Simulation of Induction Motor Driven Submersible Pump using Matlab/Simulink

V.Vivek, R.P.Kumudini Devi, G.Uma and C.Chellamuthu

Abstract—This paper presents a generalized formulation for the computer-aided analysis of induction motor driving a submersible pump. A simple and more realistic MATLAB/SIMULINK model of the induction motor driven submersible pump has been developed. This paper proposes a simple algorithm to predict the performance of the system under various heads (H) at a given voltage (V) and frequency (f) which reflects the existing situation in the industrial as well as the agricultural sector. The discharge (Q) of the submersible pump is a function of head, torque, speed and efficiency. The efficiency of the pump is a non-linear function of head and discharge at given voltage and frequency. This paper uses variable efficiency instead of static one in the modeling of the pump. In order to predict the efficiency of the pump at the particular head and discharge for a given speed neural network function are used Hence a more accurate model is developed to predict the performance of induction motor driven submersible pump unit under the real time conditions.

Index Terms— Induction Motor, Saturation, Submersible Pump, neural network.

I. INTRODUCTION

A submersible pump powered by three-phase induction motor is being widely used in many industrial areas [1] consuming the major part of the energy. The performance of motor pump unit has been discussed in depth for the various assumed parameters like material coefficients, design dimensions etc [2]. A detailed study is needed to predict the performance of the motor pump unit under real time conditions. This paper lays emphasis on predicting the efficiency of the over all unit under different operating conditions using a commercially available software package, MATLAB. The performance of the induction motor driven submersible pump is studied under different operating heads and voltages, which is the condition existing in the industrial as well as agricultural sector for sinusoidal voltage source.

The submersible pump unit consists of a pump powered by a three-phase squirrel cage induction motor. The induction motor, submersible pump is modeled mathematically using software package MATLAB/SIMULINK as shown in Fig 1.
A. INDUCTION MOTOR MODEL

The continuous–time electromechanical model of an induction motor is of fifth order with the states being stator and rotor flux linkages and speed. The model is developed without taking into account the core loss and hysteresis, which can be incorporated at the expense of slower simulation. The mathematical modeling can be derived using stationary two axis (d-q) or synchronous two axis (dq) frame. In this paper synchronous two-axis frame model is used. The dynamic model of induction motor in synchronously rotating frame [7] is described by a set of first order linear vector differential equations as shown in the equations (1)-(3).

\[ \psi = \frac{1}{L} \left[ V - R_s \left( \psi_s + \psi_r \right) - \omega_m \left( \psi_s + \psi_r \right) \right] \]  

(1)

\[ T_e = \frac{n}{J} \left( \psi_s \left( C_{11} \psi_s - C_{12} \psi_q \right) - \psi_q \left( C_{11} \psi_q - C_{12} \psi_s \right) \right) \]  

(2)

\[ \omega_m = - \frac{n}{J} \omega_m + \frac{1}{J} \left( T_e - T_{L(\omega)} \right) \]  

(3)

Where \([\psi], [V]\) represents the matrix of flux linkages and voltages of stator, rotor axes, \(C_{11}, C_{12}, C_{22}\) are constants and \([A] = -R_s C_{11} R_s C_{12} \omega_m 0 \) \(R_s C_{12} - R_s C_{22} 0 \left( \omega_m - \omega_m \right) \) \(- \omega_m 0 - R_s C_{11} R_s C_{12} \) \(- \omega_m 0 - R_s C_{12} - R_s C_{22} \) is being.

The equations that describe the steady state as well as transient behavior based on the following assumptions

- Stator and rotor windings are symmetrical, and distributed so that the MMF’s are sinusoidal.
- The effects of hysteresis and eddy currents are neglected.
- The motor parameters are independent of temperature.

Under steady state condition \(p[\psi] = \alpha m = 0\)

The equations (1)- (3) can be written as

\[ \left[ A \right] \psi = - \left[ V \right] \]  

(4)

\[ T_e = \frac{n}{J} \left( \psi_s \left( C_{11} \psi_s - C_{12} \psi_q \right) - \psi_q \left( C_{11} \psi_q - C_{12} \psi_s \right) \right) \]  

(5)

\[ \omega_m = \frac{T_e - T_{L(\omega)}}{b} \]  

(6)

Improved computational stability is expected in solving these equations because flux linkages vary more slowly than do the currents. Hence it is preferred to use flux linkages as variables. The non-linearity in the induction motor model is introduced due to saturation. The saturation in the main flux path is included in the modeling. Fuzzy logic control technique is used to predict accurately the variation of \(X_m\) with a change of magnetizing current and air gap voltage. The surface of \(X_m\) is given in figure (2).

The value of magnetizing current is calculated by the following equation

\[ i_m = \sqrt{\left( i_d^2 + i_q^2 \right) + \left( i_d^2 + i_q^2 \right)} \]  

(7)

Where

\[ i_d = C_{11} \psi_s - C_{12} \psi_q \]  

\[ i_q = C_{12} \psi_s - C_{12} \psi_q \]  

\[ i_d = -C_{12} \psi_s + C_{22} \psi_q \]  

(8)

The value of magnetizing current calculated above along with air gap voltage is given to fuzzy controller that is trained for predicting magnetizing inductance. The magnetizing inductance thus got is used for the next iteration. It is possible to model induction motor in block-diagram representation or enter the equations directly into m file. The block-diagram of induction motor can be constructed from the component blocks available in SIMULINK block diagram library. MATLAB allows the flexibility of a mixed block diagram and equations type of modeling. The graphical block diagram method of entering system descriptions is inefficient since the time of simulation will be more, as number of state variables is five. Therefore, the mixed type of entry was chosen.

