

A Web-Based Educational Tool For Simulation of Reactive Power Compensation With Synchronous Motor

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ABSTRACT

In this study, reactive power demand of the load or the load groups has been provided with a synchronous motor through a web interface as user controlled. For the realization of reactive power compensation and monitoring the system via Internet, a data acquisition card (DAQ) has been used which has superior properties compared to other controllers such as PLC and PIC. In this study, adding inductive and resistive load to the network, three-phase voltage and three-phase current values are taken from the network and the power factor value of the system can be monitored via a visual web interface. Active, reactive and apparent power value can be observed in real time via the interface. A new approach for computer-controlled and monitored reactive power compensation systems through the internet that is uncommon in the literature is presented with this experimental system.

Key Words : Synchronous Motor, Reactive Power Compensation, Data Acquisition Card.

1. INTRODUCTION

In recent years, the developments in the field of education have focused around distance learning in parallel with the technological developments. Place limitations of educational institutions, population explosion, and increasing need of the society to have education without attending any educational institution constitute only a few of the reasons why the concept of distance learning has developed. Not only educational institutions but also companies prefer distance learning in personnel education for economic reasons and to prevent time loss. In the institutions providing technical and engineering education, laboratory studies support theoretical studies of students as well as development of practical skills by them. When the laboratory infrastructure and the number of experimental equipment are compared to the number of students, generally significant problems arise in application. Today, education system is going through a re-shaping process. Combination of educational technologies and internet has enabled rapid development of web-based educational systems in addition to face-to-face education model [1-5].

In the past, one-type traditional education model was applied due to lack of technological infrastructure. Some literature studies on the use of modern technologies in this scope are summarized below:

With the development of semiconductor technology, compensation processes are performed using switching elements which have relatively higher speed than the classical systems. Gelen et al. researched and compared in both simulation and experimental environment the voltage, current and power flow of the energy

transmission systems in static and dynamic load by using two FACTS elements of Thyristor-Controlled Reactor (TCR) and Static VAR Compensator (SVC). Compensation process was compared using PI controller in the simulation environment and fuzzy logic control method was found to work in a more efficient and stable manner [6].

In the study realized by Cötelı et al., MATLAB-SIMULINK Toolbox was used to consist a computer-based simulation of STATCOM (Static Synchronous Compensator), a converter-based FACTS device, to control power flow of a transmission line. Results of the simulation program showed STATCOM to be capable of responding to even unexpected sudden changes in a very rapid manner [7]. Dynamic compensation with synchronous motor is also one of the reactive power compensation types. A more stable operation can be achieved via control of the excitation current by different control algorithms. By using object-based software which can produce Artificial Neural Networks (ANN) model which can run under the control of Reactive Power Compensator (RPC) with synchronous motor, Sesveren developed a simulator to simulate RPC operation which uses ANN structure produced by the software. ANN model, which can be used under the control of RPC with synchronous motor, was prepared and showed how to control a synchronous compensator. Moreover, as well as supporting student education via modern technologies by using the developed software showing applicability of artificial intelligence to different fields, it aimed to introduce a new approach to be adopted in technical and engineering education [8]. The process of compensating reactive power, needed by load or load groups, by using specific techniques is called reactive power compensation. These techniques have both advantages and disadvantages compared to each other. Selection of

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the most appropriate technique enables stable system operation and increases system efficiency. In his thesis study, Bilki examined compensation techniques and realized PLC-controlled reactive power application in a facility [9]. Using capacitor groups, Bilki [9] has performed a computer-controlled reactive power compensation experimental set application. PLC was used in the monitoring and controlling of the system by computer. Use of PLC in the reactive power control in the scope of the study enabled monitoring of such important circuit parameters as voltage, current, active power and power factor. The user can follow these values from the computer interface and take on load to the system [10]. Since the system runs as computer-controlled, the user is limited to the space. In their study, Bayındır and Gorgun performed a compensator application using a synchronous motor. A PIC18F452 micro controller was used to perform PI control of the synchronous motor and the motor was run in inductive, capacitive and ohmic modes at different excitation currents. The user could view from the LCD display the instantaneous system values of current, voltage, frequency and power factors [11].

Energy crises the world has faced in recent years has directed researchers to new energy resources on one hand and has focused the studies on designing of more efficient systems and utilization of existing energy resources in the most efficient and highest-quality way on the other hand. One of the most effective measures to improve efficiency and ensure energy saving is “Reactive Power Compensation”. Different methods are used in reactive power compensation. In these methods, the reactive powers required by loads are compensated either statically by capacitors and reactors through different switching element) or dynamically by synchronous motors [12-14].

In the method where a synchronous motor is used for compensation, excitation current is changed to enable drawn of active and reactive power from the network. In the present study, the user connects to the system through the internet using the web interface and creates inductive effect on the system by including inductive load or load groups to the network the system is connected to. Since this is an unsolicited status, the system enables approximation of power factor to 1 by automatically applying capacitive load to the system via synchronous motor.

