Rules Base

ce/e	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

3.2.1. Defuzzification

In this stage, the fuzzy variables are converted into crisp variables. There are many defuzzification techniques to produce the fuzzy set value for the output fuzzy variable. In this paper, the centre of gravity defuzzification method is adopted here and the inference strategy used in this system is the Mamdani algorithm.

3.2.2. The Reference Rotor Flux Linkage Required

The reference rotor flux linkage required at any speed is calculated based on this maximum flux linkage, which corresponds to the minimum rotor speed hence at any rotor speed the reference rotor flux linkage is given by [2].

$$\psi_r^* = \frac{\omega_{\min}.\psi_{r\max}}{\omega} \tag{21}$$

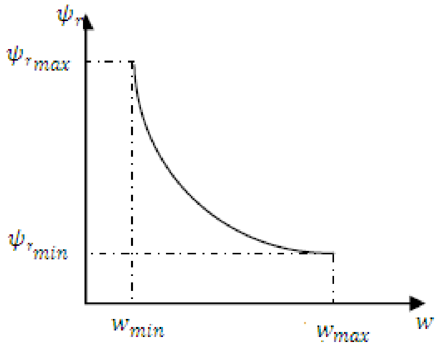


Figure 9. Relationship between rotor speed and rotor flux linkage

3.2.3. Mathematical model of PWM Converter

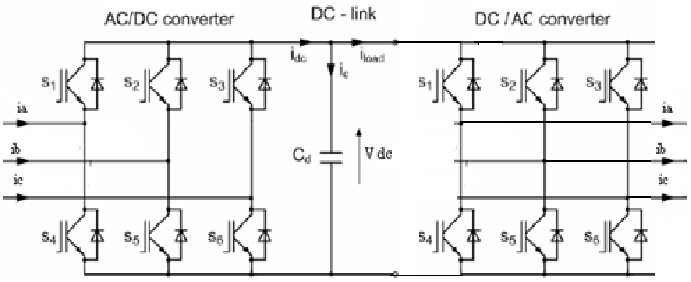


Figure 10. PWM Converter

The DC bus voltage reflects at the output of the inverter in the form of the three-phase PWM AC voltages V_{sa}, V_{sb} and V_{sc}. These voltages may be expressed as:

$$V_{sa} = \frac{1}{3} V_{dc} (2S_a - S_b - S_c) \tag{22}$$

$$V_{sb} = \frac{1}{3} V_{dc} (2S_b - S_c - S_a) \tag{23}$$

$$V_{sc} = \frac{1}{3} V_{dc} (2S_c - S_a - S_b) \tag{24}$$

The derivative of the DC bus voltage and when non linear load is present is defined as:

$$\frac{d}{dt} V_{dc} = \frac{1}{C} (S_a . i_a + S_b . i_b + S_c . i_c - i_{load}) \tag{25}$$

While i_{load} current drawn by the pump and S_a, S_b and S_c are the switching functions for the ON/OFF positions of the rectifier switches S_1-S_6.

The relation of the inverter input and output current are given by the following expression:

$$i_{load} = S_a . i_a + S_b . i_b + S_c . i_c \tag{26}$$

S_a, S_b and S_c are the switching functions for the ON/OFF positions of the inverter switches S_1-S_6.

3.2.4. Modeling of the control scheme for induction motor

Following the same procedure for the control of the generator, but in this case our regulation based to control rotor speed, the block diagram explain the control strategy as show in Figure 6.

It becomes possible to control the torque independently by the q-axis stator current, and the rotor flux can be controlled with the d-axis stator current with a delay. In this case, the torque can be expressed as:

$$C_e = p . \frac{M}{L_r} . \psi_r . i_{sq} \tag{27}$$

By keeping the rotor flux constant, the expression of the rotor flux can be given by:

$$\psi_r = \frac{M}{1 + p\tau_r} . i_{sd} \tag{28}$$

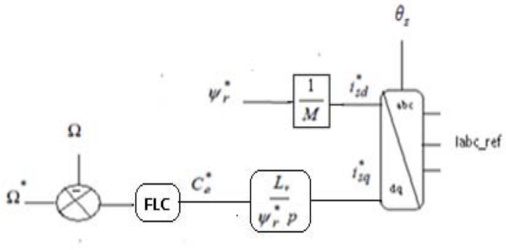


Figure 11. Block diagram control scheme of induction motor

In order to operate the motor at high efficiency, the inverter works on the principle of bang-bang control with three independent hysteresis controllers. The calculated values of the three-phase stator currents are compared with the reference values and the inverter elements are switched accordingly to impress the necessary terminal voltages to the motor phases [15].