B. SUBMERSIBLE PUMP MODEL

The submersible pump is modeled with the inputs as shaft speed, torque and head. The output variable is chosen to be Discharge. Mathematically we can relate discharge as a function of head, torque, speed, and efficiency.

\[ Q = f(H, T_{L(\omega)}, \omega, \eta) \]  

(8)

\[ Q = \frac{T_{L(\omega)}}{\rho g H} \]  

(9)
The efficiency of the pump is a function of head (H) and discharge (Q) at a given speed [3].

\[ \eta = f(H, Q) \]

The surface plotted to the non-linear relation between efficiency, head and discharge is shown in Fig 3.

![Fig 3. The non-linear relation between efficiency, head and discharge](image)

The efficiency of the pump is determined from the predetermined data available from the manufacturer as shown in Table 1.

<table>
<thead>
<tr>
<th>Head (m)</th>
<th>Discharge (m³/Sec)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.71</td>
<td>0.006</td>
<td>12.9</td>
</tr>
<tr>
<td>17.32</td>
<td>0.0056</td>
<td>31.56</td>
</tr>
<tr>
<td>27.05</td>
<td>0.0052</td>
<td>46.07</td>
</tr>
<tr>
<td>36.74</td>
<td>0.0047</td>
<td>56.81</td>
</tr>
<tr>
<td>46.34</td>
<td>0.0042</td>
<td>63.39</td>
</tr>
<tr>
<td>56.1</td>
<td>0.0036</td>
<td>66.69</td>
</tr>
<tr>
<td>61.59</td>
<td>0.0031</td>
<td>66.34</td>
</tr>
<tr>
<td>67.37</td>
<td>0.0027</td>
<td>65.17</td>
</tr>
<tr>
<td>72.41</td>
<td>0.0026</td>
<td>59.53</td>
</tr>
<tr>
<td>76.94</td>
<td>0.0010</td>
<td>39.01</td>
</tr>
</tbody>
</table>

Table 1: The table showing the values of efficiency for a given head and discharge

**B1- CALCULATION OF EFFICIENCY USING “NEURAL NETWORK”**

The efficiency of the pump is obtained using “Artificial Neural Network”. The inputs to the ANN are head and discharge and the output is efficiency. The feed-forward back propagation technique is used to train the neural network. The network has five neurons in the hidden layer and one output neuron. Feed-forward networks consist of three layers using the DOTPROD weight function, NETSUM net input function, and the specified transfer functions. The first layer has weights coming from the input. Each subsequent layer has a weight coming from the previous layer. All three layers have biases. The last layer is the network output. Each layer's weights and biases are initialized with INITNW. Adoption is done with ADAPTWB, which updates weights with the specified learning function. Training is done with the specified training function. Performance is measured according to the specified performance function. The error tolerance is taken to be 0.0000001 and solution converges in 9 iterations. The block diagram representing the neural network model is given in Fig 4.

![Fig 4: Neural Network Block diagram for predicting the efficiency.](image)

The model is tested for a head and discharge that is not the subset of eleven patterns. Let head and discharge be 30 Mts 0.00501 m³/Sec respectively. The efficiency predicted using ANN is 51.2563% having sum-squared error of 0.5*10⁻³ with the actual value. The error plot is shown in the fig 5.

![Fig 5: The error surface obtained after training the network for predicting the efficiency](image)

**IV. SIMULATION PROCEDURE**

The matrix and nonlinear equations (4) to (11) are entered in m-file. These equations are solved using a R-K fourth order, a solver. The saturation in main flux path is simulated using “anfis”. The “anfis” is a function available in MATLAB that uses a hybrid-learning algorithm to identify parameters of Sugeno-type fuzzy inference systems.
The inputs given to the developed model are voltage, frequency and head. The output of the model is discharge. To maintain the simulation accuracy a step size of 120µs was used in Range-Kutta routine.

V. RESULTS AND DISCUSSIONS

The behavior of the induction motor driven submersible pump unit is studied for Indian conditions. The Indian grid voltage varies from 380V to 450V and the frequency remaining almost constant at 48.5 Hz. In the simulation the frequency is kept constant at 48.5 Hz and the voltage (V) and Head (H) are varied from 380 V-450 V and 15 to 70 Mts. From the simulation results the critical values are chosen and the results is shown in the Fig 6.

Fig 6. Surface plot of the unit for determining the discharge at different operating voltages and head

From the results certain critical observation was made:
- Discharge decreases with the increase in head where as discharge is almost constant when the voltage is varied from 380V to 450V for a given head.

VI. CONCLUSION

In this paper induction motor driven submersible pump unit is modeled using MATLAB/SIMULINK. The non-linearity present in the induction motor is modeled using a special function namely “anfis” present in MATLAB/SIMULINK package. The non-linearity present in centrifugal pump is modeled using “Neural network” so that the efficiency of the pump can be accurately predicted at the expense of simulation time. MATLAB is effectively used to implement feed-forward back propagation, Sugeno-type fuzzy inference systems for the identification of efficiency and magnetizing reactance was presented in equations in m-file. This m file was operated in stand-alone manner from the system to reduce simulation time and allowed offline investigation on the properties of the algorithms. This shows the suitability of the model to quickly evaluate for new designs that can be incorporated in the system. The simulation results closely agree with experimental results obtained from industry. This shows the effectiveness of the model developed.

VII. REFERENCES