

Dynamic Modeling of Pump Drive System utilizing Simulink/MATLAB Program

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Abstract - This paper presents a new modeling and dynamic design for pump drive system utilizing MATLAB /SIMULINK Program to control the speed of motor. In this modeling we use MATLAB program implementation to reduce the energy consumption by the implementation of Variable Frequency converter (VFC) and hence the proper control of fluid flow rate.

Key Words: Variable frequency drive; pump drive system; Simulink / MATLAB Dynamic I.M.

I. INTRODUCTION

However, about a third of the world's electrical energy is consumed by electric motors in fixed-speed centrifugal pump, fan and compressor applications. The processes, in the form of liquid or gas flow, are typically driven by large electric motors with the power demand following affinity laws. Pumps are devices that deliver a pressure increase to liquid and it's a largest consumer of energy in the industrial sector. The pump provides the energy necessary to drive the fluid (water) through the system and overcome friction and any elevation difference.

Driving the pumps with fixed speed motors and controlling them at partial loads either by throttling or mechanically by fluid coupling decreases the power plant's efficiency tremendously. When large flows must be controlled and motor energy consumption is significant, varying the motor's speed is the answer. In order to reduce maintenance costs and further improve the plant's efficiency, the pump drive systems were upgraded with a variable speed converter (VFC) system or called a variable frequency drive (VFD). Controlling pumps by adjusting speed avoid wasting energy. Variable speed drives in a pump system are now a mature technology, which can generate large benefits to the user in cost savings and reliability improvements, in the right applications. Pump's drive means a sequence of energy conversions from electrical input power to mechanical output power and then to hydraulic power (figure 1). Each conversions is described by his specific equations and reference frames.[1,2,3,4,5,6]

The theory of operation of pumps can be characterized by the affinity laws:

- Liquid flow is linearly proportional to the pump speed (equ.1)
- Head changes with square of the ratio of speed (equ.2)
- Power demand changes with cubic of the ratio of speed (equ.3).

$$\frac{Q1}{Q2} = \frac{N1}{N2} \tag{1}$$

$$\frac{H1}{H2} = \left(\frac{N1}{N2}\right)^2 \tag{2}$$

$$\frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3 \tag{3}$$

When a centrifugal pump is used with an adjustable speed AC drive, the energy costs can reduce by (10 to 60) % of full energy if the pump is designed to operate between(40 to 80)% of full speed[7,8].

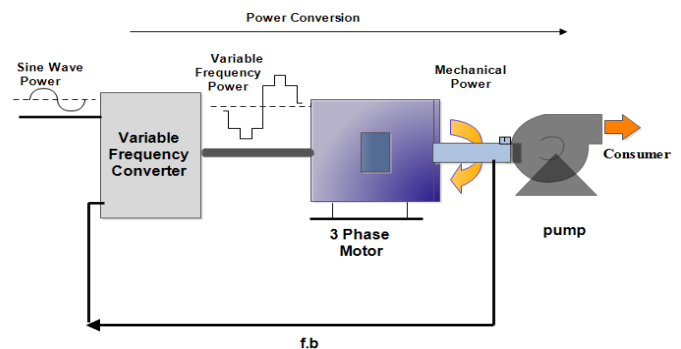


Figure 1: Pump drive system diagram

Figure1 shows the proposed model of pump drive system, it's consists of three main units:

1. The variable frequency converter (VFC)
2. The A.C. motor
3. The pump

1.The variable frequency drive (VFC)

The variable frequency drive (VFC) is a device used to apply a desired frequency to control the speed of the induction motor, and the motor controls the pump speed. It consists from three units:

1.1-Rectifier and filter stage

A full-wave, three- phase 50 Hz solid-state diode rectifier converts power from a standard 220V or higher utility supply to either fixed or adjustable DC voltage. The DC bus comprises with a filter section where the harmonics generated during the AC to DC conversion are filtered out [1, 3, 8,9].

1.2-Inverter

The inverter adjusts the output voltage or frequency values of the motor, and controlled by pulse width modulation (PWM) from controller, so that the output current waveform closely approximates a sine wave (quadrature-axis). Electronic power switches (IGBT) Insulated Gate Bipolar Transistor, switch the rectified DC **on** and **off**, and produce a current or voltage waveform at the desired new frequency to controls the motor torque. [2,9,10].