4. PUMP MODEL

The pump used is of centrifugal type which can be described by an aerodynamic load which is characterized by the following load equation:

$$C_r = K * \Omega^2 \tag{29}$$

Where *K* is the pump constant

5. SIMULATION RESULTS AND DISCUSSION

The global of all circuit components. The system is implemented using MATLAB/SIMULINK .The dynamic performance of the whole system for different operating conditions is studied; the sequence of simulation is as follows:

a) The simulation completed with in 30 seconds.
b) The reference DC voltage is set at 600V.
c) The voltage build up process is under no load condition.
d) The pump applied to the induction generator at t=2s.
e) The system was simulated for variable wind speed after connected the pump as show in Figure 12.
f) Then reference pump speed is set to different value of 120 rad/s to 170 rad/s, and 140 rad/s, as show in Figure 17.

The SEIG output voltage is converted into DC voltage by using the controlled rectifier circuits. The output voltage of the rectifier is 600 volts. This DC voltage is given to the source inverter to produce required output voltage of the pump.

The Induction motor loaded with a centrifugal pump. suddenly is applied at t=2s it is observed that the value of the DC bus voltage is maintained at a constant value even if the wind speed changes at 14s and 18s and variation of pump speed at 12s and 20s. The fuzzy voltage controller provides a rapid and accurate response for the reference. The reference flux and estimate is shown in Figura 14. Also Figure 15 shows the variation in d-axis, q-axis stator currents in the rotating reference frame.

The Figure 16 shows the stator current at the terminals of the induction generator.

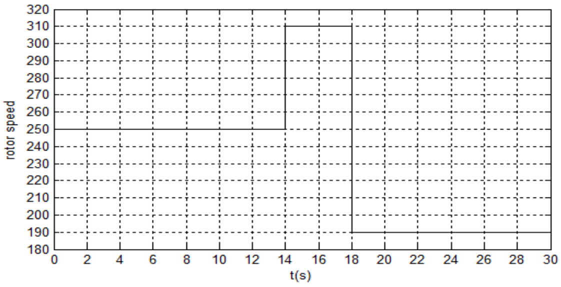


Figure 12. Variation of wind speed (rad/s)

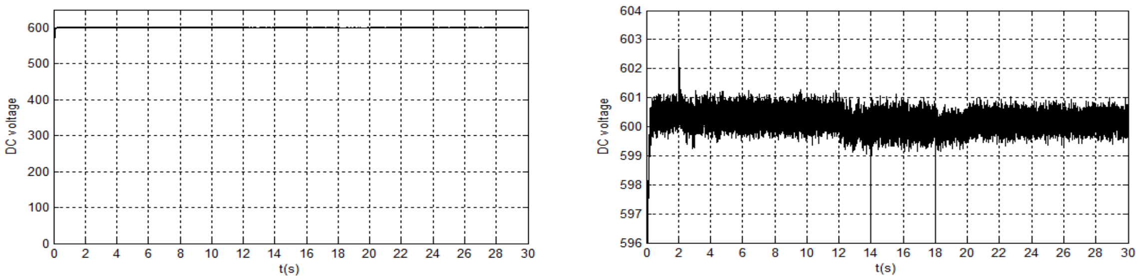


Figure 13. DC capacitor voltage profile of the SIEG

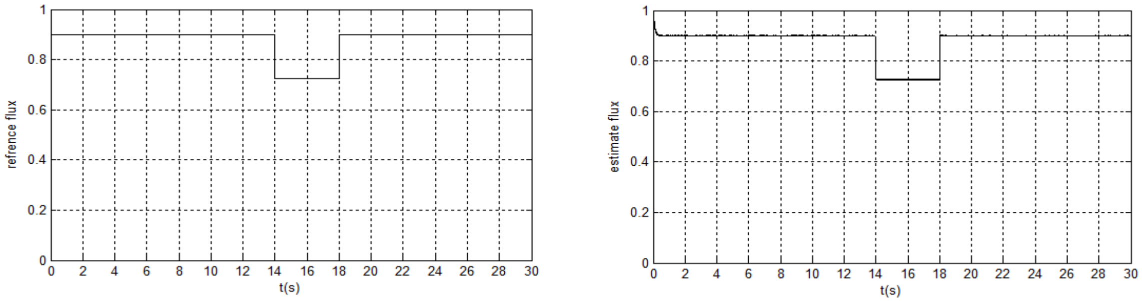
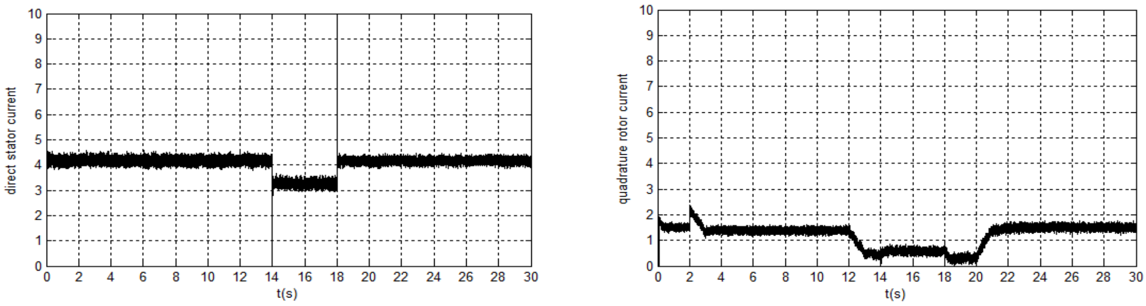
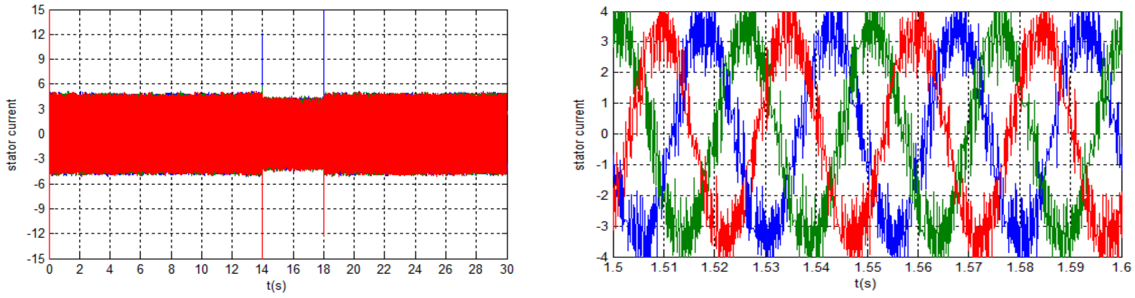


