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Full Length Research Paper

Microcontroller-controlled reactive power measurement and saving circuit design for residences and small-scale enterprises

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In the present day, the requirement for electric energy is increasing rapidly with the advancement of the technology. One of the most effective methods of achieving savings in electrically-operated systems and increasing its efficiency is the reactive power compensation. According to the presently enforced regulation, compensation is mandatory in the industry and it is made at certain intervals, however, there is no arrangement for residences and small-scale enterprises and this issue is neglected. It is possible to make significant amounts of savings if the reactive power compensation is implemented over the whole country. In this study, measurement of the reactive power in single-phase systems has been developed, as well as calculation for directing for energy saving through a microcontroller. In the implemented system, the phase difference between the current and the voltage is measured, and the direction of saving is implemented according to the used reactive power. Implementation results demonstrated that the designed system has a simple structure and small dimensions, it brings up the power coefficient of the system to the optimum level, it reduces the faults to minimum and also reduces the cost. With these features, it is more useful and more economical than the devices sold on the market.

Key words: Compensation, reactive power factor, microcontroller, energy savings.

INTRODUCTION

Electrical energy is one of the most widely used energy sources, is a product which must be consumed while it is being produced. The importance of electrical energy is increasing every day with the impact of the technological advancements (Güntürkün, 2003). The cost of the investments made for generation, transmission and distribution of the electrical energy is quite high. For this reason, it has gained significant importance to use the electrical energy efficiently, to minimize the exiting losses, t reduce the generation costs and to protect the environment by reducing the consumption (Demirkol, 2006).

One of the most effective methods of increasing the savings and efficiency is power compensation. In this method, a trial was made to balance the reactive power caused by inductive loads such as generators, transformers, coils and motors with capacitive loads. In Turkey, the Electric Tariffs Regulation made it mandatory to use compensation for consumers with installed power over 9 kW and it is limited. There are no requirements for consumers with installed power less than 9 kW. The cost of the used reactive power is not taken seriously and it is calculated over the active power when preparing the invoice and reflected on the bill (Epdk, 2010). In recent years, some compensation systems are now developed for energy savings and efficiency for this type of users. The distorted waveforms of current and voltage versus time in a system without compensation are shown in Figure 1.

In this study, measurement of the reactive power in single-phase systems has been developed, as well as calculation for directing energy saving through a microcontroller in residences and small-scale enterprises. Current and voltage data have been taken from the single-phase line through sensors. Current data have been obtained with the current waveform over the cable that passes through the sensor. Voltage data have also been

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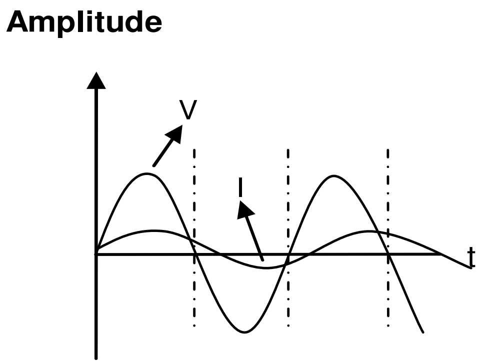

Figure 1. Distorted current and voltage waveforms that require compensation.

taken from the output of the voltage sensor connected to the 220 volt mains voltage. The current and voltage signals thus obtained were passed through the zero-cross detector. The clipped current and voltage signals from the output of the zero-cross detector were applied at the inputs of the microcontroller and the data crossing at zero was compared. As a result of the comparison, the time difference (phase difference) between the current and the voltage was used to calculate the reactive power coefficient. It has been established that the compensation made with the implemented circuit is superior to the other devices regarding saving and efficiency. It has also been observed that the service lives of the used compensation components have been prolonged.

MATERIALS AND METHODS

In the implemented measurement circuit, the current and voltage signals have been obtained with the help of the sensors connected to the mains line, which are used for determining the reactive power coefficient. To obtain the current data, Honeywell CSNP661 current sensor was used. To obtain the voltage data, LEM LV-25P voltage sensor was used. Zero-cross detector was formed in order to compare the zero crossing times of current and voltage data. LM358 integrated circuit was used for the zero-cross detector. For the microcontroller circuit, the 18F452 controller used was from PIC series of Microchip Company. For the microcontroller, 10 MHz crystal was used. As the peripheral interfaces were integrated in the integrated device in microcontrollers, the system speed and reliability increased and cost was reduced. The delay times between the current and voltage signals were compared with the software written in the PIC 18F452 controller; the reactive power coefficient was determined and directed to saving.