2. USE OF SYNCHRONOUS MOTOR AS A COMPENSATOR

In grids, the loads are generally inductive. Because the induction motors, transformers, ballast bulbs, etc. connected to the network are all inductive loads. Since inductive loads are decreased actual power capacities of alternators, they result in drastic voltage drops in transmission lines, in turn, efficiency loss. Moreover, as reactive energies drawn by the inductive loads used in industry overload energy transmission lines, it becomes

necessary to increase the conductor size of the energy transmission line in order to increase the amount of active energy drawn from the line. Reactive energies the loads require can be compensated either by capacitors statically or by synchronous motors dynamically.

Change in the excitation currents of synchronous motors enables capacitive and inductive running mode of the motor. Moreover, the amount of the reactive power drawn by the synchronous motor from the network can be adjusted by excitation current. Thanks to such positive features, synchronous motors are used as dynamic power compensators.

Vector diagrams of the synchronous motor connected to energy transmission line and the load are presented in Fig. 1. If the active power of the system is P_{total} , then it is equal to the sum of P_1 and P_2 , which are, respectively, the active power of the synchronous motor and active power of the load. When the power of the synchronous motor is sufficient, it is possible to zero the system's reactive power by increasing excitation current [17].

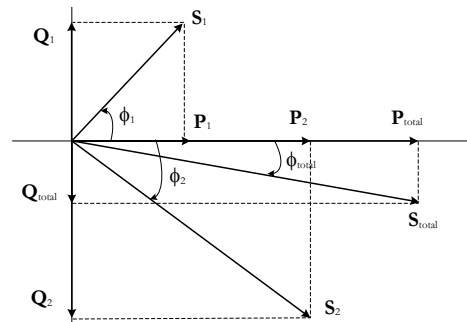


Fig. 1. Vector diagrams of the synchronous motor connected to energy transmission line and the load

Changing of excitation current characteristic of the synchronous motor at stable source voltage and frequency is explained by the V-curves presented in Fig. 2. These curves are obtained from the phasor diagram of the synchronous machine. In unloaded condition, the excitation current I_f is adjusted to run the machine at unit power factor ($\cos=1.0$). In this case, stator current I_s is at minimum. Input power factor of the synchronous machine can be adjusted lagging/leading by decreasing/increasing excitation current. Change in the I_s current (referring to the excitation current) is recorded in the form of V-curves. Synchronous motor V-curves at full and half loads are shown in Figure 2-2 [17].

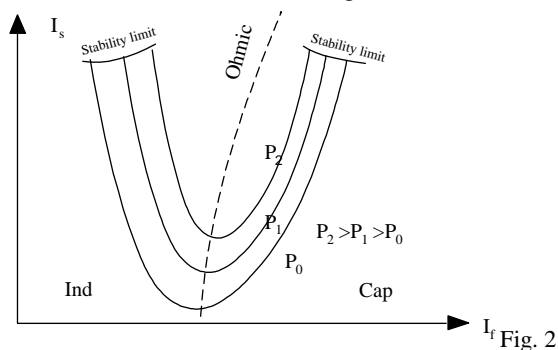


Fig.2. Synchronous motor V-curves

3. SYSTEM ARCHITECTURE

The developed system has an integrated structure composed of a combination of different software and hardware units. Although each hardware and software unit has different tasks, all hardware operates in harmony.

3.1. Hardware Infrastructure

Fig. 3 shows the block diagram of the system composed of current and voltage measurement card, PIC, data acquisition card, zero-crossing circuit, DC source, IGBT circuit, loads and synchronous motor. In this study, a synchronous motor at 4kW power was used for reactive power compensation. Capacitive effect of the synchronous motor enables stabilizing the system's power factor at 0.98

Display on the user web interface of the operating voltage of the load or loads connected to the system and of the current values they draw from the network requires sensing of the voltage and current values. Since the

analogue voltage measurement level of the data acquisition card is maximum +5.0 V, the amplitude of the resulting alternating voltages needs to be reduced. Fig.4 presents the application circuit designed to reduce the amplitude of the current and voltage values.

