Design Of A Computer Controlled Speed Control System for Wound-Rotor Inducion Machines

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***Abstract*—This study introduces a novel and powerful speed control system with computer interface for wound-rotor induction machines (WRIM). In order to improve the sensitivity and stability of the control process, a high-speed digital signal processor (DSP) is used as the main controller. A serial resistor is connected to rotor side of WRIM to control the output power of the machine. The power consumed on the serial resistor is continuously controlled by PWM signals generated from DSP. A zero-crossing detector is used for calculating the rotor frequency. Thus, the rotor speed is obtained without using a mechanical sensor like external encoders. Thanks to using this method, measurement accuracy is increased and the total cost is decreased as well. After calculating the mechanical speed using the measured rotor frequency, the rotor speed is fixed to the reference value by a PI controller. In addition to speed control system, a graphical user interface (GUI) is also designed to set the reference speed through a computer screen. On this GUI, users can also observe and monitor the some parameters in real time such as rotor frequency, rotor slip, actual rotor speed, actual effective value of the serial resistor, switching ratio of PWM signals.**

***Keywords*— Wound-rotor induction machine, speed control, graphical user interface**

I. INTRODUCTION (*HEADING 1*)

One of the most important factors that affect the development level of countries is independent energy potential of those countries. For this reason, a great deal of academic and industrial studies are focused on renewable energy sources and their usages as well. Especially, solar power, wind energy conversion systems, bioenergy and geothermal energy are dealt with in these studies.

As a sustainable and clean energy source, the wind energy has a great importance among the other renewable sources [1-4]. In wind energy systems, the mechanical energy obtained from the wind turbine is converted to the electrical energy using generators. Afterwards, voltage and frequency stability of the generated electrical energy is provided by some power electronic circuits. Basically, the generators used in wind energy conversion systems can be classified in three types as squirrel-cage induction generators, wound rotor induction generators and double-fed induction generators [5-7].

Squirrel-cage induction generators can be connected to an AC grid directly and can be operated as fixed speed. Double fed induction generators has the ability to adjust the rotor speed in more wide ranges depending on the size of power electronic converters. Wound-rotor induction generators can also be connected to AC grid directly by using external resistors connected to rotor circuit. It is possible to control and adjust the rotor slip by changing the actual value of these serial resistors. On the other hand, wound-rotor induction machines (WRIM) can be used not only as a generator in wind energy systems, but also as a motor in several industrial systems. WRIMs offer a number of advantages over other types of induction machines, most notably the ability to produce high starting torques at lower starting currents. Large size WRIMs are also easier to assemble than comparatively sized squirrel-cage induction machines. Due to these advantages, WRIMs are commonly used in industry for any application requiring a large rotating machine. In such cases, the ability to produce a high starting torque with a reasonable starting current is crucial [8].

In order to provide an efficient solution for above requirements, this study presents a novel control system for WRIMs using up-to-date hardware and software technologies. The presented control system is more economic and more sensitive as compared with the traditional ones. The system is also integrated with a computer control tool in order to observe and to control the parameters of the WRIM in real time.

II. EXPERIMENTAL STUDY

Since this study aimed to develop an effective real time speed control system for WRIMs, several hardware and software units have been used during the research and development stage. These units can be outlined as following:

- TMS320F2812 socketed eZdSP System kit
- 2MBI100U4A-120 IGBTs
- IGBT drivers
- MAX 3232 interface circuit
- Relay circuits
- Variable external resistors for WRIM
- Zero crossing detector
- MATLAB/Simulink software
- TI C2000 Code Composer Studio v3.1.0
- Visual Studio platform for GUI design

In order to obtain the best control schema, several simulations under several configurations have been studied during the development stage. Finally, the best performance has been achieved from the model given in Fig 1. Simulation result of this model is illustrated in Fig 2. As seen on this figure, the system reaches to steady-state condition in 0.4 seconds which is considerably adequate for the WRIM.

Once the persuasive results has been obtained from the simulations, the system is installed in a laboratory in real time conditions. Fig 3 depicts the whole system located in the R&D laboratory. The hardware units in Fig 3 and their functions in the experimental set is as following:

- MAX 3232 Circuit: Enables the RS232 connection between PC and DSP.
- Relay circuit: Controls the contactor using GPIO signal of DSP
- Contactor: Connects the WRIM to the grid.
- IGBT Driver: Drives the IGBT
- IGBT: According to switching signals, changes the actual value of external resistor connected to the rotor side of WRIM.
- Three-phase rectifier: Converts the output AC signal of rotor to DC signal
- Zero crossing detector: Produces a square wave signal, of which frequency is equal to the frequency of actual rotor voltage.
- Filter circuits: Filters the output voltage and current of rectifier output.
- Variable resistor (0-120 ohm): Since its actual value changes continuously according to switching signals of IGBT, it fixes the rotor speed to the reference.
- Resistor connected serial to IGBT (10 ohm): Prevents IGBT from short-circuits during switching periods and also limits the maximum value of rotor speed.
- 3 phase wound rotor induction machine (WRIM): Technical parameters of the WRIM used in this study are given in Table 1.

