A Proficient Approach for Monitoring Induction Motor by Integrating Embedded System with Wireless Sensor Network

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Abstract

In this paper aims at monitoring parameter of induction motor like current, voltage, torque and efficiency in real time by employing embedded system with wireless sensor networks. An embedded system is employed for acquiring electrical signals from the motor in a noninvasive manner, and then performing local processing for torque and efficiency estimation. The values calculated by the embedded system are transmitted to a monitoring unit through an IEEE 802.15.4-based Wireless Sensor Network (WSN). At the base unit, various motors can be monitored in real time. The Air Gap Torque (AGT) method is used to find out the torque and efficiency in induction motor. It is used to measure efficiency in a much less invasive manner. The AGT method can be employed without interrupting the motor operation and it is not based on the motor nameplate. This method generally is more accurate than the other methods. The proposed model has a supervisor (PC) which Communicates with the remote terminal unit, processing the variable parameters and controlling the systems. The Receiver Terminal Unit (RTU) is a local controller in distributed processes environmental which acquires the data from sensors, process the collected data puts the required data together, forming the frame for transmitting to the Supervisory Controls (S.C). RTU also receives and processes Control commands from S.C and executes them accordingly. The communication utilizes a full duplex communication for data transmission between S.C and RTU. The communication through wireless by using Zigbee.

Key words: Wireless Sensor Network, AirGap Torque, Receiver terminal Unit

1. Introduction

In industrial environment most of the electric motor are induction based because their cost effectiveness and mechanical robustness. Torque is the one of the main parameter of the induction motor identifying this parameter will helpful to find out the equipment failure in induction motor. Various method are available to measure the torque in the rotating shaft they are direct torque measurement on the shaft and estimated torque measurement from motor electrical signals. Direct torque estimation method is very easy to find out the torque and accurate but it need some of coupling devices between the motor and the load. The estimated torque from the motor’s electrical signals makes the system less invasive, but it is less accurate when compared to direct measurement systems. There are problems, such as noise in signal acquisition, those related to numerical integration, this and low levels of voltage signals at low frequencies. However, in many cases, high precision is not critical, and low invasiveness is required. Various methods are available to measure the efficiency of the induction motor on dynamometer, duplicate machines, and equivalent. However, their application for in-service motors is impractical, because it requires interrupting the machine’s operation to install the instruments.

There are some simple methods for in-service efficiency estimation, like the nameplate method, the slip method,
and the current method\textsuperscript{13}. These methods present as the main limiting factors the low accuracy, estimative based on nominal motor data and the need of typical efficiency-versus-load curves. In the ORMEL96 method\textsuperscript{4}, the efficiency is obtained from an equivalent circuit that is generated from the motor nameplate and the rotor speed measurement. In the OHME method\textsuperscript{15}, the efficiency estimation is performed from the input power measurement and data from the motor nameplate.

Hsu and Scoggins\textsuperscript{16} presented the air-gap torque (AGT) for energy efficiency estimation. In the AGT is also used to measure efficiency in a much less invasive manner. The AGT method can be employed without interrupting the motor operation and it is not based on the motor nameplate. This method generally is more accurate than the other methods described earlier. In this study, the AGT method was used for the estimation of the motor shaft torque and efficiency, because it is the noninvasive method for determining torque and efficiency that has less uncertainty.

Besides the high cost, the wired approach offers little flexibility, making the network deployment and maintenance a harder process. In this context, wireless networks present a number of advantages compared to wired networks as, for example, the ease and speed of deployment and maintenance, and low cost. In addition to that, Wireless Sensor Networks (WSNs) provide self organization and local processing capability. Therefore, these networks appear as a flexible and inexpensive solution for building industrial monitoring and control systems.

We have adopted the IEEE 802.15.4 standard for wireless communication. This standard allows the formation of a large network of sensors, in various industrial segments, where the standard is expected to have a significant impact. This standard has been employed also in the Mechatronics field. In comparison with other standards such as IEEE 802.11 and IEEE 802.15.1 (Bluetooth), the IEEE802.15. standard have advantages related to energy consumption, scalability, reduced time for node inclusion, and low cost.

2. Motivation

Motor torque is directly measured on the shaft of the motor with the use of torque sensor are used to find out the torque. There are some simple methods for finding the torque and efficiency of operating motor such as the nameplate method, the slip method, and the current method. These methods provide low accuracy. The direct torque measuring method is more invasive so this method cannot use in real time application. These methods are giving large amount of the data for transmission so that the bandwidth requirement is more. This paper presents an embedded system for determining torque and efficiency in industrial electric motors by employing WSN. AGT method is used to find out the torque and efficiency with help of the embedded system. Local processing is performed so that only target value is transmitted.

The estimated torque from the motor’s electrical signals makes the system less invasive. It does all the data processing locally, transmitting to the base unit only the targeted parameters previously calculated. Thus, there is a large reduction in the amount of transmitted data, enabling real-time and dynamic monitoring of multiple motors.