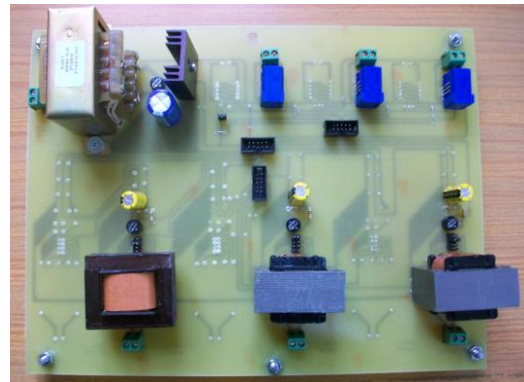


Fig.4. Current - voltage sensing and transformation circuit

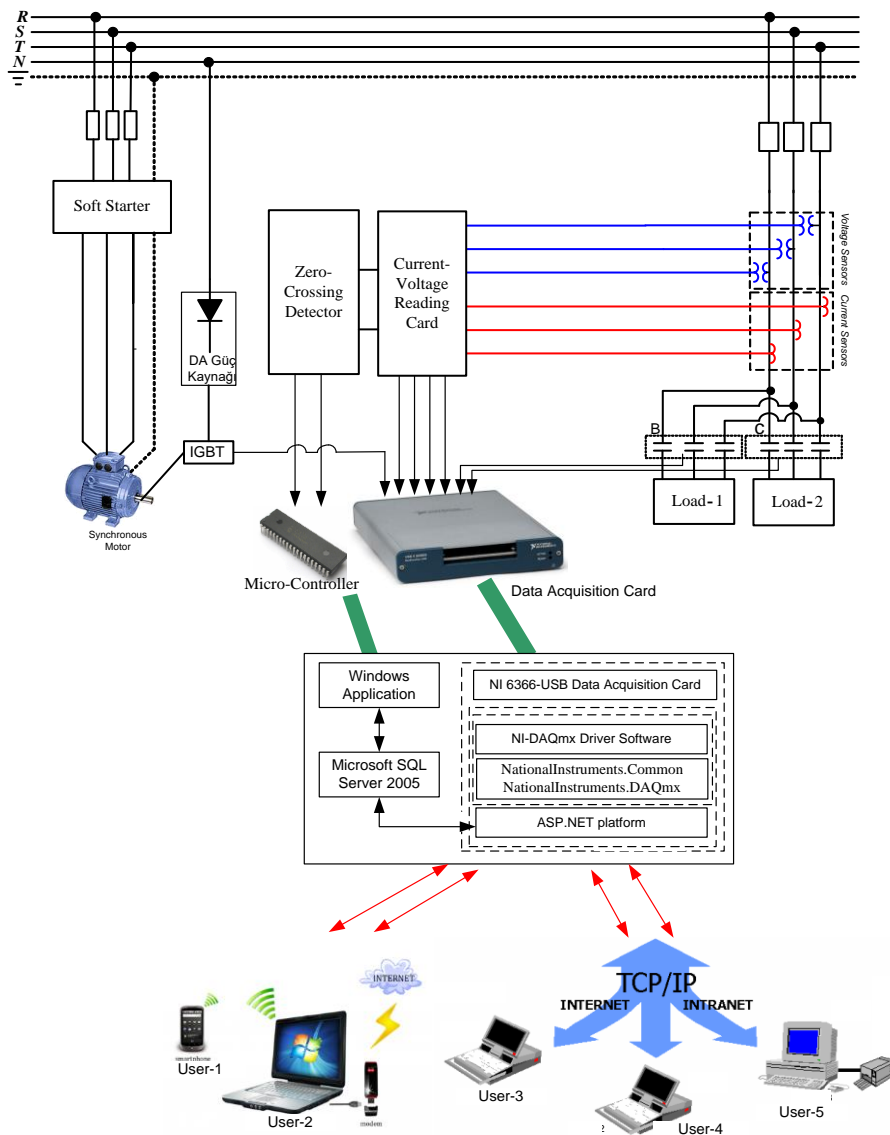


Fig. 3. Block diagram of system

Voltage transformers were used for each phase in obtaining alternating voltages. Cas-R 25 NP current sensors were used to measure the current amount drawn by the system from the network at each phase. When maximum 25A current flows through current sensor's primary circuit, 5V DC voltage is produced as output. The sensor also produces the output signal for the current zero-passing circuit in the form of AC signal.

Zero-crossing circuit was used while measuring power factor of the system. Power factor was produced using PIC microcontroller to calculate the square wave signals produced by this circuit. Circuit diagram of the zero-crossing detector designed in this scope is shown in Fig. 5.

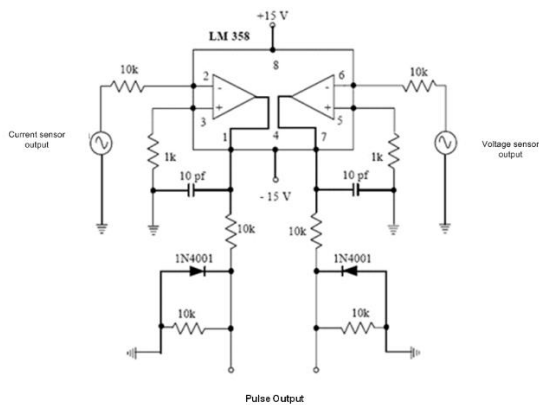


Fig.5. Zero-crossing detector

Signals applied to the input and signals obtained from the outlet of the zero-crossing detector are listed in Fig.6a and Fig.6b, respectively. Time difference between the positive tips of the voltage and current signals transformed into square wave is sensed by PIC and power factor value is obtained in such way that each second corresponds to 18 degrees.

