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Use of the Maximum Torque Sensor to Reduce the Starting Current in the Induction Motor

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Abstract: Use of the maximum torque sensor has been demonstrated able to improve the standard ramp-up technique in the induction motor circuit system. The induction motor used was of a three-phase *squirrel-cage motor* controlled using a microcontroller 68HC11. From the simulation done, it has been found that this innovative technique could optimize the performance of motor by introducing low stator current and low power consumption over the standard ramp-up technique. *Copyright © 2010 IFSA.*

Keywords: Standard ramp-up, Modified ramp-up, Starting current, Induction motor, Microcontroller

1. Introduction

An induction motor is considered an important component that is widely used in many electronic equipments such of automotives, machineries, and industries. The characteristics of that motor have introduced some superiorities of simple maintenance, low cost and more compact in dimension compare than that of DC motors. Based on the operational technique of motors, the classical technique called as a direct-on-line is usually used by applying voltage directly to the motors. This technique is considerably impractical for many electronic systems as the “voltage blink” will be produced in the power line during the operation that potentially able to disturb the electronic equipments. Therefore, any innovation techniques are expected in order able to solve that problem. Another common strategy used to reduce the starting current is by reducing the voltage of coil in a stator field using some possible techniques of delta-star, autotransformer, and primary impedance. For this technique, the problem still arises when a relatively high starting current produced during the operation that will affect the drop voltages and lead the motor to break down [1, 2].

Beside the above techniques, another well-known technique called a ramp-up technique is also common used. This technique bases on the concept of providing the voltage gradually to the motor from 0 volt to the nominal value of a certain rate. This technique is different from the direct-on-line mentioned before that base on providing the voltage directly for a certain nominal value. The ramp-up technique has also been used for other applications in the integrated circuit (IC) devices [3]. In our research work, we have built-up a design of a control system to reduce the starting current as experienced in the ramp-up technique by a modification in its algorithm called a modified ramp-up technique. The basic concept of this technique has been done by providing the additional maximum torque detector in the electrical circuit to monitor the torque position. With this method, the system will always monitor the torque performance and control the voltage supply simultaneously based on the ramp-up voltage instead of the standard ramp-up used in a common system. The implementation of a power supply could be carried out through the control system of stator voltage using a thyristor circuit. For the investigation, the simulation has been carried out using Mathlab software.

2. Theory, Design and Simulation

2.1. Starting Current Model of Induction Motor

It is noticeable that the ideal model of a three-phase of induction motor is complex, therefore the approximation model is required to simplify the analysis for a starting current produced during the motor operation. For the above problem, Dewan *et al.* [4] have proposed a model of a three-phase of induction motor (squirrel-cage type) as schematized in the equivalent circuitry given in Fig. 1.

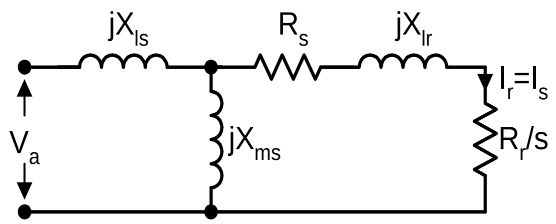

Fig. 1. An Approximation model for a three-phase of motor induction.

From that figure, parameters of a three-phase motor induction notated as X_{ms}, X_{ls}, X_{lr}, R_s, and R_r are per-phase magnetizing reactance, per-phase stator leakage reactance, per-phase rotor leakage reactance, per-phase stator resistance, and per-phase rotor resistance, respectively. Notation S is a slip, defined as a ratio between actual and synchronous angular speed. Theoretically, the increase of motor speed leads to the decrease the slip. From that figure, notation V_a is voltage of phase a, meanwhile I_r and I_s are current flows in the circuit for rotor and stator, respectively. The model of that starting current was developed by Chattopadyay and Rao [5] that could be used to analyze the transient condition of an induction motor. That model could be implemented into a direct-on-line or a ramp-up technique. For that method, the model could be expressed as a differential equation given in Eq. 1. This equation will be solved using a simulation work by doing the integration function of the equation by referring to the Runge-Kutta method as this function is available in the software used.