Figure 14. Reference and estimate rotor flux of the SIEG



(a) (b)

Figure 15. Variation in d-axis, q-axis stator currents in the rotating reference frame



(a) (b)

Figure 16. Stator current of the SIEG

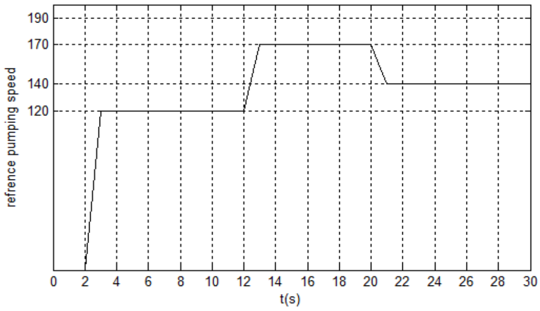


Figure 17. Reference pump speed ans pump speed

5.1. Regulation of the Pump Speed

After connecting the pump we can say that the pump speed follow the given reference as shown in Figure 18 at 12s and 20s ,also is observed that pump speed not affected by the variation of wind speed of the generator ,then the system became more stable and more robust. The Figure 19 shows the variation of stator currents of the pump.

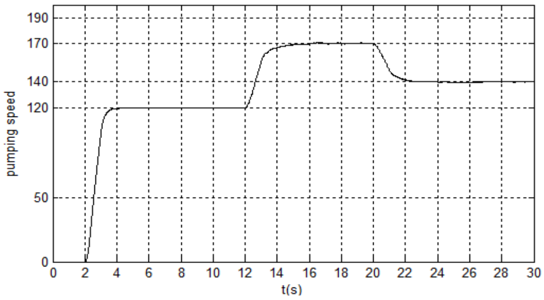


Figure 18. Reference pump speed ans pump speed

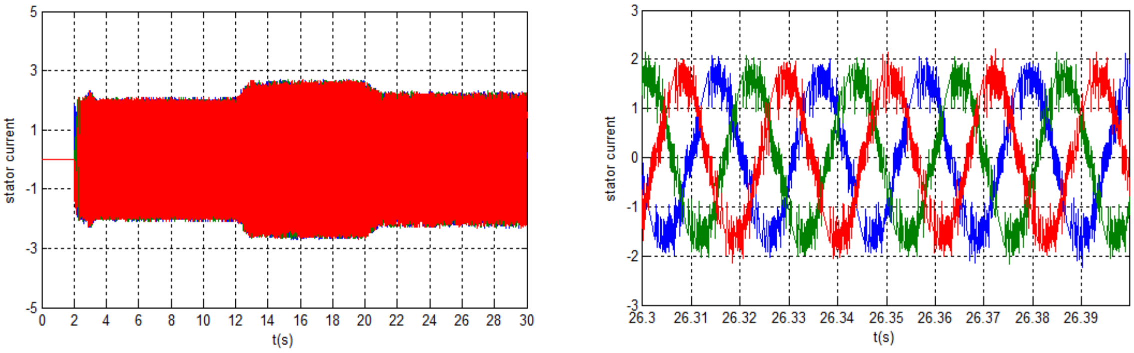


Figure 19. Stator Current of the Pump

6. CONCLUSION

This paper introduces the modeling and simulation of the wind electric pumping systems using MatlabSimulink the studies are made by formulating the mathematical models and control for global system. It has been demonstrated that the system is able to feed pump system by regulated DC bus voltage and satisfactory desired debit from variation reference speed of the pump under variable wind speed. All results obtained confirm the effectiveness of the proposed controllers and it has been found to be satisfactory such wind electric pumping successfully in windy remote locations.

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