1.3- Controller circuit

The controller is essential unit in the circuit and it's used to vary the output speed of induction motor according to environment temperature degree, the pumping will change according to speed of motor.

Controller circuit may incorporate many complex control units:

A. proportional-integral-derivative (PID):

The input to this unit are two values, one is drive speed of the motor as a reference voltage and the second is speed as temperature function equation, the PID will comparative these values and then generates three control signals [9,11]:

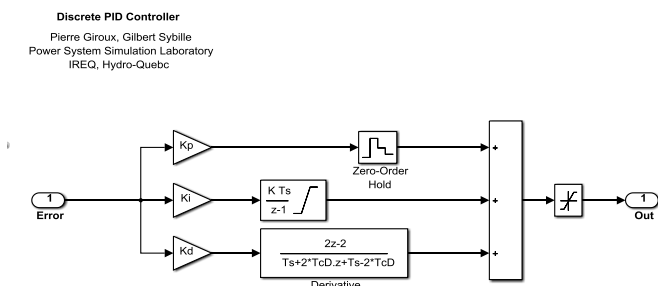


Figure 2: Simulink scheme of the PID unit
B. Pulse width modulation(PWM)unit

This unit is generate a three phase PWM to control the inverter [2,3,6,10].

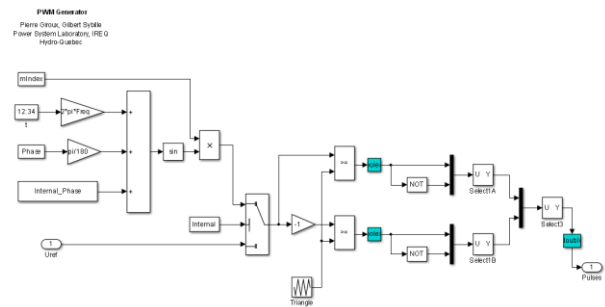


Figure 3: Simulink scheme of the PWM unit

C. Sensor

The environment temperature degree is measured by a sensor as a criterion and it is transmitted to PID controller as voltage signal.

2.Induction motors (IM)

The three phase induction motor works as a converter of electrical energy to mechanical energy that exerts the electromagnetic torque to centrifugal pump [1,4].

Induction motor parameters are: 220V; 3phase; 50 Hz; 4 poles; 1480 rpm; 75 KW; 0.87 P.F.

3. The pump

Centrifugal pump is a type of a turbo machine in which mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid. It is classified as rotor dynamic type of pump in which dynamic pressure is developed which enables the lifting of liquids from lower level to higher level. Since lifting of liquid is due to centrifugal action, it is called as centrifugal pump. Centrifugal pump has high output and high efficiency compared to other types of pumps [12].

II. VARIABLE SPEED CONTROL STRATEGY

At this strategy, the VFD changes the three phase AC sinusoidal voltage into DC voltage through rectifier stage, the harmonics generated during the AC - DC conversion are filtered out and send to inverter unit, which comprises six insulated gate bipolar transistors (IGBT) where the filtered DC supply is being converted into quasi-sinusoidal wave of AC supply and supplies to the induction motor. Therefore by varying the frequency of the power supply according to the environment temperature degree through VFD, the speed of the motor can be controlled, see figure 9. The controller circuit receives feedback information from the driven motor and sensor to adjust the output voltage or frequency to the selected values. Usually the output

voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz) [2,3,5,6,9,11,13].

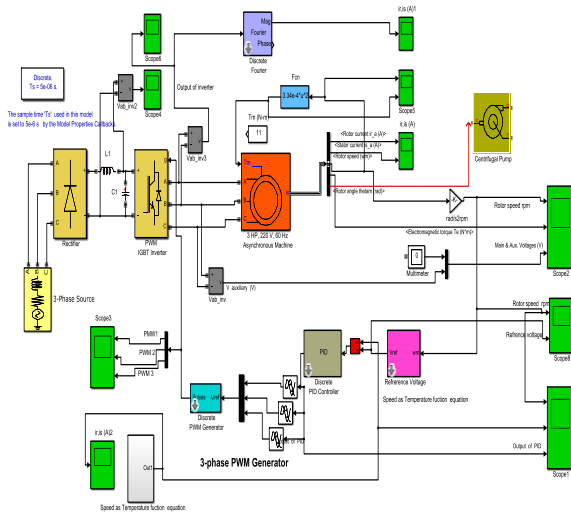


Figure 4: MATLAB/Simulink model of drive pump system

III. SIMULATION RESULTS

The simulation results of the pump drive is done by MATLAB/SIMULINK are presented below,