Synchronous motor is started in the induction mode for the first start. Soft start method was adopted to run the synchronous motor in the induction motor mode.

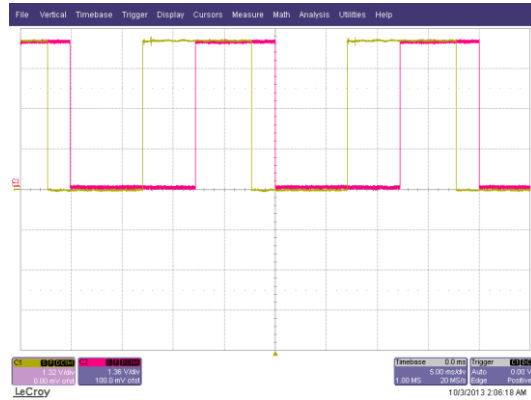
Switching frequency applied to IGBT drive circuit for adjustable direct voltage to be supplied to the excitation winding of the synchronous motor is shown in Fig.7. Switching frequency was set at 5 kHz.

3.2. Software Infrastructure

Computerization of system data, data monitoring and system control was performed using NI-6366 USB DAQ (Data acquisition Card) card produced by the National Instrument Co. This card connects with the computer through USB port. Fig.8 illustrates the block diagram of the structure to be used in processing data acquisition card through the interface.

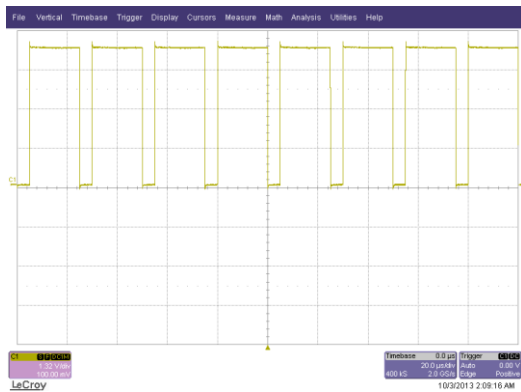


a) Current-voltage signal



b) Current-voltage zero-crossing signal

Fig.6. Output signal of the zero-passing detector



(a) Switching signal at 70% duty cycle



(b) Switching signal at 5% duty cycle

Fig.7. Switching signals at different duty cycles

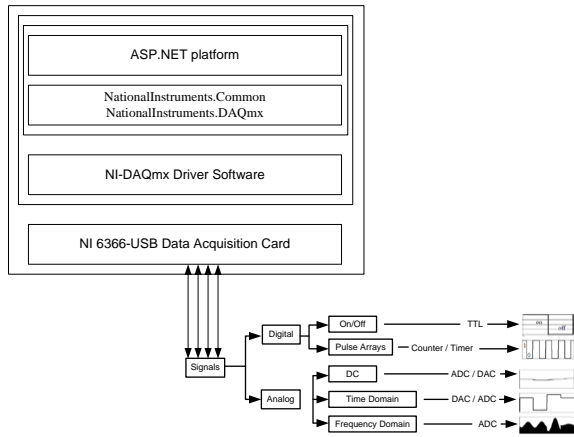


Fig. 8. Block diagram of data acquisition

User web interface was developed in Visual Studio ASP.NET platform. This platform was preferred thanks to its features such as performing driver applications, database management and communication with external equipment, which are impossible to be achieved by HTML codes. Moreover, in addition to its developed software infrastructure, it provides functionality to the web interface thanks to its visual components. Since the data acquisition card cannot process in the internal memory, system's power factor parameter is retrieved by the developed web application from the microcontroller through USB port and is stored in the database in the computer. Microsoft SQL Server 2005 database software was preferred as the study database.

4. EXPERIMENTAL STUDY

A general e-learning platform was developed to serve control and monitoring works over internet. As can be seen in Fig.9, this platform is composed of 2 main parts:

window display part and active part. Window display part is composed of theoretical expression pages which give information on subject and which are open to any user. The second part, active part, provides the application area. System control and monitoring processes are performed in this part.