In the compensation methods used by residences and small-scale enterprises, the reactive power coefficient measurement was not developed. The compensation without reactive power coefficient measurement caused the efficiency to be low and formed unbalanced loads. In the developed system, directing to saving action has been implemented for effective and efficient compensation in residences and small-scale enterprises. For ideal compensation action, reactive power coefficient measurement has been developed with the help of the microcontroller; making use of the phase difference between the current and the voltage. The compensation components directed for saving, on the other hand, provided effective saving. Another useful aspect of the method is that it prolongs the life of the electrical appliances by working as a harmonic wave filter and prevents potential damages that may occur in voltage fluctuations. In this case also, the faults in the system have been minimized and saving was achieved. As a result of all these savings, costs were reduced, effective and efficient systems were obtained, environmental adverse effects caused by electrical energy generation were tried to be eliminated.

Application

Alternating current consumers draw alternating current from the mains. This current is composed of two components as the active current and reactive current. The active current drawn by the devices is converted into active power and made useful; the reactive power caused by the reactive current is not useful. The magnetic flux needed for normal operation of all operating machinery such as generators, transformers, coils and motors that run on induction principle was generated by the reactive current. All these machines and devices draw a magnetizing current in order for the magnetic flux to be generated; this magnetizing current is called the reactive current. Active-reactive current and active-reactive power equations is shown in Equation (1), (2), (3), (4) (Machmoum et al., 2002; Barsoum, 2007; Lin et al., 2001; Çolak and Bayındır, 2003):

Active Current; $I_p = I \cos\varphi$ (1)

Reactive Current; $I_q = I \sin\varphi$ (2)

Active Power; $P = S \cos\varphi$ (3)

Reactive Power; $Q = S \sin\varphi$ (4)
(S: Apparent power)

In the designed single-phase reactive power measurement circuit, current and voltage data were obtained with the help of a 12 volt transformer and sensors connected to the alternating current (AC) mains. The obtained current and voltage data were applied to the inputs of the zero-cross detector. The values obtained at the output of the zero-cross detector were compared with the microcontroller software and the delay time between the current and voltage were calculated. This delay time was also used in the reactive power measurement. The block diagram of the designed reactive power measurement circuit is shown in Figure 2.

Reading the current data

In order to read the current data from the single-phase system, a CSNP661 current sensor has been connected to the circuit. 15 volt was applied as the supply voltage of the sensor. Current signals were read out with the help of a cable passed through the current sensor. The output of the sensor, which is connected in series to the circuit, was applied to a 10-Ω resistor and current data was obtained over the resistor. The current data thus obtained was connected to the zero-cross detector. The current sensor and circuit schematic are shown in Figure 3 (Çolak and Bayındır, 2003; Rüstemli and Ateş, 2009; Honeywell, 2010).

Reading the voltage data

In order to obtain the voltage data, a LEM LV 25P voltage sensor was connected to the single-phase line, which has a conversion ratio of 220/5 volt, and supply voltage of +15 and -15. Voltage data was read out from the output of the voltage sensor and transferred

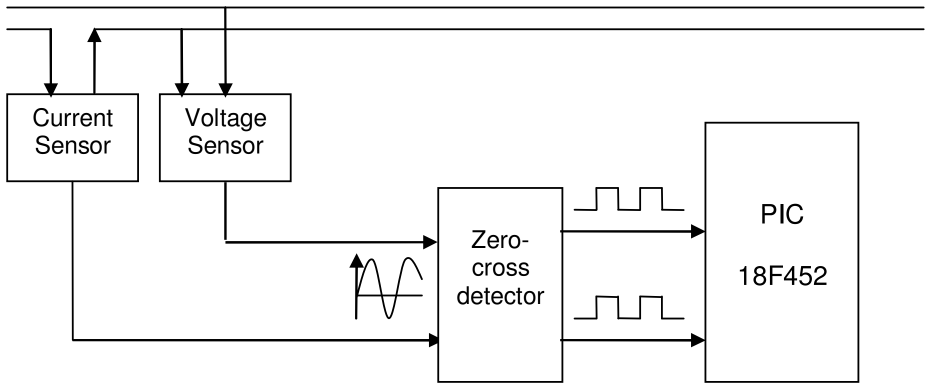

Figure 2. Block diagram of the designed reactive power measurement circuit.