$$\frac{p}{\omega_b}\bar{i} = \bar{X}^{-1}\bar{V} - \bar{X}^{-1}\bar{R}\bar{i}\ , \tag{1}$$

where, p is a differential operator (= *d/dt*), ω_b is a base angular speed used to determine the motor parameters. Eq. 1 consists of a parameter of three-phase induction motor characteristics in the form of matrices and vectors, each parameter could be expressed as below.

$$\bar{X}^{-1} = \frac{1}{X_{ls}X_{lr} - X_{ms}^2}\begin{bmatrix} X_{lr} & 0 & -X_{ms} & 0 \\ 0 & X_{lr} & 0 & -X_{ms} \\ -X_{ms} & 0 & X_{ls} & 0 \\ 0 & -X_{ms} & 0 & X_{ls} \end{bmatrix} \tag{2}$$

$$\bar{V} = \begin{bmatrix} \frac{2}{3}(V_a - \frac{1}{2}V_b - \frac{1}{2}V_c) \\ \frac{1}{\sqrt{3}}(-V_b + V_c) \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

From Eq. 3, V_a, V_b, and V_c are voltages for each phase a, b, c, respectively from the power supply in a sinusoidal form that could be expressed as

$$V_a = V_m \text{Sin}\ \omega t \tag{4a}$$

$$V_b = V_m \text{Sin}(\omega t - \frac{2\pi}{3}) \tag{4b}$$

$$V_c = V_m \text{Sin}(\omega t + \frac{2\pi}{3})\ , \tag{4c}$$

where, V_m is a maximum voltage of supply.

Meanwhile, matrix construction, $\bar{R}$ is

$$\bar{R} = \frac{1}{X_{ls}X_{lr} - X_{ms}^2}\begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -\frac{\omega_r}{\omega_b}X_{ms} & R_r' & -\frac{\omega_r}{\omega_b}X_{lr} \\ \frac{\omega_r}{\omega_b}X_{ms} & 0 & \frac{\omega_r}{\omega_b}X_{lr} & R_r' \end{bmatrix} \tag{5}$$

where, ω_r is an angular frequency of rotor. Variable $\bar{i}$ in Eq. 1 is a current vector which could be expressed as

$$\bar{i} = \begin{bmatrix} i_{qs} & i_{ds} & i_{qr} & i_{dr} \end{bmatrix}\ , \tag{6}$$

where, i_{qs}, i_{ds}, i_{qr} and i_{dr} are transient currents as a function of time in the model at d-q axis. Model of d-q axis is a transformation form of stator and voltage variables of reference for a stationer coordinate of a three-phase to a reference of two coordinates (d and q) in the rotor. This transformation is used based on the theory of a two-axes introduced by Blondel *et al*. and Park [6]. In Eq. 6, subscripts s and r refer to the stator and rotor, respectively. From the above parameters, the electromagnetic torque, Te could be found through a calculation using the equation below.

$$Te = X_{ms}(i_{qs}i_{dr} - i_{ds}i_{qr}) \tag{7}$$

Once Te could be obtained, the angular speed of motor rotation could be obtained using the following equation.

$$p\left(\frac{\omega_r}{\omega_b}\right) = \frac{T_e - T_L}{2H}, \tag{8}$$

where, H is an inertial constant of motor (unit in second), and T_L is a load torque.

2.2. A Standard Ramp-up Technique

By using a standard ramp-up technique, a starting current of motor could be reduced. The basic concept of a standard ramp-up technique as named by Nguyen and Ramaswamy [7] is well-known for motor inductions. Therefore, to produce low current at a starting-up condition, a supply voltage biased to the motor should be low. Meanwhile, to generate the electromagnetic torque required to rotate the rotor, the voltage bias is increased linearly and gradually. With this technique, the stator current is relatively low when the motor at a starting-up condition. Nevertheless, according to a ramp-up technique (without a feed-back component) as schematized in Fig. 2, due to the decrease of slip, this technique will increase the rotor resistance and produce low current. When the torque achieved a maximum value, the stator current will decrease to its nominal value. This technique is similar to the open loop control system where the ramp-up voltage is provided until a certain nominal value at a certain time (not the optimum time) achieved. In this work, the simulation will be done to the algorithm of this technique (based on Eq. 4) with a modification in the maximum torque sensor in order the input voltage could increase gradually.