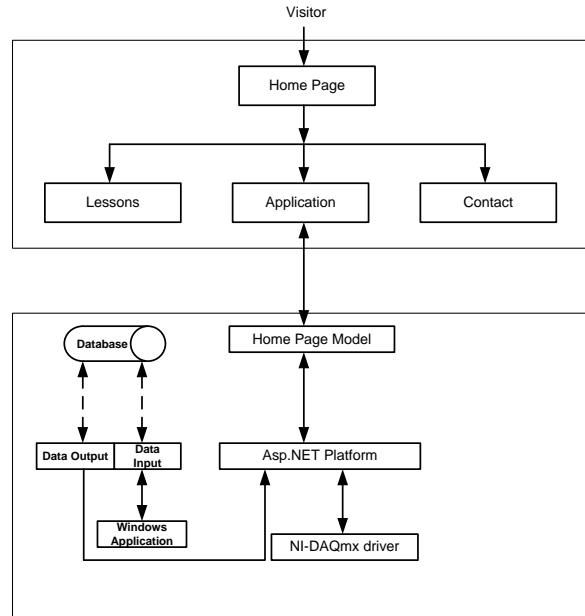


Fig. 9. Block diagram of the designed e-learning platform

Homepage of the web interface developed to enable system monitoring and control by users is shown in Fig.10. User web interface presents the purpose and importance of the thesis and block diagram of the study.

Application part of the study can be accessed by clicking the "Application" tab. The user can monitor and control the system on this page. This part is given in Fig.11.