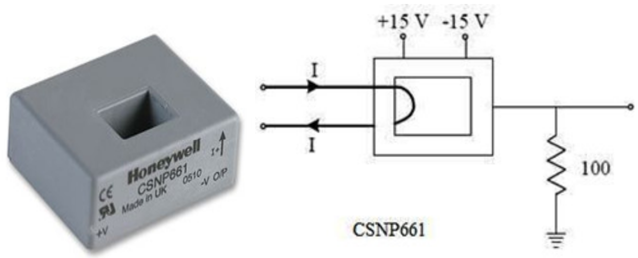

Figure 3. Reading the current data.

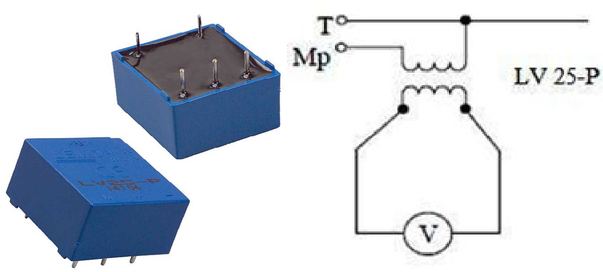

Figure 4. Reading the voltage data.

to the zero-cross detector. The circuit schematic of the voltage sensor connected in parallel to the circuit is shown in Figure 4 (Rüstemli and Ateş, 2009; Bayındır and Kaplan, 2007; LEM, 2010).

Zero-cross detector

The signals obtained from the current and voltage sensors were applied at the inputs of the LM358 integrated circuit in the zero-cross detector. The purpose of the zero-cross detector is to determine the moments when the signals crosses the zero level. The detector outputs a logic 1 signal, when the signals crosses zero. Current data has been applied at input number 2 of the Op-Amp and voltage data was applied at input number 6. The angle between the square signals obtained from the outputs number 1 and 7 represent the phase difference between the current and the voltage. This phase difference is used in reactive power calculation.

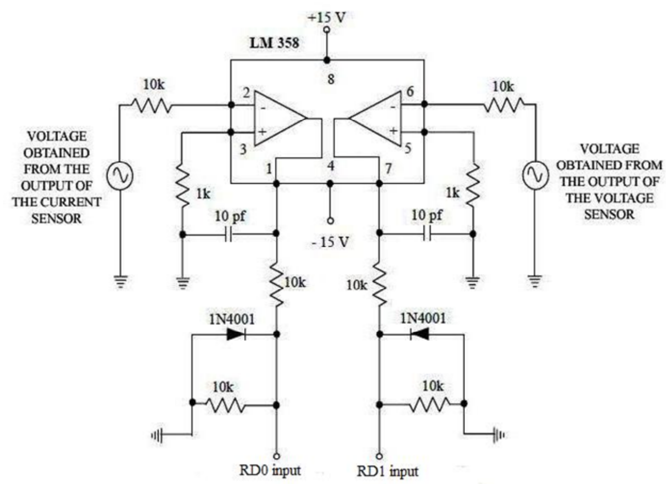

Figure 5. Zero-cross detector.

The block diagram of the zero-cross detector is shown in Figure 5 (Epdk, 2010; Çolak and Bayındır, 2003; Bayhan and Demirbaş, 2009).

Ideally, there should be no phase difference between the current and the voltage. As a result of the effect caused by the inductive or capacitive loads, the phase of the current signal shifts by maximum ±90˚ with respect to the voltage signal. However, in practice, inductive loads never display ideal coil properties. For this reason, the angle between the current and the voltage changes between 0˚ and 90˚. Ideally, this angle is as shown in Figure 6 (Wikipedia, 2010; Bayram, 2000; Kumar, 2008).

The current and voltage signals after passing through the zero-cross detector are as shown in Figure 7. “φ” The angle represents the phase difference between the current and the voltage.

Microcontroller circuit

Zero-cross detector outputs a logic 1 signal when the current and voltage signals crosses zero. These signals are applied at the inputs of the microcontroller. Of these logic signals, the current signal was applied at RD0 pin and voltage signal at RD1 pin of the

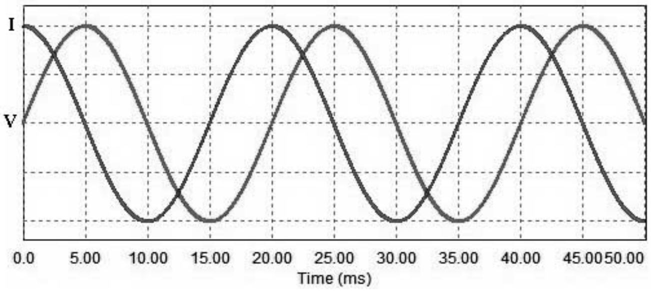

Figure 6. Ideal phase difference between current and voltage.