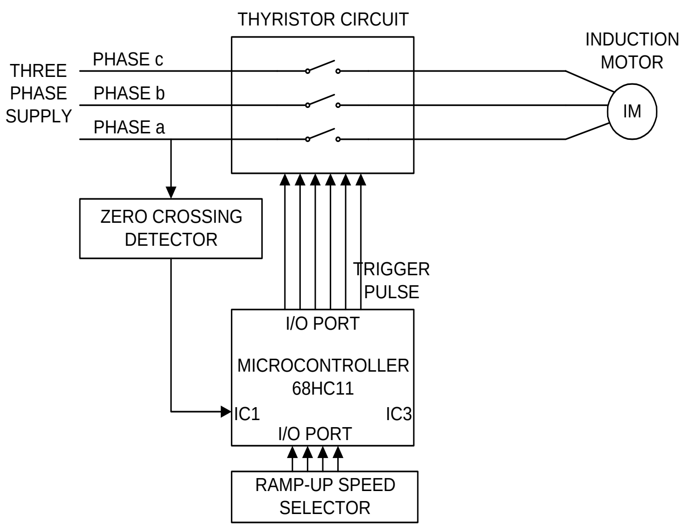

Fig. 2. A schematic diagram of standard ramp-up technique.

2.3. A Modified Ramp-up Technique

By referring to the standard ramp-up technique mentioned before, the starting current produced by the motor will decrease from around 6 to 2.5 times of the nominal value. Unfortunately, the power supply does not achieve a nominal value while the torque was at a maximum position. This condition could affect the stall when the start-up time is occurred for any longer. Therefore, to overcome that problem, a modified standard ramp-up has been designed in this work in order the system could be monitored continuously. This method was carried out by providing the maximum torque detector in the circuitry as a feedback element as this is usually done in the closed loop control system. Initially, the voltage bias was increased to the motor (this method is commonly done in the standard technique) while monitoring the performance of torque. When the torque achieved a maximum position, then the voltage is increased at a nominal value. To generate the ramp-up voltage while monitoring the performance of torque, we used a thyristor circuit to control the voltage bias. For this technique, the signal generator and torque were controlled using a microcontroller. The design of a modified ramp-up system is schematized in Fig. 3. From that figure, the maximum torque detector of a thyristor component is added to the circuitry connected to the induction motor and a microcontroller. Meanwhile, the procedure to control the motor is given in the flow chart as shown in Fig. 4. As we can see from that figure, after the torque is set at a maximum angle through the circuitry command, then the circuitry shifts the pulse at a lower angle, meanwhile the detector is being monitored continuously. When the torque achieved at a maximum position then setting the pulse at a minimum angle otherwise shifting the pulse to the lower angle. This method will allow the circuitry always adjust the torque until achieved a maximum value before setting the pulse at a minimum angle.

