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Legal regulation of reactive power compensation in energy efficiency

Enerji verimliliğinde reaktif güç kompanzasyonunun yasal düzenlemesi

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Legal Regulation of Reactive Power Compensation in Energy Efficiency

Highlights

- *In this study, a flexible system with a fast response was designed and the power coefficient was over 97%.*
- *A hybrid system has been preferred and designed to achieve a continuous and effective power factor corrector system.*

Graphical Abstract

In this study, a real energy system is considered. This system has been studied in three stages and its results are emphasized. Firstly, the design and application of a computer and microcontroller based compensation system in the laboratory environment have been realized. In the second step, a software was developed with the C # programming language to be able to control the system centrally and store the data in the desired format. The results of the performed applications are found in different load conditions experimentally and in a simulation program then they are analyzed and compared.

Aim

In this study, in order to reduce the reactive energy consumption, it was aimed to design a flexible power factor corrector system with fast response. In the system, 97% of the power factor is continuously studied. According to the results of the study, a legal regulation request was made.

Design & Methodology

The system was simulated primarily without going into system implementation. Necessary capacities have been determined thanks to the simulation. After the results were obtained from the simulation, the application was made.

Originality

In this study, a hybrid system with rapid response and high power factor that can provide continuous operation has been developed. The need to use such systems and legal support is emphasized.

Findings

In our world where energy is gradually decreasing, measures to increase efficiency must be taken. This should sometimes be achieved by law. Reactive power consumption can be prevented by laws. We now have technologies to prevent reactive power consumption.

Conclusion

As a result of the work done, the power coefficient can be approached to 1 even in large capacity systems. Serious energy savings can be made here. In order to achieve this, it is necessary to use hybrid systems, not just static compensations. It is seen that the biggest problem, insufficient static compensation, can be overcome by suitable synchronous motor control. The success of the application shows that more radical changes can be made about the power coefficient. With the legislative amendment to be made, energy savings will be very large in the whole country.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Legal Regulation of Reactive Power Compensation in Energy Efficiency

Araştırma Makalesi / Research Article

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ABSTRACT

Electrical energy is one of the most important issues in the world. Electricity generation is a problem for many countries. In many countries in the energy field is also dependent on the outside. In some countries, such as Turkey's foreign dependency with loss and leakage it is also high. This is a problem that needs to be overcome. This makes it mandatory not only to investigate new energy sources but also to use electrical energy more efficiently. One of the most effective methods reducing the losses and increasing the efficiency of the electric energy systems is Reactive Power Compensation. Countries are working to improve efficiency, by publishing law or communique on reactive power compensation. In many countries, power is being tried to be kept between 85% and 95% using law enforcement. From a technological point of view, the power factor can be approached to 1. By increasing the power factor from 90% to 97% all over the world, a very large energy source will be obtained. In this study, a flexible system with a fast response was designed and the power coefficient was over 97%. According to the results of this study, legal regulation was requested.

Keywords: Hybrid power systems, reactive power control, power quality, power system economics.

Enerji Verimliliğinde Reaktif Güç Kompanzasyonunun Yasal Düzenlemesi

ÖZ

Elektrik üretimi, birçok ülke için bir sorundur. Elektrik üretimi birçok ülke için bir problemdir. Hatta birçok ülke enerji alanında dışa bağımlıdır. Birçok ülkede, Türkiye de dahil olmak üzere, az kaynak olmasına rağmen, yüksek kayıp ve kaçaklar vardır. Bu, üstesinden gelinmesi gereken bir problemdir. Bu, yalnızca yeni enerji kaynaklarını araştırmakla kalmayıp aynı zamanda elektrik enerjisini daha verimli kullanmak için de zorunlu hale getirmektedir. Elektrik enerjisi sistemlerinin kayıplarını azaltmak ve verimliliğini artırmak için kullanılan en etkili yöntemlerden biri Reaktif Güç Kompanzasyonu'dur. Ülkeler kanunlarına reaktif güç kompanzasyonu ile ilgili maddeler ekleyerek verimliliği artırmaya çalışmaktadır. Bir çok ülkede kanun gücü kullanılarak güç katsayısı %85 ile %95 arasında tutulmaya çalışılmaktadır. Gelişen teknoloji ile bu rakam %100' yaklaştırılabilir. Tüm dünyada ortalama %95 ten %97'ye yükseltme yapıldığı varsayılsa çok büyük bir enerji kaynağı elde edilmiş olacaktır. Bu çalışmada hızlı tepkili esnek bir sistem tasarlanarak, güç katsayısında %97 üzeri çalışılabilirlik durumu incelenmiştir. Bu çalışma sonucuna göre de kanuni düzenleme talebinde bulunulmuştur.

Anahtar Kelimeler: Hibrit güç sistemleri, reaktif güç kontrolü, güç kalitesi, güç sistem ekonomisi.

1. INTRODUCTION

Depending on today's population growth, industrialization and technological developments, the need for the electrical energy is constantly increasing. The sources for generating electric energy are limited. This makes it mandatory not only to investigate new energy sources but also to use electrical energy more efficiently.