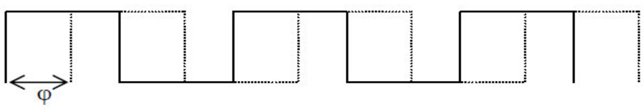

Figure 7. Phase difference between current and voltage.

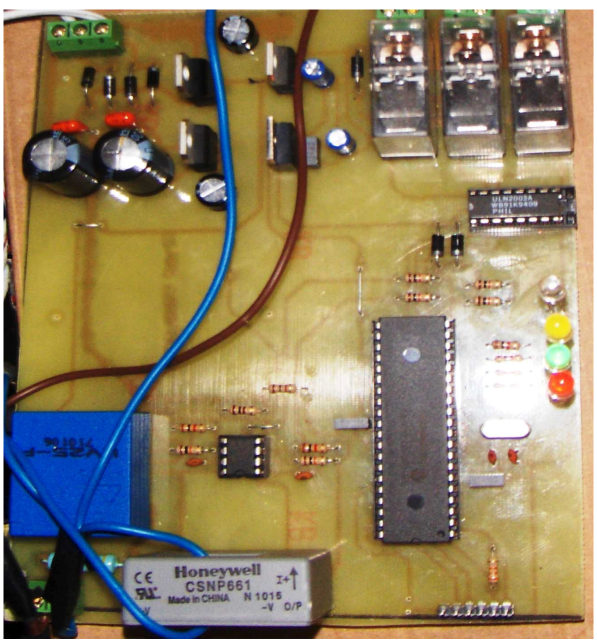

Figure 8. Implemented microcontroller measurement circuit.

microcontroller. When the voltage signal crosses zero, the suitable TIMER0 timer of the PIC 18F452 microcontroller was ignited and when the current signal crosses zero, it was stopped. The time elapsed between the starting and stopping of the TIMER0 timer has been saved in a variable as the phase difference. Based on the value of this variable, relays have been closed or opened, thus switching the compensation components into the circuit and directing action for saving were performed. As the microcontroller is easily programmable and the programming language is flexible, values were changed according to the features of the used device, thus design was made to achieve a more effective saving (Microchip, 2010). The implemented circuit and the schematic of the

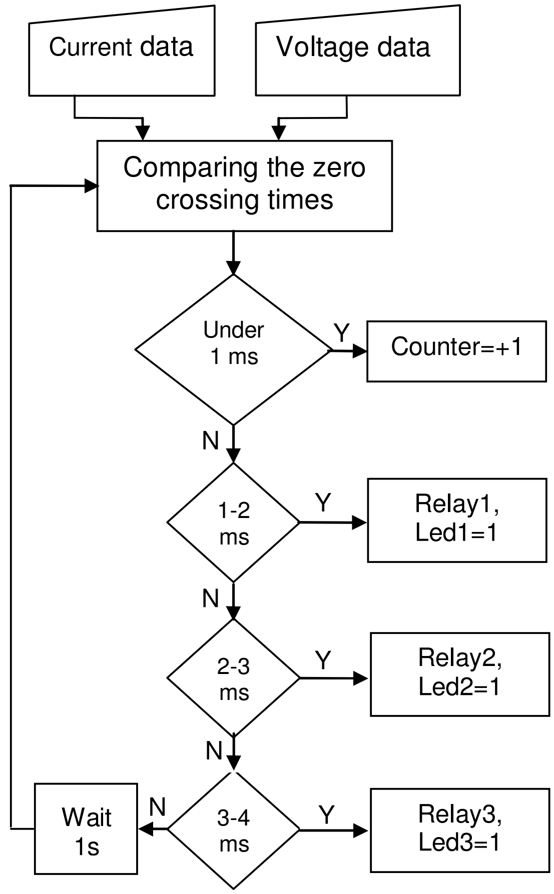

Figure 9. Flow chart of program.

microcontroller are shown in Figure 8.

The values used in PIC programming may change according top the features of the device. This variability makes it possible to have maximum saving and efficiency. The flow chart of the program is given in Figure 9.