Figure 5 shows the three phase pulse width modulation output (pulse signal) to inverter, where the phase shift between the signals is 1200

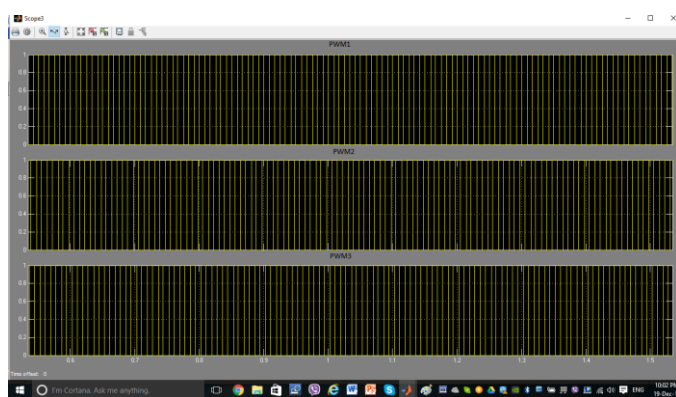


Figure 5: PWM waveforms

Figure 6 shows the rotor and stator currents with open Loop control, and figure 7 the electromagnetic torque, it is clear that the constant speed leads to constant current and constant torque.

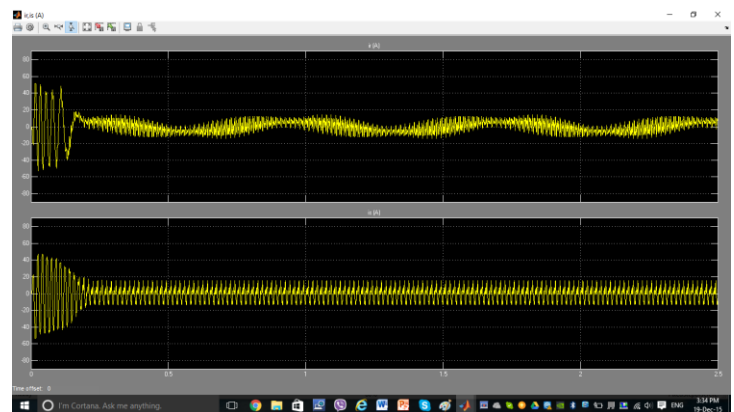


Fig -6: Open Loop rotor and stator current waveforms



Fig -7: Open Loop electromagnetic torque waveforms

Figure 8 shows the rotor and the reference speeds with open Loop control, it is clear that the rotor speed is constant(1780 rpm),it doesn't variation with the environment temperature degree.

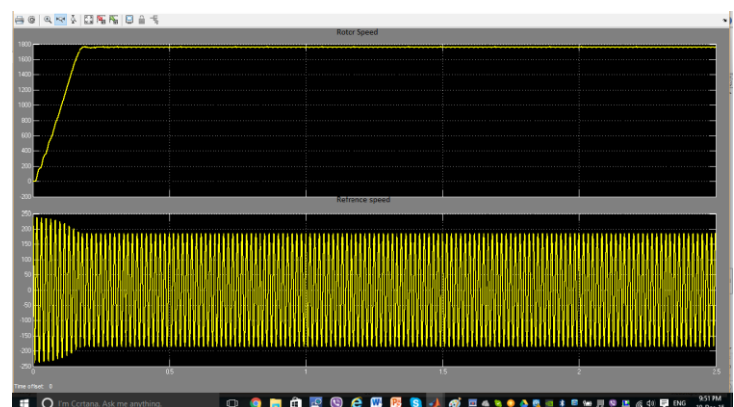


Fig -8: Open Loop rotor and reference speeds waveforms

The simulation result and gating signals for closed loop are shown in figure 9, it is clear that the effect of the frequency variation on the stator current, electromagnetic torque and leads to change the speed of rotor, where the frequency is a function of a temperature degree.