One of the most effective methods to reduce the losses and increase the efficiency in electrical energy systems is "Reactive Power Compensation" [1-4]. When the literature surveys, different implementations of reactive power compensation works are performed. Miller performed the reactive power compensation with a capacitor by switching various capacitors or capacitor groups gradually [5]. Microcontroller-based reactive power relay design has made in different application [6 - 10]. Tiwari et al designed an automatic power factor corrector for a system and simulated this design by using a simulation program [11]. Rustemli measured the power factor by using a microcontroller and performed the implementation of compensation by using a capacitor and the simulation [12]. Afridi and Ali designed an automatic power factor corrector for a single-phase system and performed the implementation and the simulation of the compensation system [13, 14]. Kok et al simulated the power factor corrector circuit they designed for a single-phase system with a computer-aided design program [15]. Mienski et al in theirs paper

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a PSCAD model are discussed for the system including supply network, arc furnace as a heavily disturbing load, STATCOM controller, and a special measurement system for power quality assessment. Two STATCOM systems, 12-pulse and 24-pulse, have been compared. [16]. Wang in his paper, the Phillips-Heffron model is established for both single-machine infinite-bus and multi machine power systems installed with a STATCOM. Applications of the model established are demonstrated by an example single-machine infinite-bus power system and an example three-machine power system to investigate the effect of the STATCOM on power system oscillation stability. A simple analysis indicates that the STATCOM DC-voltage regulator contributes negative damping to power-system oscillations, which is confirmed by both eigenvalue computation and nonlinear simulation. [17]. Chun An Cheng and friends papers present and implement a single-stage high-power-factor light-emitting diode (LED) driver with coupled inductors, suitable for streetlight applications. The presented LED driver integrates an interleaved buck-boost power factor correction (PFC) converter with coupled inductors and a half-bridge-type series-resonant converter cascaded with a full-bridge rectifier into a single-stage power conversion circuit [18, 19].

In general, Var generators are classified depending on the technology used in their implementation and the way they are connected to the power system (shunt or series). Rotating and static generators were commonly used to compensate for reactive power. In the last decade, a large number of different static Var generators using power electronic technologies have been proposed and developed. There are two approaches to the realization of power electronics based Var compensators: the one that employs thyristor-switched capacitors and reactors with tap-changing transformers, and the other that uses self-commutated static converters [20].

In this study, a real energy system is considered. This system has been studied in three stages and its results are emphasized. Firstly, the design and application of a computer and microcontroller based compensation system in the laboratory environment have been realized. The developed system is basically a hybrid compensation system. The system is based on the hybrid operation of synchronous motor and static capacitors. As a result of the measurements, the required capacitor groups are automatically activated and compensated with the capacitors. In addition, with the adjustment of the excitation current of the synchronous motor, the more sensitive compensation is made. In other words, for precision and flexibility, if the system does not have the proper power factor with the capacitors in the system, the operation of the system is achieved by controlling the excitation current of the synchronous motor with ANN. By means of the synchronous motor, step values can be obtained which cannot be obtained with static capacitors and the power coefficient is made close to 1. In the second step, a software was developed with the C # programming language to be able to control the system centrally and store the data in the desired format. The values measured from the sample network where the compensation is applied are continuously monitored with a computer interface created via C# software language and recorded in certain periods in a computer environment. The results of the performed applications are found in different load conditions experimentally and in a simulation program then they are analyzed and compared. In the last stage, the system was tried to be put into practice by making the application.

2. DESIGN OF REACTIVE POWER COMPENSATION

The use of renewable energy sources, conventional reactive power control systems have been a troublesome situation. Cos φ terms in a system not only backward, it must be examined in the forward direction [21]. The block diagram of the designed tree phase compensation system is given in Figure 1. Communication of the system with the computer is made through a USB port. For this communication, the microcontroller PIC18F4550 is used.

Current and voltage signals of the system are applied to the microcontroller inputs via current, voltage reading module and zero crossing detectors. Necessary measurements are made by processing these signals by the microcontroller software. The measured values are monitored through the computer interface and by recording these values, the database of the system is formed. Since 3-phase sample system is loaded with balanced loads in the implementation of the compensation in this study, the measurements in all phases are equal. Therefore, performing the measurements in the designed system through tree phase will increase the cost unnecessarily. As a result, obtaining the measurements from a single phase is found to be appropriate.

