Intelligent controller for speed control of three phase induction motor using indirect vector control method in marine applications

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Marine electric propulsions generally use variable speed electric propulsion motors associated to propellers in which numerous types of converter control schemes are applied. This paper, reviews existing control schemes of the propulsion drive system and an accomplishment of intelligent controller for speed control of three phase induction motor (IM) using indirect vector control with Anti-Windup (AW) technique has been developed and analyzed. This manuscript is fully mathematical model of field orientation control (FOC) induction motor is described and simulated in MATLAB for induction motor has been considered. In this paper the performance and results have given analyzed for the proposed controller using indirect vector control method with Neural Network and antiwindup techniques. Due to high installation cost and mechanical robustness the use of flux and speed sensors are to be avoided. From this analysis IVCNN with AW based controller is found to be a very useful technique to attain a high accuracy speed control. This strategy IVCNN with AW is proposed to enhance the performance of the drive.

[Keywords: FOC, IM, DVC, IVCNN with AW technique]

Introduction

The conventional marketable and military ships had a mechanical propulsion system that uses gas turbines as the prime mover. As they are so huge and weighty that ship designing engineers have to concentrate to design and build the rest of the ship approximately it rather than creating a tailored mechanical propulsion system for the ship. All induction motors are variable speed AC (alternating current) motors.

In the entire AC motor world the squirrel cage induction motor is the most popular and very low cost with effective performance¹. The induction motors are broadly used in all type of industries. By providing optimum design or superior control to induction motors, the motor performance will be improved and it results in power saving for quite long period. The motor which consists the flux and speed sensors having few notable drawbacks, such as intricacy in construction and frequency, periodic maintenance. So from the past twenty years the interest about the sensorless drives for electric motors is increasing in day by day¹. These applications contain and well suitable for ship propulsion system along with various propulsion systems, domestic equipment, and industrial equipment and electric power generation systems etc. So in this research work the most popular three phase induction motor has been choose to analyze its performance with the proposed controller using IVCNN. The conventional vector control based speed controller must require a speed sensor. But, for the machines which placed unfriendly environment and ultra-high speed drives it is not possible to mount the speed sensor¹, as well as it is very essential to provide much careful electric wiring provision and should consider electrical noise also. Moreover, it leads to become costly in the system price and huge in the size of the motor. To avoid this problem the researchers are focusing and put their efforts over sensorless speed control drives. In general the estimation and control of AC drives are significantly more difficult compare with DC drives, and this kind of intricacy rises remarkably when effective performances are required¹.

Nowadays most of the industries required adjustable speed drives with harmonic free power converters which should be suitable to operate under
crucial dynamic operating conditions and it is difficult to process feedback signals with harmonics. This leads to increase the system complexity in both design and operation. The drive selection for motor control is depends on some of factors which listed here\(^3\). Before select the drive for speed control operations the following factors must be considered such as the type of quadrant operations, unique or group motor drives, precision and response time, reliability, efficiency with change in load, power consumption, harmonics and power factor etc.

**Materials and Methods**

**Review of available techniques for Induction motor speed control.**

1. **Scalar control**

   In this scalar control the motor speed can be controlled by adjusting the magnitude of supply voltage and frequency only and no need to consider the coupling effect and the same can be disregarded. Both flux and frequency can be tuned by adjusting the input voltage and the torque can be tuned by adjusting the slip. So it is very clear that the deep saturation can be obtained by making concurrent adjustments in the magnitude of flux and input voltage\(^4,5,6,7\).

2. **Vector Control**

   In DC motor the torque can control independently by tuning the field current or armature current separately due to its orthogonal property between field and armature currents\(^8,9\). But in AC motors there are some interactions between stator and rotor fluxes which cause some troubles and diverge with respect to expected operating performance\(^6\). In AC machine it is possible to get the performance which similar to DC machine by keeping the perpendicular orientation between the armature and field fluxes. The discrete flux and torque control can be achieved by making the AC motor fields perpendicular to stator current depends rotor flux. This is called vector control (or) flux oriented control.

   This vector control is suitable for both AC induction motor and synchronous motors. The direct vector control is most popular one and it provides smooth speed control. Besides the requirement of motor parameters causes much complication when put into real-time implementation. Fig.2 illustrates the simplified block diagram of direct vector control system\(^10\). The speed control is achieved by tuning the inverter switching states after complete the necessary computations in vector control computation block.

   The magnitude value of phasor currents remains unchanged and it is also independent of reference frame. The input currents and developing electromagnetic torque of the motor can be found as follow,

\[
\begin{align*}
    i_{q} &= i_{q} \sin \theta \\
    i_{d} &= i_{a} \cos \theta \\
    T_{em} &= \frac{3}{2} \frac{L_{m}}{L_{r}} \lambda_{d} i_{q} 
\end{align*}
\]

By choosing this technique for squirrel cage induction motor, it is possible to get superior dynamic characteristics and can get long term stability with the help of closed loop control. For getting high performance from the drive systems, the motor speed must be followed the desired reference speed with independent of any load variations and problems associated to parameter variations\(^11\). The system performance very much depends the design algorithm of controller. In this speed control technique, the change in the motor parameters leads to affect the decoupling characteristics. Hence this method of speed control also named as Decoupled control or Independent control\(^12\).