3. System Architecture

Figure 1 depicts Embedded System Integrated into WSN. End nodes are composed by the embedded systems located close to the electric motors. The values of motor voltage and current are obtained from the sensors, and the embedded system performs the processing for determining the values of torque, speed, and efficiency. Information obtained after the processing are transmitted to the base station through the WSN.
Depending on the distance between end nodes and the coordinator, it may not be possible to achieve direct communication, due to the radio’s limited range and the interference present on the environment, among other factors. Therefore, the communication among nodes and coordinator can be done with assistance of routers. Base unit of system contain the voltage and current sensor connected with embedded unit. Then the processed value is calculated through the Zigbee. Control unit of the system which receives the transmitted value and the received value is monitored. Figure 2 show a simplified block diagram of the proposed embedded system. For current measurement, Hall Effect sensors are employed due to their robustness and noninvasiveness. Transformers with grain-oriented core are used to measure the voltage between phases, which provide the voltages in the secondary and primary without delay. The acquisition and data processing unit (ADPU) is responsible for data acquisition and conversion, besides the data processing. The printed board’s power supply supplies the current and voltage for the sensors, the IEEE 802.15.4 transceiver, and the ADPU. The main element of the ADPU is a ARM LPC 2148, which is a digital signal controller designed for applications that require high processing capacity. It has integrated ADC, which perform simultaneous acquisition of the voltage and current sensors. The input/output channels can be used for user interface, and possible connections to auxiliary sensors and actuators. The values of torque and motor efficiency are transmitted using the IEEE 802.15.4 Transceiver. We have used an MRF24J40 transceiver, designed by Microwire. The connection between the transceiver and the ARM is accomplished using a Serial Peripheral Interface Bus.

4. Activity Diagram

The internal operation of the embedded system is illustrated by the activity diagram shown in Figure 3. When the system starts, the embedded system parameters are configured. These parameters include the wireless network settings and the ADC settings. To obtain good accuracy from a simple numerical integration method, such as trapezoidal a sample rate greater than 2 kHz should be used. In our system, we set the ADC to operate with 3 kHz and 10 bits of resolution .After the first step, the system connects to the WSN.

The embedded system only begins to acquire and process data after successfully connecting to a coordinator operating in the same channel. Then, the system gets into the acquisition loop, processing, and transmitting data, which is repeated until the system shuts down. The voltage and current values, after acquired, must be adjusted to reflect the real values measured from the sensors. After that, the algorithm is executed to compute the AGT. After that, the losses are removed, and the shaft torque is estimated.

Using the shaft torque values, the system estimates the motor speed and efficiency. The embedded systems were configured to calculate a set of 360 values (2 bytes each) of torque and efficiency, and then transmit these values aggregated into 20 packets with 72 bytes of payload each. The time necessary to acquire the signals and

Figure 2. Block diagram of the embedded system.

Figure 3. Activity diagram.
calculate the 360 values of torque and efficiency is about 11 s (6s to acquire 360 cycles of current and voltage, and 5 s to perform the calculations). Thus, the system transmits data in burst mode, spending only about 8% of the time transmitting data, at a rate of 20 packets/s.

5. Background Torque Estimation

In an induction motor, the air gap is the region between stator and rotor, where occurs the electromechanical conversion process. The AGT is the conjugate formed between the rotor and the stator magnetic flux. In this study, the AGT method is used to estimate the motor shaft torque the estimation of the AGT can be performed noninvasively taking current and voltage measurements from the electric motor

\[
T_{AG} = \frac{P\sqrt{3}}{6} \left\{ (i_a - i_b) \int [v_{ca} + r(2i_a + i_b)] \, dt 
+ (2i_a + i_b) \int [v_{ab} - r(i_a - i_b)] \, dt \right\}
\]

where, \( P \) = number of motor poles;
\( i_a, i_b \) = motor line currents, in ampere
\( v_{ca}, v_{ab} \) = motor power line voltages, in volt
\( r \) = resistance of motor armature, in ohm.

Equation can be applied using instantaneous and simultaneous acquisitions of \( i_a, i_b, v_{ca}, v_{ab} \) and a measured value of \( r \). It is valid both for motors connected in Y with no connection to the neutral, or \( \Delta \). Its integrals corresponding to the stator flux linkages. AGT equations have also been used in many works that use other types of motors. The torque on the shaft can be estimated by subtracting the losses occurring after the process of electromechanical energy conversion from AGT, according to following equation

\[
T_{shaft} = T_{ag} - \frac{L_{mech}}{\omega_r} - \frac{L_{rd}}{\omega_r}
\]

Mechanical losses (i.e., friction and wind age \( L_{mech} \)) vary according to the particular motor and the industrial process to which it belongs. If it is not possible to estimate the losses, then it is necessary to perform a no-load test. The additional losses (i.e., stray-load loss, \( L_{rd} \)) result from nonlinear phenomena of different nature, difficult to quantify. These can be approximated by a percentage of motor power \( L_{mech} \) is the rotor speed, in radian per second.