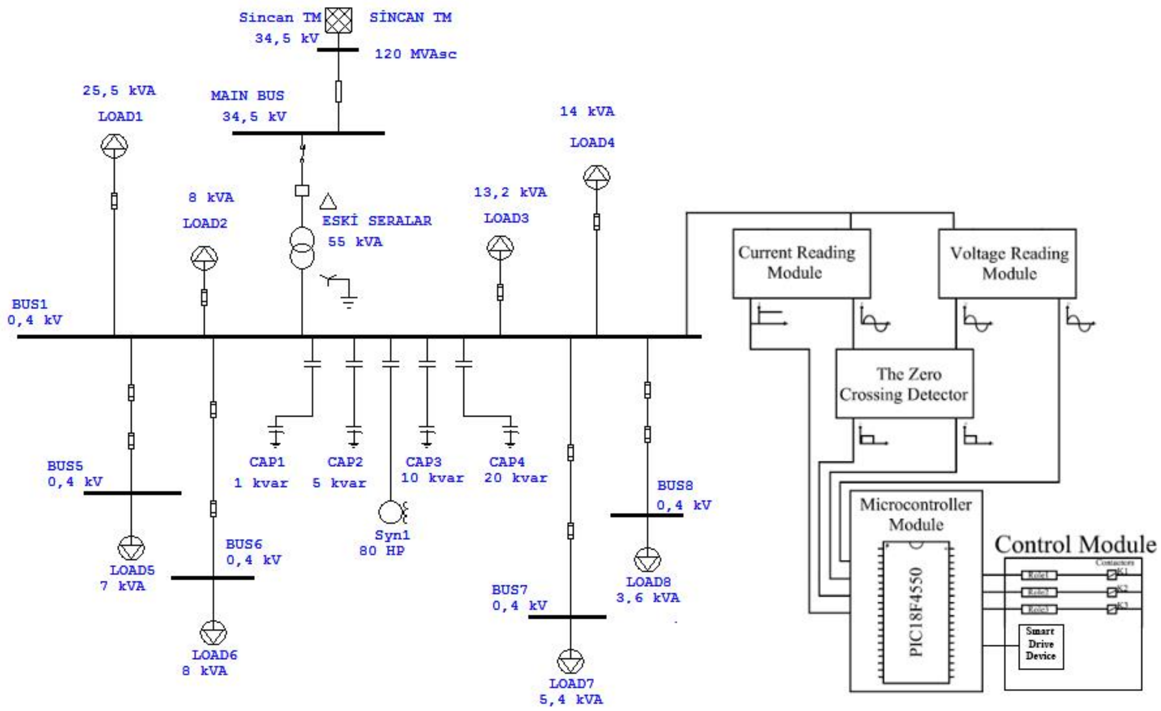


Figure 1. The block diagram of the system

The control module consists of a PWM controlled smart drive and a capacitor control module. The PWM controlled smart drive device provides the excitation current of the synchronous motor. According to the results of measurement against the loads in the circuit, the need for compensation in the system is determined by the control module. If the system needs compensation, the control module determines the method by which the compensation should be performed. The system decides one of three methods: compensation with capacitor or compensation with synchronous motor or compensation with both capacitor and synchronous motor. By selecting the appropriate method, the targeted correct power factor is obtained. The control module is controlled by a microcontroller module regulated by the computer. In addition, phase difference between the voltage and current signals of the system is measured by an oscilloscope.

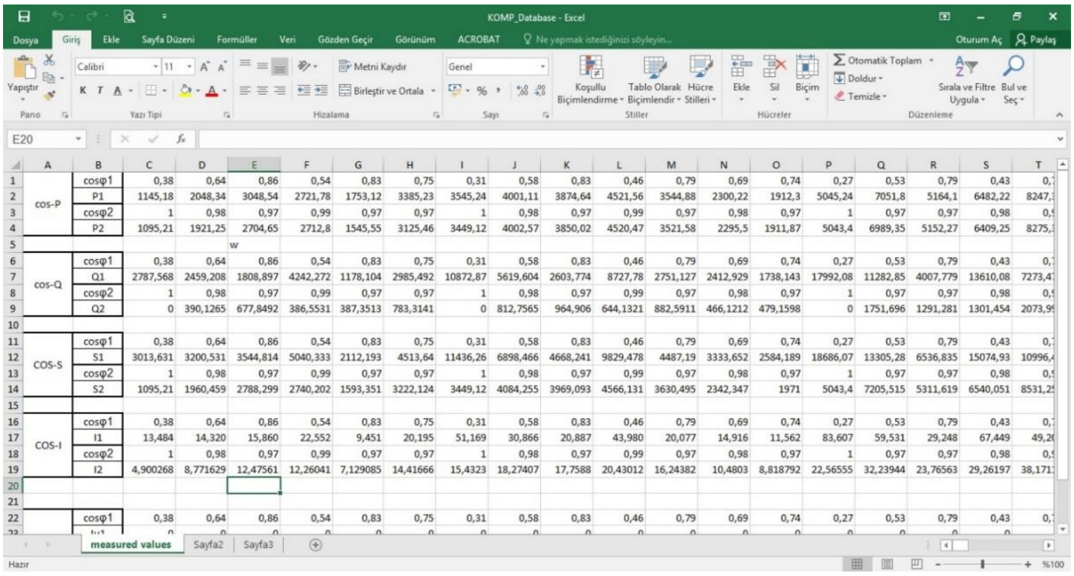
3. MICROCONTROLLER MODULE AND COMPUTER INTERFACE

In order to control the power factor in a system voltage, current, power, frequency, power factor ($Cos\varphi$) must be known. These values can be measured with much different equipment like voltmeter, ammeter, wattmeter, frequency meter and $Cos\varphi$ meter. To perform the measurements with a single device and for the control of the all hardware rolled in the control process of the power factor, a microcontroller module is designed. The average value of this product is the real power P. Taking V_i and I_i as the instantaneous value of input voltage and current varying in time, as well as V_{RMS} and I_{RMS} their rms values, the power factor is obtained with the formula (1).

$$Cos\varphi = \frac{P}{S} = \frac{\frac{1}{T}\int_0^T V_i(t)\times i_i(t)\times dt}{V_{RMS}\times i_{RMS}} \qquad (1)$$

In order to monitor the values of the system measured by the microcontroller, to record into the computer environment and to control the implementation of the compensation with the computer, an interface is made. The microcontroller controls the whole system. The computer interface checks the operations of the microcontroller, makes it viewable and record in the computer environment. Microsoft Office Access 2007 data base management system is used as the database and the $Cos\varphi$ besides current values of the system are recorded in ten-minute intervals. These recorded values are seen in Figure 2.