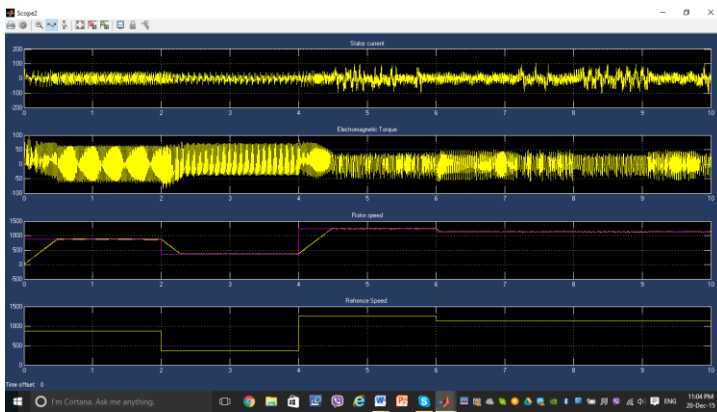


Fig -9: Closed Loop waveforms

IV. CONCLUSIONS

- Using VFC can save energy according to affinity law, so that a small reduction in speed can save a large amount of energy (improve the speed control of pump).
- Using the VFC unit is a good solution for improving the response and control precision of hydraulic motor.
- Using the VFC will changes the electrical frequency of the supply voltage , that lead to changes the rotor speed of the motor and hence the flow rate of water, that lead to changing the environment temperature degree.
- Using PID control will increase the cost of the drive system and control complexity, but achieves the expected energy savings target.

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REFERENCES

- [1]. Aleck W. Leedy. Simulink / MATLAB Dynamic Induction Motor Model for Use as A Teaching and Research Tool. International Journal of Soft Computing and Engineering (IJSCE), Volume 3, Issue 4, September 2013.
- [2]. Enemuoh F. O., Okafor E. E., Onuegbu J. C., Agu V. N. Simulation and Performance Analysis of A Variable Frequency Drive in Speed Control Of Induction Motor - International Journal of Engineering Inventions, Volume 3, Issue 5, December 2013.
- [3]. Neetha John, Mohandas R, Suja C Rajappan. Energy Saving Mechanism Using Variable Frequency Drives. International Journal of Emerging Technology and Advanced Engineering, Vol. 3, Issue 3, March 2013.
- [4]. Christophe Versèle, Olivier Deblecker , Jacques Lobry. Implementation of Induction Motor Drive Control Schemes in MATLAB/Simulink/dSPACE Environment for Educational Purpose, Book, MATLAB for

Engineers - Applications in Control, Electrical Engineering, IT and Robotics.

- [5]. A.Sangeetha, B.Parthiban. Review of Modeling and Dynamic Analysis of Three Phase Induction Motor Using MATLAB Simulink, Volume 3, Issue 3, March 2014.
- [6]. A A Ansari, D M Deshpande. Mathematical Model of Asynchronous Machine in MATLAB Simulink, International Journal of Engineering Science and Technology, Volume 2(5), 2010.
- [7]. Yao Chen, J. Pan, L. Gertmar, R. W Vesel. Economic Benefits Analysis of Variable Speed Drive in Coal-fired Power plant Auxiliary, International conference on Electrical Engineering, 2009.
- [8]. I.-F. Soran, I. Sztojanov. Performance Evaluation Of A Pump Driven At Variable Speed. Timisoara, September 2008, PP.249-252.
- [9]. Krupa Gandhi, K.L.Mokariya, Deepa Karvat. Simulation of PWM inverter for VFD application Using MATLAB, International Journal of Engineering Research and Development, Volume 10, Issue 4, April 2014.
- [10]. Tamal Aditya. Research to study Variable Frequency Drive and its Energy Savings, International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064.
- [11]. Jafar Ghafouri, Farid Khayatzadeh H., Amin Khayatzadeh H. Dynamic Modeling of Variable Speed Centrifugal Pump Utilizing MATLAB / SIMULINK, International Journal of Science and Engineering Investigations, Volume-1, Issue-5, June 2012.
- [12]. Raghavendra S Muttalli , Shweta Agrawal , Harshla Warudkar. CFD Simulation of Centrifugal Pump Impeller Using ANSYS-CFX, International Journal of Innovative Research in Science, Volume 3, Issue 8, August 2014.
- [13]. Sameer Khader, Abdel-Karim Daud. PV-Grid Tie System Energizing Water Pump, Smart Grid and Renewable Energy journal, August 2013.

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