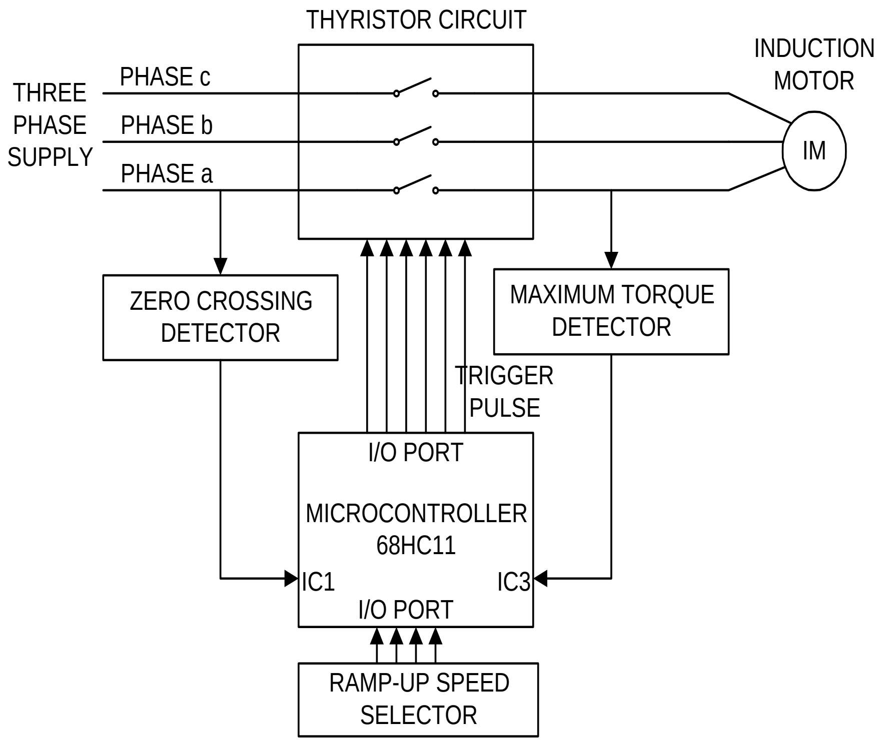

Fig. 3. A schematic diagram of modified ramp-up technique used by connecting the maximum torque detector.

For the simulation, the parameters of ω_b, torque and speed of motor as a function of time will be given their values through a calculation by referring to Eq. (1), (7) and (8), respectively. The results obtained from the simulation work will be compared to that of the standard ramp-up technique.

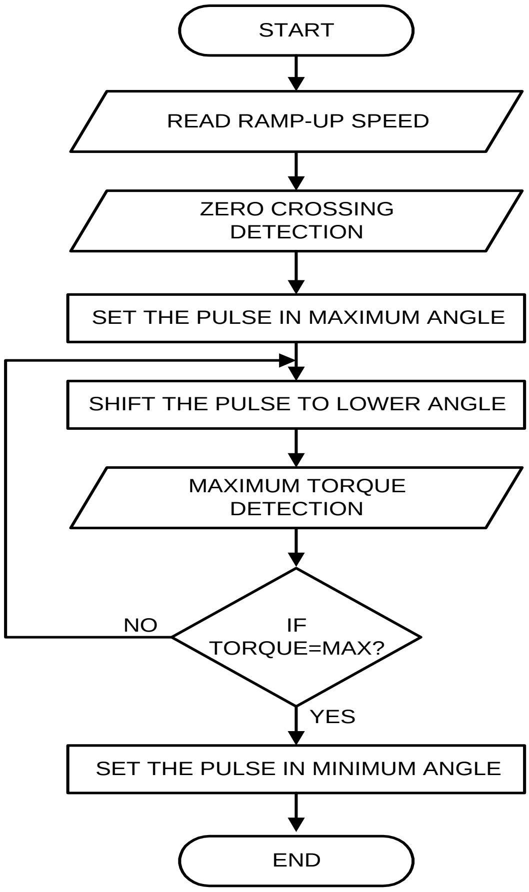

Fig. 4. A flow chart of motor induction control based a modified ramp-up technique.

3. Results and Discussion

Simulation has been done to investigate the motor characteristics using standard and modified ramp-up techniques and compare their results. From the results, the characteristic of induction motor based on a standard ramp-up technique has been obtained as shown in Fig. 5. This figure shows the pattern of stator current, torque and speed characteristics of induction motor as indicated by the arrows. From those results, it was found that for a standard ramp-up technique, the stator current increased linearly by the increasing time as the torque also increases until achieves a maximum value at 1 second. At this condition the speed of motor increased but has not achieved yet the maximum and then reaches a stable condition. The stable condition was achieved starting at 1.4 seconds. As we can see in Fig. 5, the pattern of stator current shows a decrease after achieved a maximum magnitude and then start again to increase slowly with a tale for a longer time tend to stable.