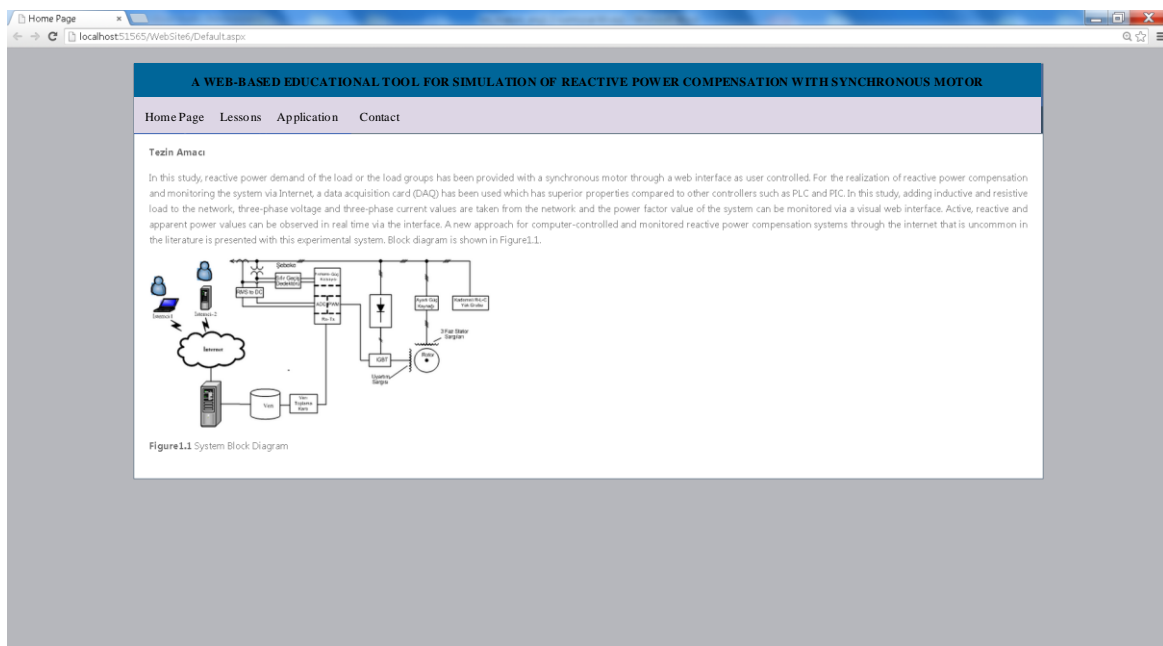


Fig.10. Homepage display

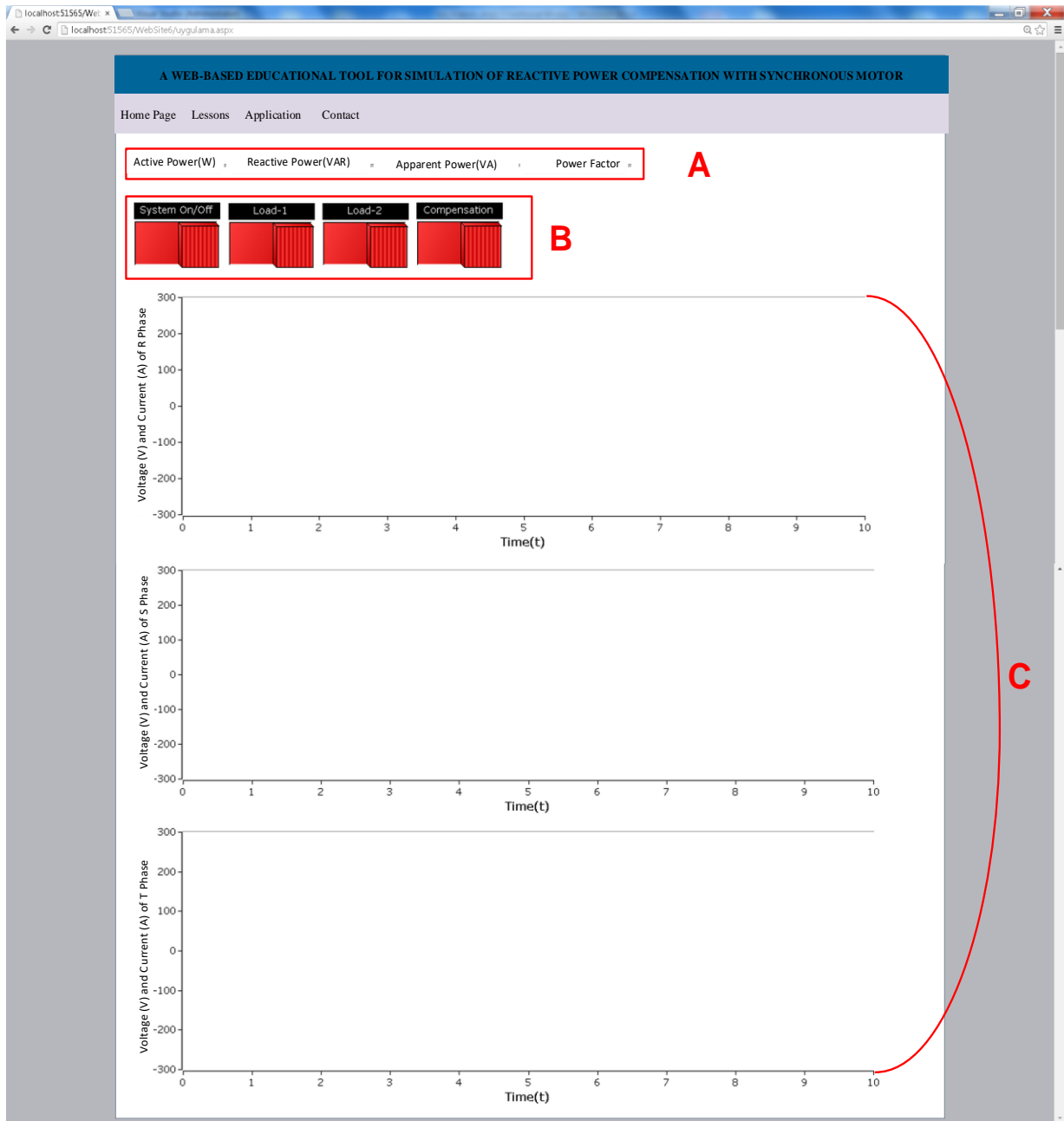


Fig.11. Picture of main webpage

A: Load management panel

This panel enables system On/Off and selection of the load or loads to be activated. By clicking System On/Off button, connection is ensured for system monitoring and control and load activation is enabled. In addition, when the system is activated, the synchronous motor runs parallel to the load run in the asynchronous mode.

B: Power monitoring panel

A part in this panel enables visual monitoring of the active, reactive and apparent power parameters belonging to the load or loads.

C: Graphic Window

Numerical system parameters are presented in graphics in this part. Graphics of current and voltage values are drawn for each phase separately in the interface.

Flow diagram ensuring stable operation of the software designed for the hardware is given in Fig.12. As can be concluded from the flow diagram, system's power factor was stabilized at 0.98, as specified in the standards.