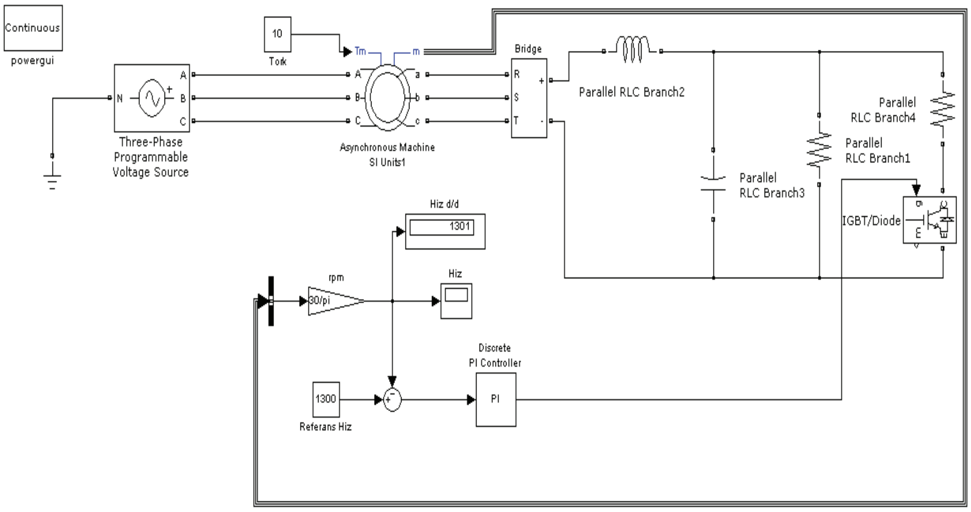


Fig. 1. Simulation model of the system

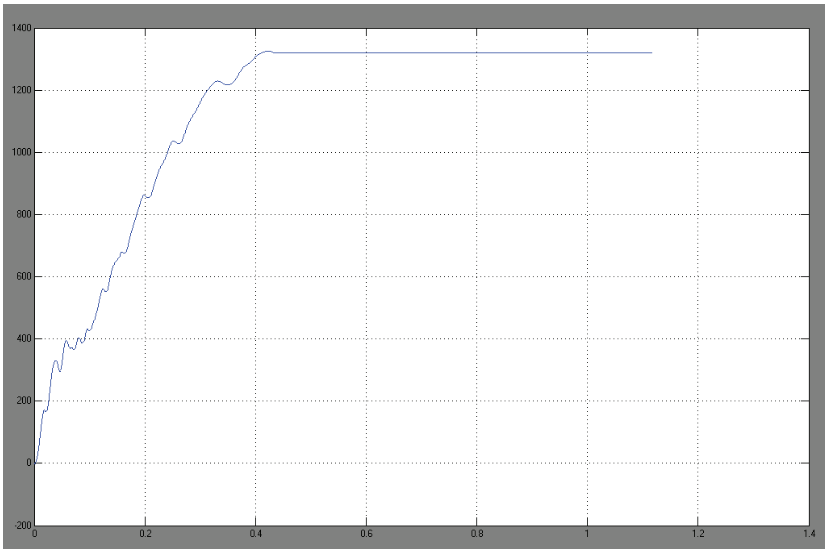


Fig. 2. Simulation result of the speed control schema

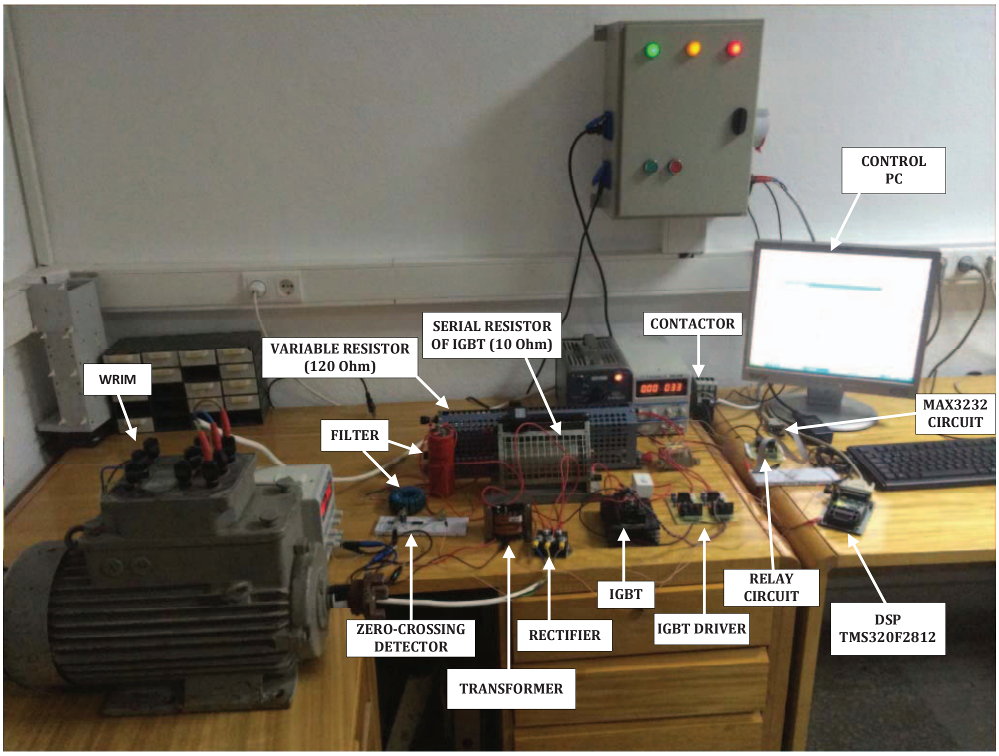


Fig. 3. Experimental set achieved

In the study, actual rotor speed is measured by a zero crossing detector instead of using mechanical encoders. Thus, measurement accuracy is increased and the total cost is decreased as well. As well-known, zero-crossing detectors generates a square-wave signal on its output and the frequency of this square-wave signal is equal to the frequency of input signal. In this study, input of the zero-crossing detector measures the frequency of rotor voltage and the detector generates a square wave signal at the output according to input. Fig 4 illustrates both the input and the output signal waveforms of the zero-crossing detector during real time operation.

Once the rotor frequency is measured by zero-crossing detector, the actual rotor speed is calculated using Eq. 1, where n_r is the actual rotor speed, f_s is the stator frequency, f_r is the rotor frequency and P is the pole number of WRIM.

$$n_r = \frac{120.(f_s - f_r)}{P} \tag{1}$$