To communicate the microcontroller with the computer, PIC18F4550 microcontroller, having a USB module is used. In this study, the microcontroller is the brain of the designed system. The flow chart of the program loaded into the microcontroller is shown in Figure 3.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	cos-P	cosφ1	0,38	0,64	0,86	0,54	0,83	0,75	0,31	0,58	0,83	0,46	0,79	0,69	0,74	0,27	0,53	0,79	0,43	0,
2		P1	1145,18	2048,34	3048,54	2721,78	1753,12	3385,23	3545,24	4001,11	3874,64	4521,56	3544,88	2300,22	1912,3	5045,24	7051,8	5164,1	6482,22	8247,
3		cosφ2	1	0,98	0,97	0,99	0,97	0,97	1	0,98	0,97	0,99	0,97	0,98	0,97	1	0,97	0,97	0,98	0,
4		P2	1095,21	1921,25	2704,65	2712,8	1545,55	3125,46	3449,12	4002,57	3850,02	4520,47	3521,58	2295,5	1911,87	5043,4	6989,35	5152,27	6409,25	8275,
5					w															
6	cos-Q	cosφ1	0,38	0,64	0,86	0,54	0,83	0,75	0,31	0,58	0,83	0,46	0,79	0,69	0,74	0,27	0,53	0,79	0,43	0,
7		Q1	2787,568	2459,208	1808,897	4242,272	1178,104	2985,492	10872,87	5619,604	2603,774	8727,78	2751,127	2412,929	1738,143	17992,08	11282,85	4007,779	13610,08	7273,4
8		cosφ2	1	0,98	0,97	0,99	0,97	0,97	1	0,98	0,97	0,99	0,97	0,98	0,97	1	0,97	0,97	0,98	0,
9		Q2	0	390,1265	677,8492	386,5531	387,3513	783,3141	0	812,7565	964,906	644,1321	882,5911	466,1212	479,1598	0	1751,696	1291,281	1301,454	2073,9
10																				
11	COS-S	cosφ1	0,38	0,64	0,86	0,54	0,83	0,75	0,31	0,58	0,83	0,46	0,79	0,69	0,74	0,27	0,53	0,79	0,43	0,
12		S1	3013,631	3200,531	3544,814	5040,333	2112,193	4513,64	11436,26	6898,466	4668,241	9829,478	4487,19	3333,652	2584,189	18686,07	13305,28	6536,835	15074,93	10996,
13		cosφ2	1	0,98	0,97	0,99	0,97	0,97	1	0,98	0,97	0,99	0,97	0,98	0,97	1	0,97	0,97	0,98	0,
14		S2	1095,21	1960,459	2788,299	2740,202	1593,351	3222,124	3449,12	4084,255	3969,093	4566,131	3630,495	2342,347	1971	5043,4	7205,515	5311,619	6540,051	8531,2
15																				
16	COS-I	cosφ1	0,38	0,64	0,86	0,54	0,83	0,75	0,31	0,58	0,83	0,46	0,79	0,69	0,74	0,27	0,53	0,79	0,43	0,
17		I1	13,484	14,320	15,860	22,552	9,451	20,195	51,169	30,866	20,887	43,980	20,077	14,916	11,562	83,607	59,531	29,248	67,449	49,2
18		cosφ2	1	0,98	0,97	0,99	0,97	0,97	1	0,98	0,97	0,99	0,97	0,98	0,97	1	0,97	0,97	0,98	0,
19		I2	4,900268	8,771629	12,47561	12,26041	7,129085	14,41666	15,4323	18,27407	17,7588	20,43012	16,24382	10,4803	8,818792	22,56555	32,23944	23,76563	29,26197	38,171
20																				
21																				
22		cosφ1	0,38	0,64	0,86	0,54	0,83	0,75	0,31	0,58	0,83	0,46	0,79	0,69	0,74	0,27	0,53	0,79	0,43	0,

Figure 2. Recording of the measured values into the database

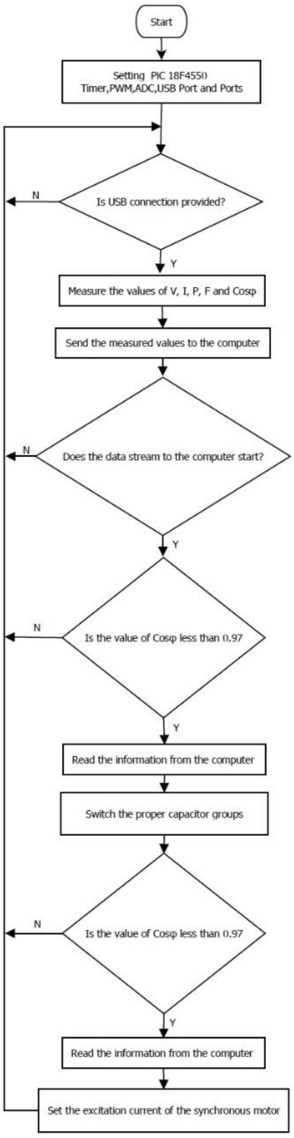


Figure 3. The flowchart of the software.

The interface made in the computer environment is developed by using C# programming language. This interface is given in Figure 4.

The computer interface is accessed manually by the user or automatically. In this study as a priority the system is automatically compensated. The manual control is only used to control the accuracy of the compensation.

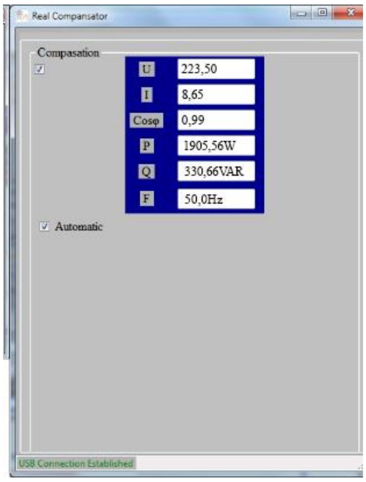


Figure 4. Computer Interface

4. SIMULATION SYSTEM

The simulation of the designed compensation system is made in Proteus software. The simulation is performed under different load conditions. The circuit diagram used for the simulation is given in Figure 5.