Meanwhile, for the modified technique, this characteristic has been obtained as given in Fig. 6. From that figure, the pattern of stator current (after achieved a maximum value at 1 second) decreases and immediately going to stable condition as this phenomenon can not be observed through a standard ramp-up technique. This immediate stability will be a very interesting point of the method for the ability to improve the optimum performance of motor.

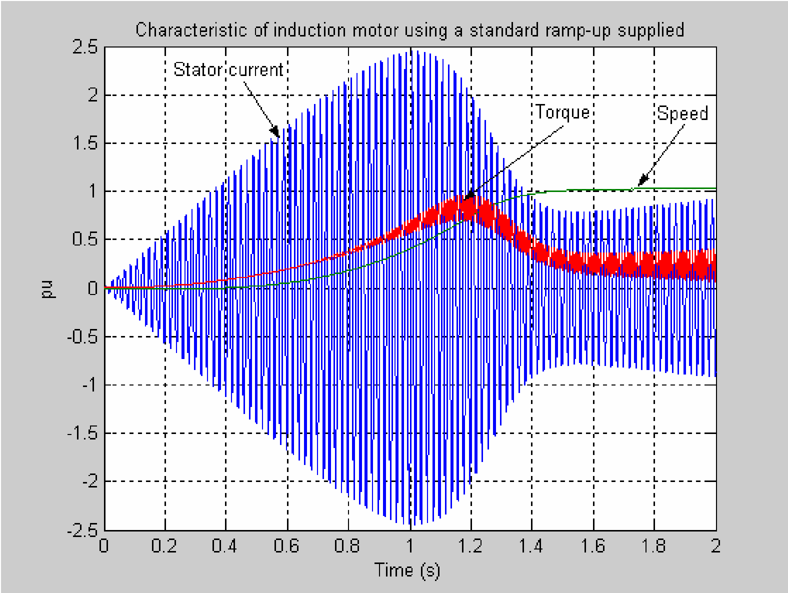

Fig. 5. Characteristics of the induction motor using a standard ramp-up supplied.

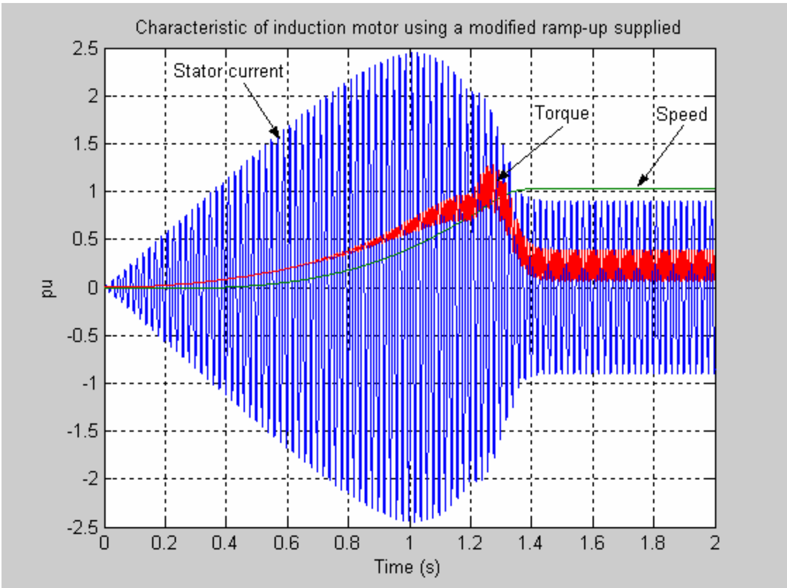

Fig. 6. Characteristics of the induction motor using a modified ramp-up supplied.