After calculating the rotor speed, the controller (DSP) compares the actual speed with the reference speed using a PI process and then sets the switching frequency of IGBT according to error signal. In order to decide the optimum PI parameters, Ziegler-Nichols methodology is used in this study and K_p is determined as ***0,47*** and K_i is determined as ***3,59***.

TABLE I. PARAMETERS OF THE WRIM

PARAMETER	***VALUE***
Power	1,5 kW
Voltage	Δ/Y 220 /380 V
Nominal Current	Δ/Y 7.8/4.5 A
Frequency	50 Hz
Pole number	4
Power factor (Cos φ)	0,73
Nominal speed	1365 rpm

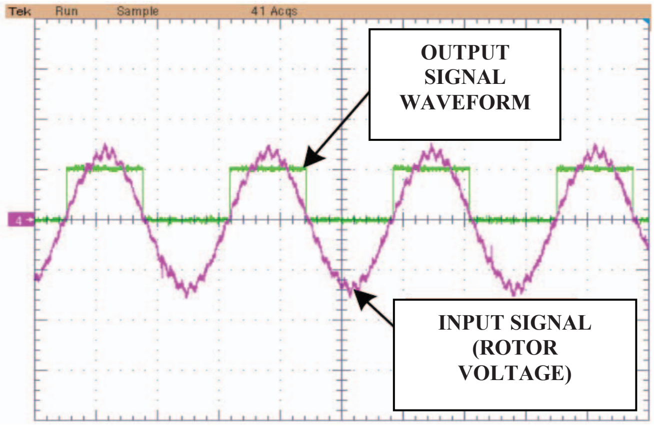


Fig. 4. Input and output signal waveforms of the zero-crossing detector

III. EXPERIMENTAL RESULTS

This study presents not only a powerful speed control system for WRIM, but also a user-friendly and functional GUI to perform the control operation with simple and easy mouse actions and to observe the operational parameters in real time. For this purpose, a Windows Form Application is designed using Visual C# language in .NET platform. Most parameters of the experimental set can be monitored in real time on this GUI screen such as actual rotor speed, rotor frequency, switching ratio of IGBT, and actual value of the resistor connected serial to the rotor. By using this GUI, users can control the speed of WRIM in the limits of 1240-1340 rpm. These limits can be expanded by using higher power IGBTs and other hardware units like serial resistor.