6. Efficiency Estimation

The motor efficiency \( \eta \) can be estimated by the relation between the electrical power supplied to the motor and the mechanical power supplied to the shaft by the motor according to the following equations

\[
\eta = \frac{P_{out}}{P_{in}}
\]

Pin of a three-phase induction motor can be calculated by the instantaneous currents and voltages, according to the following equation

\[
P_{in} = i_a v_a + i_b v_b + i_c v_c
\]

Pout can be determined by the estimated shaft toque and the rotor speed as follows

\[
P_{out} = T_{shaft} \cdot \omega_r
\]

Efficiency \( \eta \) can be estimated as follows:

\[
\eta = \frac{T_{shaft} \cdot \omega_r}{i_a v_a + i_b v_b + i_c v_c}
\]

7. Speed Estimation

Speed is either can estimate through the sensor or without sensor. Induction motor model, and the analysis in the frequency spectrum of voltage and electric current is based on sensor less method. Our proposed system is based on IR sensor based.

8. Industrial WSN

WSNs are formed by devices equipped with sensors and are capable of communicating via radio frequency. These sensors can produce responses to changes in physical conditions such as temperature, humidity, or magnetic field. Specific types of WSNs, such as for industrial monitoring, have unique characteristics and specific application requirements. Therefore, the deployment of WSNs must necessarily involve considerations of the targeted application.

The IEEE 802.15.4 standard is well suited for WSN applications. It provides wireless communication with low power consumption and low cost, for monitoring and control applications that do not require high data transmission rate. There are some protocols that implement the network layer over the IEEE 802.15.4 standard, such as Zigbee. The standard defines three frequency bands: 868 MHz, 915 MHz, and 2.4 GHz.
In industrial environments, there can be other sources of noise such as thermal noise and noise from motors and devices that cause electrical discharge. The error characteristics presented in the wireless channel depend on the propagation environment, the modulation, transmission power, frequency range among other parameters. In general, industrial wireless systems tend to have varying and often high error rates.

9. Matlab Simulation

The PowerGUI block is necessary for simulation of any Simulink model containing SimPower Systems blocks. It is used to store the equivalent Simulink circuit that represents the state-space equations of the model. The PowerGUI block also gives you access to various graphical user interface (GUI) tools and functions for the steady-state analysis of SimPower Systems models, the analysis of simulation results, and for the design of advanced block parameters.

Figure 4 shows the simplified simulink model of induction motor whose speed and torque is measured with help of scope.

Three phase programmable voltage block to generate a three-phase sinusoidal voltage with time-varying parameters. Program is done for the time variation for the amplitude, phase, or frequency of the fundamental component of the source. In addition, two harmonics can be programmed and superimposed on the fundamental signal.

Use this block to generate a three-phase sinusoidal voltage with time-varying parameters. Program is done for the time variation for the amplitude, phase, or frequency of the fundamental component of the source. In addition, two harmonics can be programmed and superimposed on the fundamental signal.

The Bus Selector block outputs a specified subset of the elements of the bus at its input. The block can output the specified elements as separate signals or as a new bus. When the block outputs separate elements, it outputs each element from a separate port from top to bottom of the block. By default, Simulink implicitly converts a non-bus signal to a bus signal to support connecting the signal to a Bus Assignment or Bus Selector block.

If a Scope window is closed at the start of a simulation, scope data is still written to the connected Scope. As a result, if you open a Scope after a simulation, the Scope window displays the input signal or signals. If the input signal is continuous, the Scope draws a point-to-point plot. If the signal is discrete, the Scope draws a stair-step plot. The Scope block only displays major time step values. The scope displays additional interpolated points between major time steps if specified by the refine parameter.

Figure 5 shows the motor speed graph with respect to time. Motor speed is increased gradually with time after the particular time it reach the constant value.

Figure 6 shows the motor torque graph with respect to time. It gradually increases, after obtain certain value it moves to constant value.

Figure 4. Simulink induction motor mode.

Figure 5. Simulink induction motor mode speed graph.

Figure 6. Simulink induction motor mode torque graph.
Figure 7 shows motor torque vs speed. When torque increases the speed also increases, but when the speed is reached to the synchronous speed its value start to decreases.

10. Conclusion

This work presented an embedded system integrated with WSN for online dynamic torque and efficiency monitoring in induction motors. It used the AGT method to estimate shaft torque and motor efficiency. The calculations for estimating the targeted values are done locally and then transmitted to a monitoring base unit through an IEEE 802.15.4 WSN. The estimated efficiency was compared with the reference efficiency. The data transmission is done using the WSN the system which is able to provide useful monitoring information; since all processing is done with embedded system. Without this, it might be impossible to use the WSN technology for this particular application. More detailed performance study in industry with more number of nodes has to be done. In addition, this work can be extended to develop spectrum-aware protocols to allow the radio to choose their operation channels dynamically, allowing the embedded systems to self-adapt to the operating environment, improving the quality of service of the network.

11. References