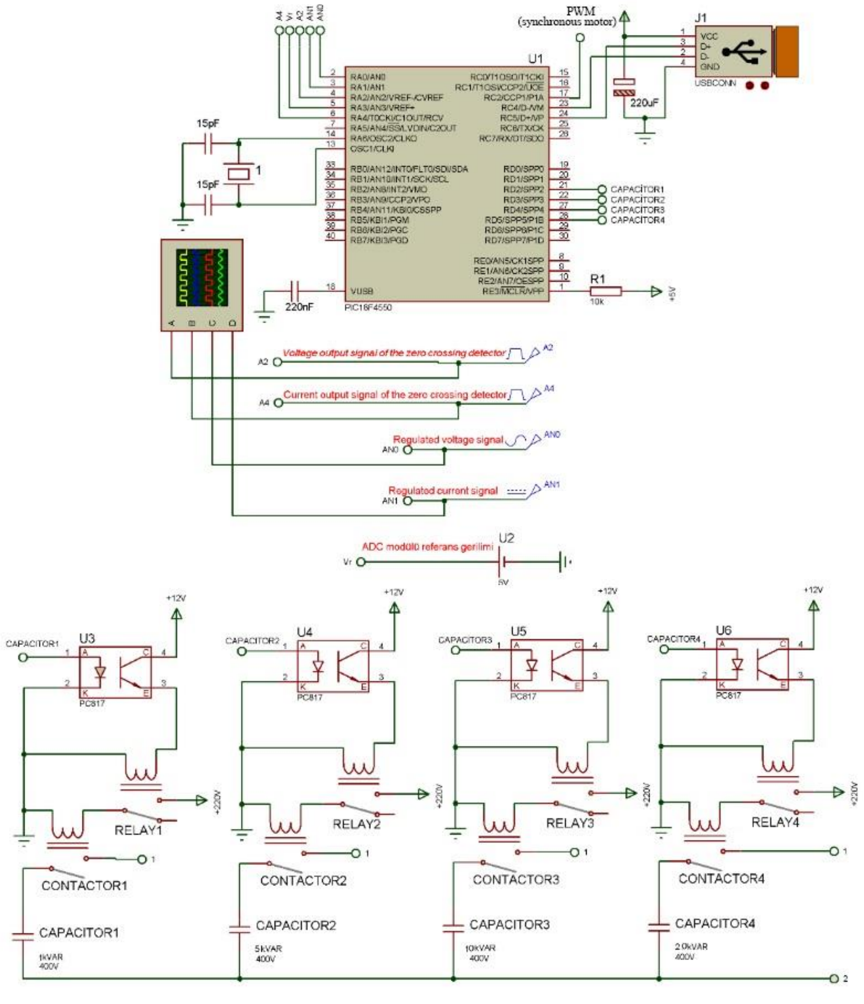


Figure 5. Simulation circuit diagram of the system.

4.1. Compensation on Load at 7th and 8th Busbars

The power factor value (*Cosφ*) before the compensation is 0.58 and the system shows inductive character. In this case, the oscilloscope display and the measurement results showing the phase difference between the voltage-current signals before the compensation of the system are given in Figure 6.

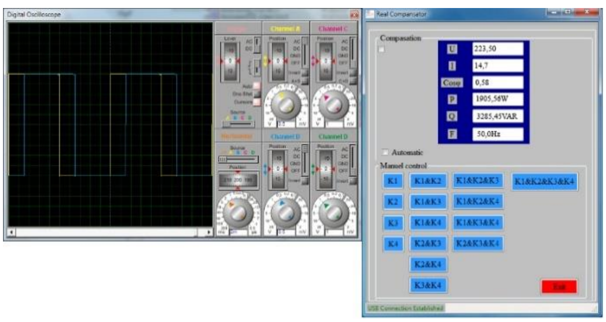


Figure 6. Oscilloscope display and measurement results before the compensation

The oscilloscope display showing the phase difference between the voltage-current signals after the compensation of the system and the measurement results in this case are given in Figure 7. Simulation circuit diagram of the control module where the capacitor group needed for the system for this load condition is switched automatically with traditional switches.

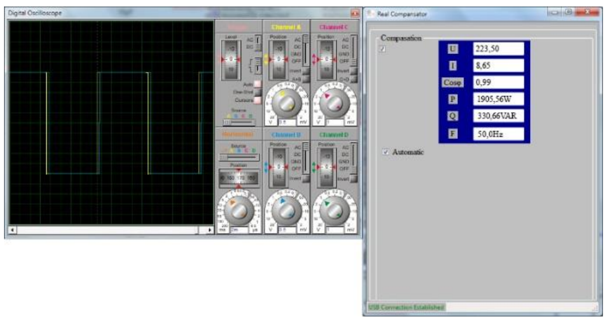


Figure 7. Oscilloscope display and measurement results after the compensation

Under these conditions, the appropriate capacitor value is determined by the computer and the microcontroller as 1 kVAR and 5 kVAR. The simulation of the compensation system is performed by switching 1 kVAR capacitor with the control circuit and 5 kVAR capacitor group automatically. With the current capacitor in the system, it was not possible for the appropriate power factor. This deficiency was eliminated by adding reactive power taken by the appropriate excitation current synchronous motor. With the rapid recovery of the system, a power factor of 0.99 was obtained. As a result, $Cos\varphi$ value is approximated to 1.

5. APPLICATION RESULTS

The designed compensation system consists of two main parts. In the first part, the measurement is made. The first part consists of microcontroller module, current reading module, voltage reading module, power source module and computer interface. In the second section, the control process is carried out. The second part consists of microcontroller module, control module, 1-5-10-20 kVAR capacitors and computer interface. In the both main sections of the system, microcontroller module and computer interface are located. Even though the microcontroller module is under the computer interface control, all the work is carried out in the microcontroller module.

Therefore, the microcontroller module is the brain of the system. The circuit designed for the measurement and the control procedures are given in Figure 8. In addition, an overview of the system for the experimental compensation implementation designed in the laboratory environment is given in Figure 9.