In Fig 5 and Fig 6, two sample experimental result are illustrated which have been captured to show the appearance of the GUI during real time operation. As seen on these figures, the reference speed has been set to 1290 rpm in Fig 5 and to 1315 rpm in Fig 6. The sections on the GUI are as following:

A : The set for reference speed

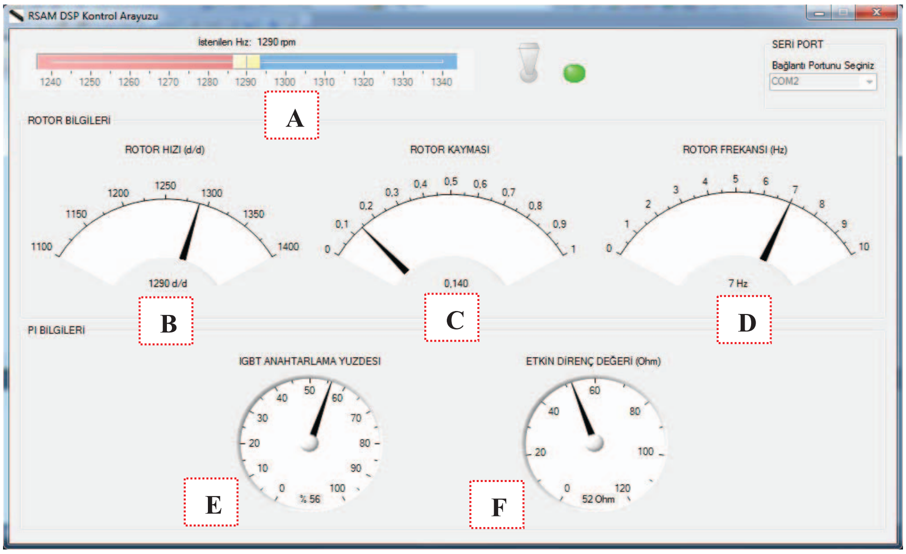
B: Actual rotor speed

C: Slip

D: Actual rotor frequency

E: IGBT Switching ratio

F: Actual value of serial resistor


İstenilen Hız: 1290 rpm

Bağlantı Portunu Seçiniz: COM2

ROTOR HIZI (d/d): 1290 d/d

ROTOR KAYMASI: 0,140

ROTOR FREKANSI (Hz): 7 Hz

IGBT ANAHTARLAMA YUZDESI: % 56

ETKİN DİRENÇ DEĞERİ (Ohm): 52 Ohm

Fig. 5. Sample screenshot of the GUI for 1290 rpm


RSAM DSP Kontrol Arayuzu

İstenilen Hız: 1315 rpm

SERI PORT

Bağlantı Portunu Seçiniz: COM2

Fig. 6. Sample screenshot of the GUI for 1315 rpm

IV. CONCLUSION

A novel speed control system for wound-rotor induction machines (WRIM) is presented in this study. Furthermore, a visual and easy to use GUI is designed to control the WRIM through the computer screen and to observe the parameters graphically in real time.

Thanks to using a zero crossing detector at the output of rotor circuit, the actual rotor speed is measured digitally. Thus, measurement accuracy is improved and the total cost is decreased without using an external encoder. In order to verify the experimental results, the rotor speed has been also measured with a digital tachometer and this measured value has been compared with the actual value seen on the GUI. According to this comparison, it has been observed that the system operates under considerably accurate ratio which is about 99.77%. In addition, the mechanical encoders can wear out over time, however, there is not such a disadvantage in the system presented in this study. The zero-crossing detector has another great advantage as compared its size with the size of any mechanical sensor and it can be easily integrated to the existing WRIM based systems in current industrial plants.

The performance of the system presented in this study has been tested both in simulation environment and in laboratory conditions as the real time study and results show that the developed speed control method operates as more stable with high accuracy and has more speed response time compared with the conventional methods. Therefore, the presented study can be used in several industrial applications as a sensitive and economic solution for speed control of WRIMs. Furthermore, it can be used in electrical engineering courses as a supplementary tool for electrical machines education.

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