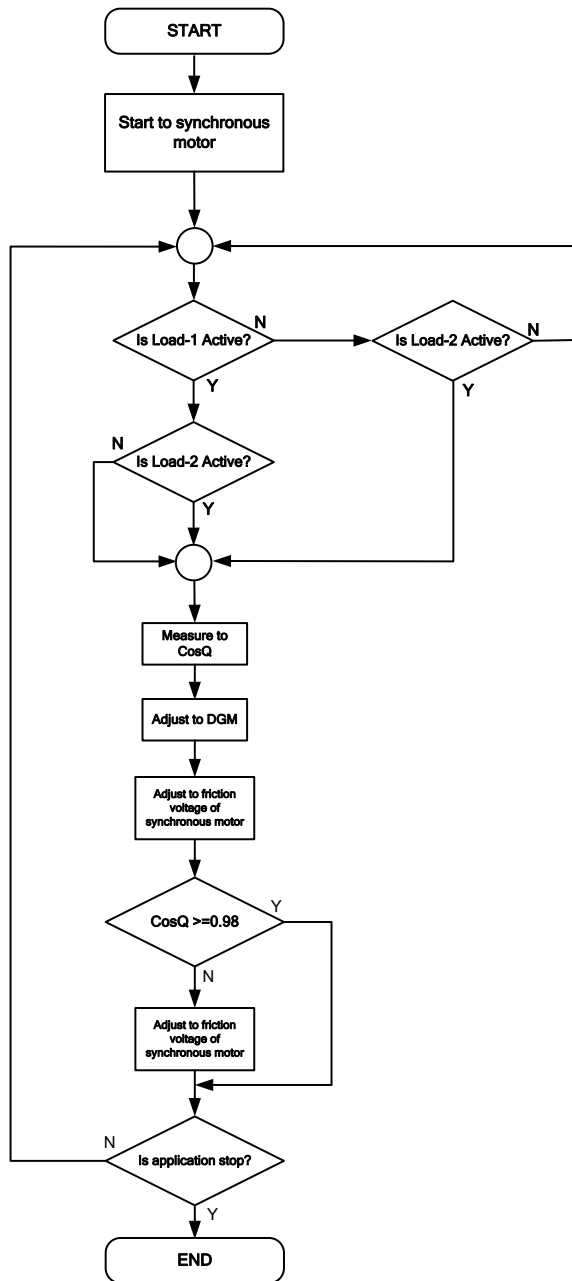


Fig.12. System operation algorithm

General view of the web-based educational tool for simulation of reactive power compensation with synchronous motor, which is designed and applied in the scope of the study, is shown in Fig.13.

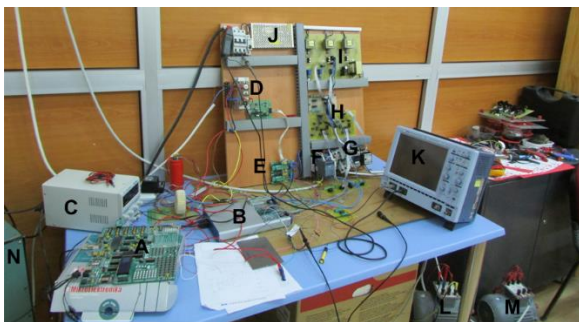


Fig. 13. Experimental Kit

When the first load is switch on; total active, reactive and apparent power and power factor parameters are calculated and displayed numerically in the user web interface as shown in Fig.14. and also the values obtained from the measurement device and illustrated in Fig.15 are observed to be nearly equal. Numerical values displayed in the interface shown in Fig.14a. Fig.14b shows web interface display developed when the user starts the system over internet by clicking "System on/off" button and switch on the first load.

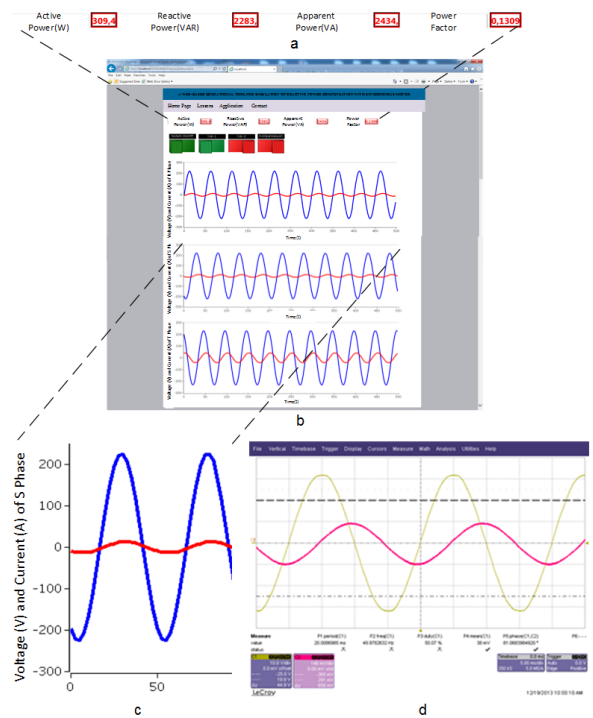


Fig.14. Interface and oscilloscope screenshot when the Load-1 is switch on

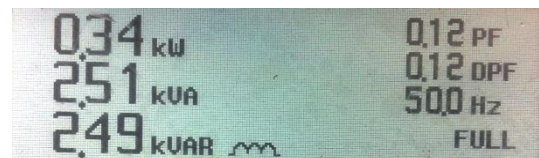


Fig. 15. System parameters and measurement device display when the Load-1 is switch on

When the user wants to perform compensation process when the first load is switch on and clicks the "Compensation" button in the web interface, application of DGM to the excitation windings of the synchronous motor at 52% duty cycle enables approximation of the power factor value (between the current and voltage) to 1, as in Fig.16a. After compensation, the power factor value increased from 0.1309 to 0.98, as in Fig.16a. Reactive power component, on the other hand, decreased from 2283 VAR to 55.89 VAR. Thus, at the end of the compensation process performed when the Load-1 was switched on, power factor value required by the compensation was achieved. Interface values shown in Fig.16a and the measurement device values presented in Fig.17 are observed to be nearly equal.