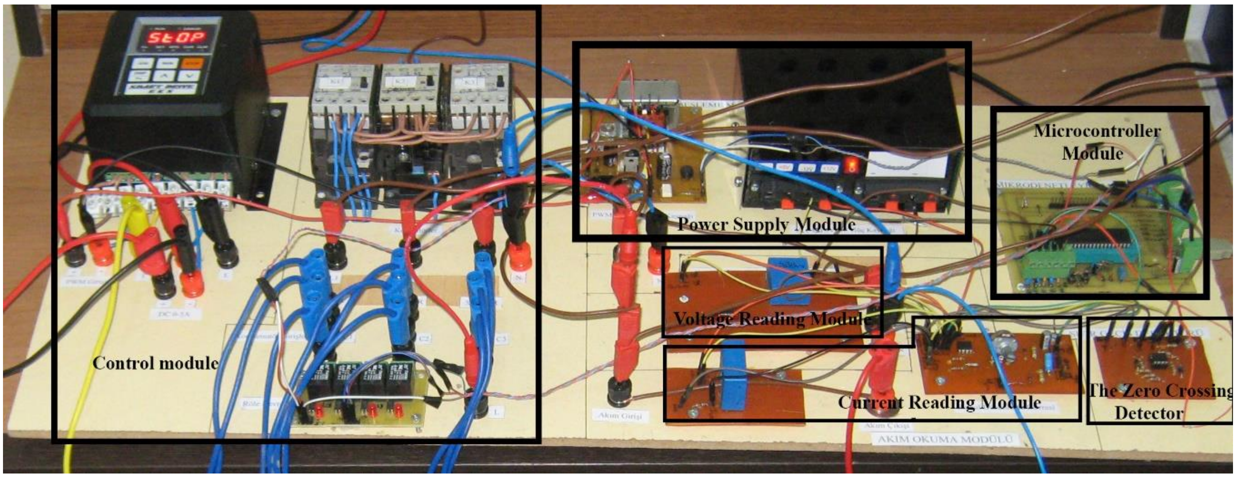


Figure 8. Circuit designed for the measurement and control procedures

Figure 9. Overview of the designed system

For a correct comparison, the load, voltage, current, cosφ, active power, reactive power and frequency values of the loads in the busbars were measured in the absence of compensation and then measured during the compensation application with the designed hybrid compensation. In addition, measured values and voltage, current waveforms were monitored by the interface.

5.1. Compensation on Load at 7th and 8th Busbars

Power factor $Cos\varphi$ value before the compensation is 0.58 and the system shows inductive character. In this case, the oscilloscope display and measurement results showing the phase difference between the voltage and current signals before the compensation of the system are given in Figure 10.

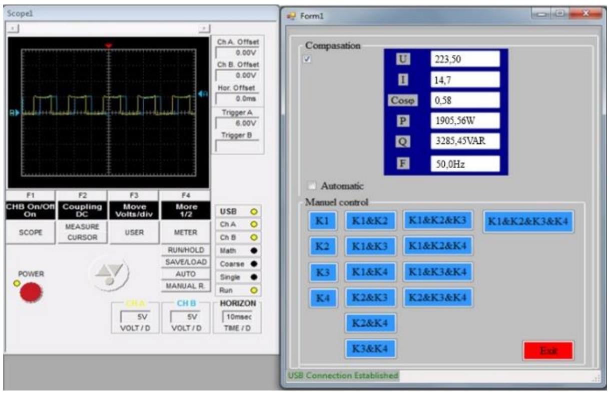


Figure 10. Oscilloscope display and the measurement results before the compensation

The results of measurement after compensation with capacitor groups are given in Figure 11. When the given measurement results are considered, compensation with 1kVAR and 5kVAR capacitors is insufficient. This situation is solved with synchronous motor applied excitation current estimated to 3.5 Ampere.

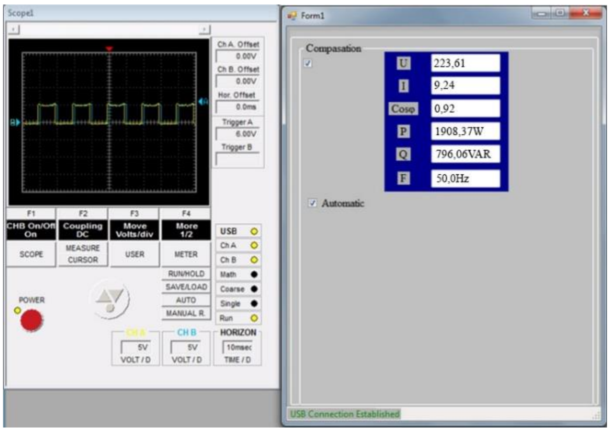


Figure 11. Oscilloscope display and the measurement results after the static compensation

After compensation, the oscilloscope display and the measurement results of the system showing the phase difference between the voltage-current signals are given in Figure 12.

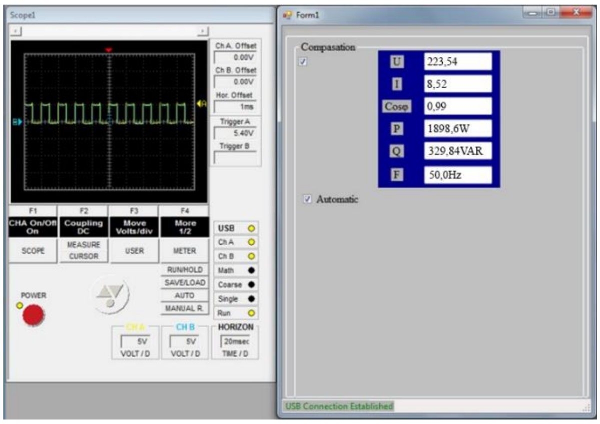


Figure 12. Oscilloscope display and the measurement results after the hybrid compensation

6. COMPARISON OF THE RESULTS

Similarities are observed among $Cos\varphi$ values under different load conditions after the simulation and experimental implementation of the designed system. This case is seen in Figure 13.

When $Cos\varphi$ values obtained as a result of the experimental implementation and simulation are compared with X^2 test, no significant difference is observed (X^2=0.150; P=1). In addition, the relationships between $Cos\varphi 1$ value of the system before the compensation under different load conditions and $Cos\varphi 2$ value of the experimental implementation and simulation after the compensation are given in Figure 14.