3. **Proportional Integral Control**

   The PI control is a universal approach for all electrical motors in industries. The expression for this speed control technique is,

\[
\begin{align*}
    i_{q} &= i_{q} \sin \theta \\
    i_{d} &= i_{a} \cos \theta \\
    T_{em} &= \frac{3}{2} \frac{L_{m}}{L_{r}} \lambda_{d} i_{q} 
\end{align*}
\]

![Fig. 1 — Vector Control or Field Orientated Control (FOC)](image1)

![Fig. 2. — Block diagram of direct vector control technique](image2)
Torque ($T$) = $K_p e + K_i \int e \, dt \quad \ldots \quad (4)$

In a closed loop the gain constants ($K_p$, $K_i$) of PI controller can be tuned automatically by using controller output which helps to provide an accurate performance even the system having some parameter variations. The performance of PI controller associated with Induction motor drive is analyzed by taking the overshoot as a reference parameter at tracking mode with load variations. From the analysis, it is very clear to keep optimum performance the gain constants should not go beyond the desired minimum value. At the time of beginning the higher value of error athwart the PI controller triggering the large deviations in the command torque. Suppose the gain constants reduced below the desired minimum value, the command torque signals deviated very much which leads to damage the system performance. By connecting a proper limiter just before the PI controller block the above mentioned problem can be reduced and the speed error can be kept within the saturation limits. Hence very good performance obtained from PI controller even the gain constants are too high. Thus by choosing the PI controller with suitable limiter for three phase Induction motor can reach the set speed in quick manner without any spikes and dependency of load variation and with less steady state error.

4. Fuzzy Logic Control

Nowadays all industries are required very much improved automation systems and very accurate speed control performance. So the earlier methods of speed control are not adequate at all times. And also some problems arise indefinitely at practical implementations. The system input and output signals can be tuned by some external factors when the relations between input and output are unpredicted. By implementing some novel technique these kind of problems can be rectified. For present requirements fuzzy logic algorithm is applicable as a new technique with adequate modifications.

The basic fuzzy theory was introduced by L.A.Zadeh on 1965 and then E.H.Mamdani has developed a first fuzzy controller on 1974. Till date fuzzy doing a prominent role in all industries and consumer products. This is the reason for introducing so many new approaches with fuzzy sets in every year by the researchers. The fuzzy rules are very simple and it is very easy to design and maintain a system and also well suited for nonlinear control. FLC is an efficient technique which provides very accurate and faithful result with minimum processing time. Linguistic if then rules are the most popular one for FLC.

5. Neural Network Control

In this research we developed a multilayer sensitivity NNC using back propagation algorithm. In a perception network, the training data must be generalized at any cost and should not over fit. The most popular technique for developing the generalization is deeply discussed and examined. The conventional controllers required multi-layer sensitivity NNC. But in this research work, we have used the new approach with predictive control technique. The performance of proposed controller is analyzed in different situations. This controller needs the system identification for predicting the upcoming plant performance.

6. Hysteresis Current Regulator

Hysteresis Current Regulator current regulator contains three hysteresis controllers, all controllers built with Simulink blocks. The actual current of the motor is provided by the measurement output from the Asynchronous Machine block. In hysteresis type relay, both actual motor current and reference current are compared.

IVCIM based on NN Predictive controller with AW technique - MATLAB Simulation

In this proposed indirect vector controller using neural network with Antiwindup technique, the speed error is given as input to the neural network and the output is obtained as reference torque. In this proposed work, out of the total input samples, 30% of the samples are used for training, 35% of the samples are used for validation and 35% of the samples are for testing. By increasing the number of hidden layers, accuracy can be increased. But at the same time learning complexity also increases with increase in the number of hidden layers.
number of hidden layers. Among various neural network algorithms, the most popular Back propagation algorithm is used in this proposed work. Reference flux is calculated based on the motor speed as follows,

\[ \phi_{\text{ref}} = k_1 \times I_d \times \frac{1}{(1 + 0.1557 S)} \]  ... (5)

where,

- \( \phi_{\text{ref}} \) = Reference flux
- \( I_d \) = Direct axis current
- \( k_1 \) = Gain constant

The dq value of current can be calculated from the supply current Iabc by using park transformation and vice versa. Here universal H bridge inverter using IGBT is used for this research work.

**Results and Discussion**

The performance and efficiency of induction motor which is used in domestic and industrial applications is determined by its control method. The performance of IVCIM using NNPC with AW technique is deeply analyzed in this section. The plant identification process has been done by using NN toolbox. Then by comparing the plant and input the training data has
developed. The most favorable value of weight and biases can be found by using back propagation algorithm. Then the optimum values given to the NNPC. In this research, 24 hidden layers, 10,000 training samples and 250 epochs have used. At 0.05 learning rate and when the epochs exceed 12 than the sum squared error reaches 3.22681e-005 and then the network will change. Here the results are given for motor current, speed and electromagnetic torque. While using this controller the machine has taken low starting current and very less settling time compare with conventional PI and FLC. The performance of proposed controller is also analyzed with different load conditions.

The proposed NN controller performance has been compared with the different loading conditions at different values of torques. Fig. 5and6 illustrates the performance for a load torque variation to the range of 0N-m to 27 N-m as against the past values of no-load.

### Conclusion

Neural Network is one of the most popular intelligent techniques in recent days it is successfully applied in almost all fields. Neural network works like a human brain, so can perform well and produce better result against complex problems. The performance of IVCIM using NNPC and antiwindup technique is analyzed. The performance analysis shows that the proposed controller is efficient and much reliable than the conventional PI and FLC under rated speed and different load variations presents in the propulsions drives. The performance of this proposed controller is independent of load variations. So the change in external factors does not affect the system performance. For providing very reasonable and smooth speed control the proposed controller requires several no of trials and feedback signals. Thus the proposed controller can be used for getting effective performance in marine applications.

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