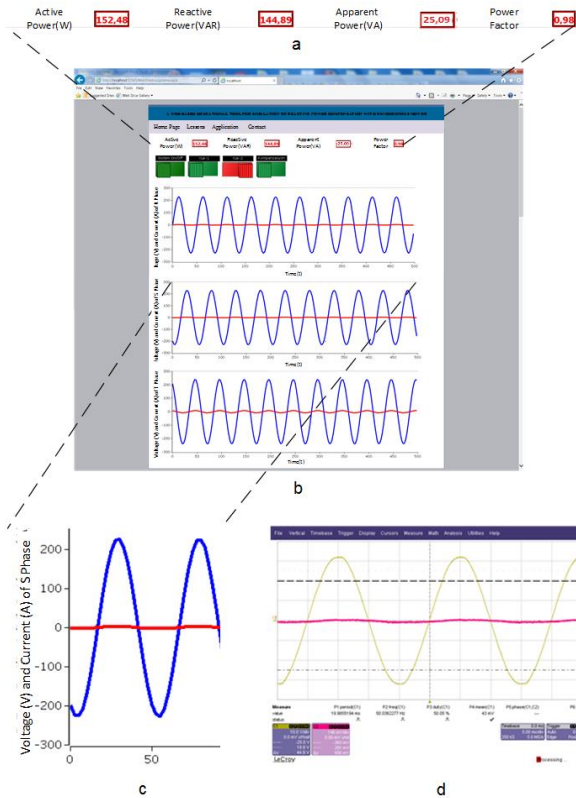


Fig.16. After compensation interface screenshot when the Load-1 is switch on

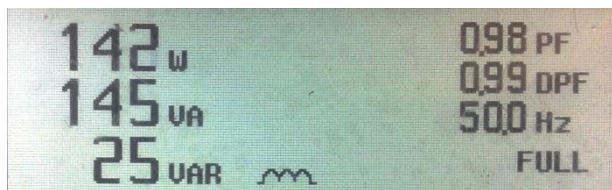


Fig. 17. After compensation measurement device display when the Load-1 is switch on

Comparison of the pre- and post-compensation oscilloscope displays of the current and voltage signals when the Load-1 is run (Figure 5.2-d and Figure 5.5-d) and the interface display shows that these signals are similar.

During analyses of the user web interface and oscilloscope images, real-time power factor parameter measurements were made as loads were run in the system during compensation by the user. By this way, current and voltage signals were kept at the same phase. After the changes made by the user in the interface were applied to the hardware, the change was reflected to the user web interface on real time basis. Pre-compensation system parameters are shown in Table.1. As can be concluded from the table, system parameters change dependent on working of the loads. Since the motors, functioning as load, run in idle mode, power factor values are recorded as seen in the table. Compensation process enables approximation of this value to 1.

When the user wants to perform compensation, reactive power is aimed to be zeroed. Table 2 shows that this value approximates to 0 and the power factor to 1.

4. CONCLUSIONS

With this experimental study, a hardware and software, which is controlled and monitored through computer over internet, has been successfully developed and run for simulation of reactive power compensation with synchronous motor, a study subject hardly studied by the related literature.

During the control phase, changes on the interface were sent to data acquisition card in a fast and appropriate manner to monitor the system response. Possible error cases were monitored on real time basis and required infrastructure was developed for remote-control trouble shooting. Moreover, only by changing the power of synchronous motor, a general-purpose experimental environment can be developed for any kind of energy-consuming load or load groups to be connected to the system. Use of visual components in the user web interface developed in this scope both makes learning more effective and differentiates this study from the rest. Moreover, distance realization of this application over internet has eliminated the risk of user inattention, measurement mistakes and possible electrical and mechanical negative developments.

Table 1. System parameters (before compensation)

Operation Mode	Active Power (W)	Reactive Power (VAR)	Apparent Power (VA)	Power Factor
Induction motor mode +Load-1	309.4	2283	2434	0.1309
Induction motor mode+ Load-2	318	2378	2535	0.1292
Induction motor mode + Load-1+Load-2	395.4	2788	2955	0.1452

Table 2. System parameters (after compensation)

Operation Mode	Active Power (W)	Reactive Power (VAR)	Apparent Power (VA)	Power Factor
Induction motor mode +Load-1	143.55	55.89	146.45	0.98
Induction motor mode+ Load-2	152.48	144.89	154.45	0.98
Induction motor mode + Load-1 + Load-2	225	60.19	229.45	0.98

Data acquisition tool lacks an internal memory and the capacity to process memory, which necessitated the use of two different controllers in practice. When considered as additional materials for educational, the study seems to have achieved its objectives.

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