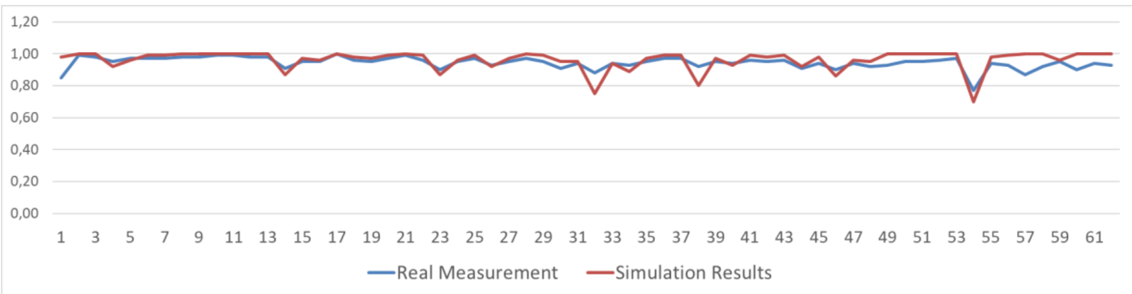


Figure 13. Measured $Cos\varphi$ values after the simulation and experimental implementation

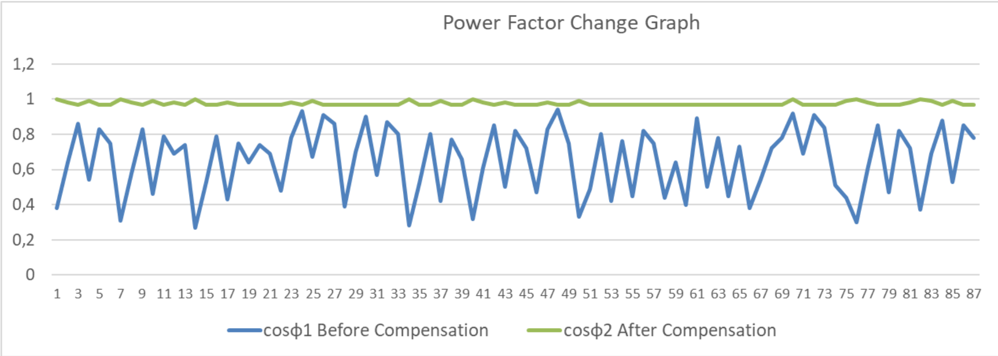


Figure 14. $\boldsymbol{Cos\varphi 1}$ and $\boldsymbol{Cos\varphi 2}$ values after the experimental implementation

The recovery of the power coefficient leads to a reduction in the consumed reactive power. The active power, defined as the power to do work, is not dependent on the power coefficient. Figure 15 shows the active power drawn from the system before and after compensation. Almost the same power was pulled as shown. Figure 16 shows that the reactive power taken before compensation is much reduced after compensation. It is an expression of what the designed system works correctly.

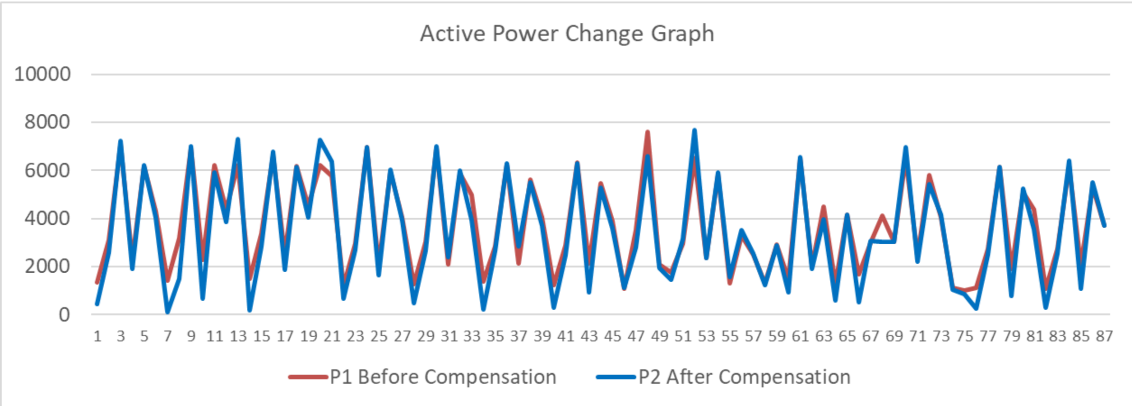


Figure 15. Active power change

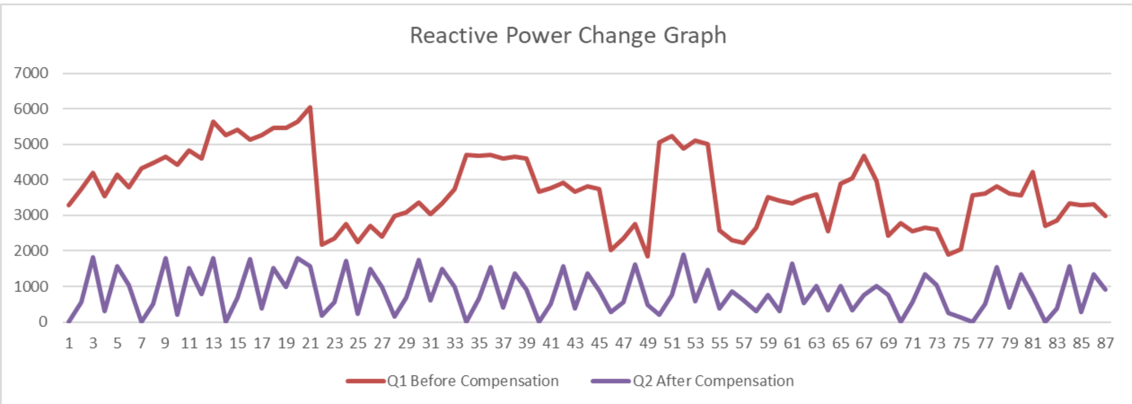


Figure 16. Reactive power chance

When the results of the system before and after compensation, P value remained constant and Q value decreased. With this study, the Cos value was approached to 1. As a result, more reactive power is not taken from the grid and energy is saved.