EXPERIMENTAL RESULTS

In the designed measurement circuit, making use of the time difference between the current and voltage signals were obtained in logical form, the reactive power coefficient was determined by the microcontroller. In order to determine the reactive power coefficient, the current and voltage data taken from the sensors were applied at the inputs of the PIC 18F452 microcontroller. By making use of the software written in the micro-controller, directing to saving was achieved according to the reactive power coefficient. The waveform used in logical form to deter-mine the reactive power coefficient is as shown in Figure 10. Here, T is defined as the period of the logic waveforms in unit time. According to the waveform in Figure 10,

$$T = 2000\ \mu s \quad (5)$$

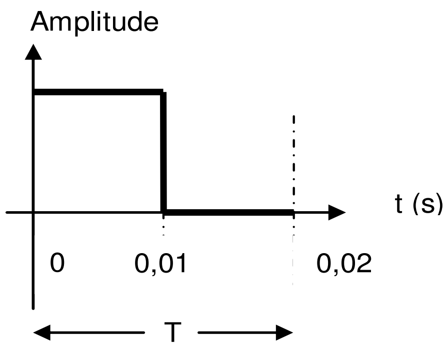

Figure 10. The waveform used in logical.

Figure 11. Application of the measurement circuit on refrigerator.

Table 1. Test results of the implemented circuit on refrigerator.

Refrigerator	Cos φ	kwh	Saving (%)
Implemented circuit not connected	0.56	0.61	0
Implemented circuit connected	0.95	0.45	26

Table 2. Saving ratios of existing device types and their adverse effects on the mains.

Existing device types	Saving rate (%)	Adverse effect (%)
Fixed on the fuse	5 - 30	20
Plugged into the nearest outlet	5 - 25	15
This Method	5 - 40	2

$$T = 360° \quad (6)$$

Applying equations (5), (6) $\rightarrow 1° \cong 55.555556\ \mu s$ was found.

In order to measure the power coefficient, the time difference between the current and voltage has been converted to angle. The cosine of this angle represents directly the reactive power coefficient. In order to make a correct and efficient compensation, this value needs to be known. Designed reactive power measurement application of a receiver with inductive character connected to a single-phase alternating current mains grid was developed.

A refrigerator with an inductive motor inside was used as the receiver. Consumption and measurement device were connected to the refrigerator, the current and voltage data from the mains were read out and the phase difference between them was determined (Figure 11). From this phase difference, the reactive power coefficient was found using Equations (5) and (6). Under normal conditions, experimental setup and measurement device were connected to the refrigerator for 3 h and test results were obtained. These results are given in Table 1. According to the obtained results, it was observed that cos φ has come to the desired interval. Refrigerator is an appliance used continuously in residences and small-scale enterprises and it is a significant reactive power consumer. According to the test results, power coefficient was brought to ~0.95 and average 26% saving was achieved.

Conclusıon

At present, the existing compensation systems used in small-scale enterprises and residences give compensation without making a reactive power coefficient measurement. As these compensation systems are fixed at the top of the mains, they give unnecessary capacitive load to the system when no current is drawn or no reactive power is consumed. In this case, the capacitive load given to the system does not provide saving, on the contrary, they impose additional burden on the invoice.

In this study, a simple, useful, precise and reliable measurement system has been developed for use in small-scale enterprises and residences. With the developed system, the adverse effects of unnecessary capacitive loading of the system when no current is drawn from the mains or no reactive power is consumed have been minimized. With the developed system, when excessive reactive power is drawn from the system, more capacitors will be switched in the circuit, thus more effective and high percentage of saving will be made. The comparison of the saving in existing systems and the adverse effect when the device does not operate is given in Table 2.

Of various existing models of compensation systems, the devices connected permanently to the fuse provide approximately factor of 5 - 30% saving, the ones connected to the nearest outlet provide factor of 5 - 25% saving. However, when devices which do not consume reactive power are operated or when electrical devices are not operated, they give unnecessary capacitive load to the system and cause factor of 15 - 20% negative saving. With the measurement circuit implemented in this study, the reactive power condition is measured and when devices which do not consume reactive power are operated or when electrical devices are not operated, loading of the system with unnecessary capacitive load is prevented. In cases, when the reactive power is increased, the compensation ratio is also increased, thus a saving of factor of 5 - 40% has been achieved. It has also been observed that with the implemented system, the effects of the harmonics are reduced and the life spans o the compensation components and devices are prolonged

ACKNOWLEDGEMENT

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