From the simulation, it has been found that the variation of supply voltages as a function of time (as we can see for a standard ramp-up technique in Fig. 7a), the pattern of voltage tends to increase its magnitude from the initial voltage without a certain stable condition at 2 seconds. This phenomenon could affect disadvantageous of more power consumption required. But for a modified ramp-up technique as shown in Fig. 7b, the voltage pattern shows to increase linearly and then a bit sudden increase (for about 1.5 seconds) before achieved a stable value. This different characteristic for the modified technique affects to more quick to have a stable condition of motor performance and this phenomenon will introduce the effective power supplied. With this technique, the motor could avoid the stall for a longer starting time.

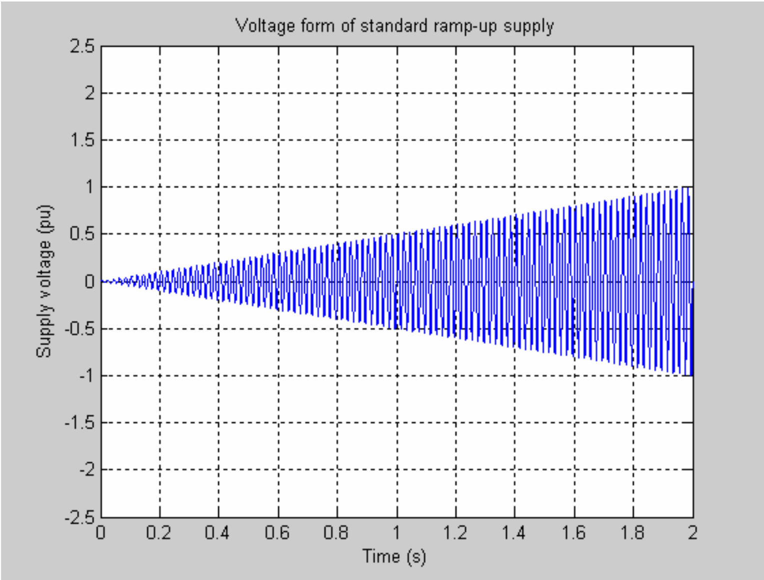

Fig. 7a. Voltage forms of a standard ramp-up.

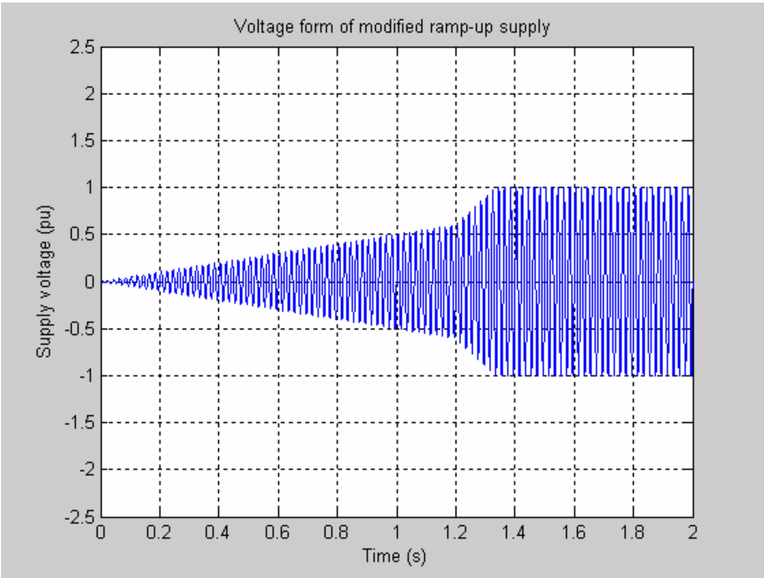

Fig. 7b. Voltage forms of a modified ramp-up supplied.

5. Conclusions

From the simulation done to both techniques, it was found that using a modified ramp-up technique, the voltage achieved a stable nominal value was relatively faster compare than that of the standard ramp-up technique beside the starting current was found to be lower. For a motor speed, the modified technique introduced a faster time to achieve a stable condition. These advantages lead to a better characteristic for induction motors, relatively longer time performance as the start-up current was controllable to more precisely. With some of these advantages, the modified ramp-up technique is encouraging for an implementation to the real motor circuitry based on the simulation work.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
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