7. CONCLUSION

This study focused on power factor correction with a significant impact on productivity. It has been investigated whether it can be held above 97% of the power coefficient in a real and unstable three-phase system. In order to achieve this, a simulation model of an existing system has been developed. The developed model is then transformed into an application. The results of the experiment and the simulation are compared and there is not much difference between them. This shows that the simulation program prepared before the application will help to design a compensation system and may even be used for educational purposes. As a result of the work done, the power coefficient can be approached to 1 even in large capacity systems. Serious energy savings can be made here. In order to achieve this, it is necessary to use hybrid systems, not just static compensations. It is seen that the biggest problem, insufficient static compensation, can be overcome by suitable synchronous motor control. The success of the application shows that more radical changes can be made about the power coefficient. With the legislative amendment to be made, energy savings will be very large in the whole country.

REFERENCES

[1]. Babu, P.C.; Dash, S.S.; Bayindir, R.; Subramani, C.; Mohanty, M.N. "A new control strategy with fuzzy logic technique in distribution system for power quality issues", *In:* ***IEEE-International Power Electronics and Motion Control Conference and Exposition,*** Antalya, Turkey, 1110-1115, (2014).

[2]. Peng, F. Z.; Ott, G. W., & Adams, D. J. "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire systems", ***IEEE Transactions on Power Electronics***, 13(6): 1174-1181, (1998).

[3]. Takeda, M.; Ikeda, K.; Teramoto, A. & Aritsuka, T. "Harmonic current and reactive power compensation with an active filter", ***In Power Electronics Specialists Conference, PESC'88 Record., 19th Annual IEEE***, 1174-1179, (1988).

[4]. Singh, B.; Al-Haddad, K. & Chandra, A. "A new control approach to three-phase active filter for harmonics and reactive power compensation", ***IEEE Transactions on Power Systems,*** 13(1): 133-138, (1998).

[5]. Miller, TJE. Reactive power control in electric systems; ***A Viley-Interscience Publication***, New York, NY., (1982).

[6]. Mandal, R.; Basu S. K.; Kar, A. & Chowdhury, S. P. A "Microcomputer-Based Power Factor Controller." ***IEEE Transactıons On Industrıal Electronıcs***, 41(3): 361-371, (1994).

[7]. Kumar, P. "Development of Power Factor Controller using PIC Microcontroller." ***Master Thesis***, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, (2008).

[8]. Barsoum, N. "Programmıng of Pıc Mıcro-Controller for Power Factor Correctıon", ***Asia International Conference on Modelling & Simulation, IEEE Computer Society***, Phuket, Thailand, 19-25, (2007).

[9]. Libo, W.; Zhengming, Z. & Jianzheng, L. "A single-stage three-phase grid-connected photovoltaic system with modified MPPT method and reactive power compensation", ***IEEE Transactions on Energy Conversion***, 22(4): 881-886, (2007)

[10]. Jain, S. K.; Agrawal, P. & Gupta, H. O. "Fuzzy logic controlled shunt active power filter for power quality improvement", ***IEE Proceedings-Electric Power Applications,*** 149(5): 317-328, (2002).

[11]. Tiwari, A.K.; Sharma, D. and Sharma, V.K. "Automatic Power Factor Correction Using Capacitive Bank", ***Journal of Engineering Research and Applications,*** 4(2): 393-395**,** (2014).

[12]. Rustemlı, S.; Ates, M. "Measurement and Simulation of Power Factor Using PIC16f877", ***Przegląd Elektrotechnıczny (Electrical Review)***, 88(6): 290-294, (2012).

[13]. Afridi, M.N. "Design and Implementation of Automatic Microcontroller- Based Controlling of Single Phase Power Factor Using Capacitor Banks with Load Monitoring", ***Global Journal of Researches in Engineering Electrical and Electronics Engineering,*** 12 (10), (2012).

[14]. Ali, M. "Design and Implementation of Microcontroller-Based Controlling of Power Factor Using Capacitor Banks with Load Monitoring", ***Global Journal of Researches in Engineering Electrical and Electronics Engineering,*** 13(2), (2013).

[15]. Kok, B.C.; Uttraphan, C. and Goh, H.H. "A Conceptual Design of Microcontroller-Based Power Factor Corrector Circuit", ***Malaysian Technical Universities Conference on Engineering and Technology,*** MS Garden, Kuantan, Pahang, Malaysia, 1-6, (2009).

[16]. Mienski, R.; Pawelek, R. and Wasiak, I. "Shunt compensation for power quality improvement using a STATCOM controller: modelling and simulation". ***Generation, Transmission and Distribution, IEE Proceedings,*** 151(2): 274 – 280, (2004).

[17]. Wang, H.F. "Phillips-Heffron model of power systems installed with STATCOM and applications", ***Generation, Transmission and Distribution, IEE Proceedings***, 146(5): 521 – 527, (1999).

[18]. Cheng, C.-A.; Chang, E.-C.; Tseng, C.-H.; Chung, T.-Y. A "Single-Stage LED Tube Lamp Driver with Power-Factor Corrections and Soft Switching for Energy-Saving Indoor Lighting Applications", ***Appl. Sci.*** , 7: 115, (2017).

[19]. Cheng, C.-A.; Chang, C.-H.; Cheng, H.-L.; Tseng, C.-H.; Chung, T.-Y. "A Single-Stage High-Power-Factor Light-Emitting Diode (LED) Driver with Coupled Inductors for Streetlight Applications", ***Appl. Sci.*** , 7: 167, (2017).

[20]. Dixon, J.; Moran, L.; Rodriguez, J.; Domke, R. "Reactive Power Compensation Technologies: State-of-the-Art Review", ***Proceedings of the IEEE,*** 93(12): 2144 – 2164, (2007).

[21]. Yilmaz, E.N.; Aydin, O. "Micro controller and computer based reactive power compensation", ***Tehnički vjesnik***, 24(2): 363-370, (2017).