Design of Saving Circuit with Fuzzy Logic Control for Residences and Small Scale Enterprises

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***Abstract*—One of the most effective methods of achieving savings in electrically-operated systems and increasing the efficiency is reactive power compensation. With the presently enforced regulation, compensation is mandatory for industrial consumers and it is done at certain power intervals, there is no regulation for residences and small scale enterprises on this subject. 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 voltage is measured, the outputs are made fuzzy according to the amount of the consumed reactive power and directing to saving is done 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 reduces the cost. Furthermore, the portability feature of the system makes it possible to prevent adverse situations that may happen when no reactive power is consumed or when no device is being used.**

***Index Terms*—Reactive power factor, Compensation, microcontroller, energy savings, phase difference, fuzzy logic control**

I. INTRODUCTION

One of the most effective methods of increasing the savings and the efficiency is power compensation. In this method, the reactive power caused by inductive loads such as generators, transformers, coils and motors is tried to be balanced with capacitive loads [1]–[3]. 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 [4]. The distorted waveforms of current and voltage versus time in a system without compensation are shown in Fig. 1.

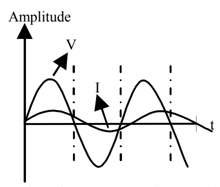

Fig. 1. Distorted current and voltage waveforms that require compensation

Fuzzy logic is defined as the mechanism of thinking and deciding that enables consistent and right decisions based on incomplete and inexact information. In classical logic, there are no partial truths. The point in question is either completely true or completely false. However, the expressions that we may call as partially true are neither completely true nor completely false. Classical logic is not sufficient to define this type of expressions [5].

In general, fuzzy logic systems are either data-based or rule-based systems. That means, at the base of the fuzzy logic system there are "If-Then" rules. Here, linguistic values are used such as *very high, high, normal, low, very low*. These linguistic values have suitable membership degrees. After deciding to design a fuzzy logic system, the first thing to do is to prepare the "*If-Then*" rules table. These rules are generally made with the help of the expert of the job being done [6,7].

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 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 been taken from the output of the voltage sensor connected to the 220 volt mains voltage. The current and voltage signals thus obtained have been passed through the zero-cross detector. The clipped current and voltage signals from the output of the zero-cross detector have been applied at the inputs of the microcontroller and the data crossing at zero have been compared. As a result of the comparison, the time difference (phase difference) between the current and the voltage has been 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.

II. MATERIALS

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 has been used. To obtain the voltage data, LEM LV-25P voltage sensor has been used. Zero-cross detector has been formed in order to compare the zero crossing times of current and

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voltage data. LM358 integrated circuit has been used for zero-cross detector. For the microcontroller circuit, the 18F452 controller has been used from PIC series of Microchip Company. For the microcontroller, 10 Mhz crystal has been used. As the peripheral interfaces are integrated in the integrated device in microcontrollers, the system speed and reliability have been increased and cost has been reduced. The delay times between the current and voltage signals are compared with the software written in the PIC 18F452 controller; the reactive power coefficient has been determined and directed to saving.

III. APPLICATION

In the designed single-phase reactive power measurement circuit (PMC), current and voltage data have been obtained with the help of a 12 volt transformer and sensors connected to the alternating current (AC) mains line. The obtained current and voltage data have been applied to the inputs of the zero-cross detector. The values obtained at the output of the zero-cross detector have been compared with the microcontroller software and the delay time between the current and voltage has been calculated. This delay time has also been used in the reactive power measurement [7]. The block diagram of the designed fuzzy logic controlled reactive power measurement circuit is shown in Fig. 2.

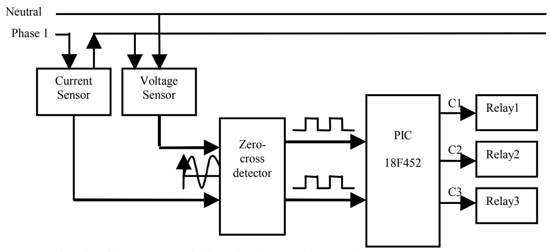

Fig. 2. a) Block diagram of the designed reactive PMC

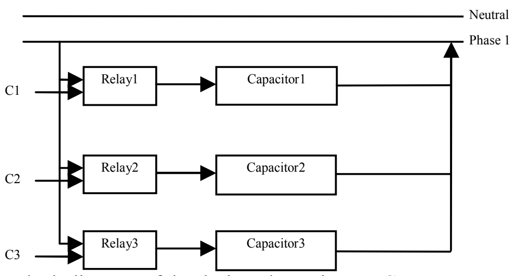

Fig. 2. b) Block diagram of the designed reactive PMC

A. 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 has been applied as the supply voltage of the sensor. Current signals have been 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, has been applied to a 10-Ohm resistor and current data has been obtained over the resistor. The current data thus obtained has been connected to the zero-cross detector [8]-[10].

B. Reading the Voltage Data

In order to obtain the voltage data, a LEM LV 25P voltage sensor has been connected to the single-phase line, which has a conversion ratio of 220/5 volt, supply voltage of +15 and -15. Voltage data has been read out from the output of the voltage sensor and transferred to the zero-cross detector [9,11,12].

C. Zero-Cross Detector

The signals obtained from the current and voltage sensors have been applied at the inputs of the LM358 integrated circuit in the zero-cross detector (ZCD). The purpose of the zero-cross detector is to determine the moments when the signals cross zero level. The detector outputs a logic 1 signal when the signals cross zero [8,13,14].

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° [15]-[18].

The "φ" angle represents the phase difference between the current and the voltage. Oscilloscope probes have been connected to the implemented compensation circuit and the view shown in Fig. 3 has been obtained.

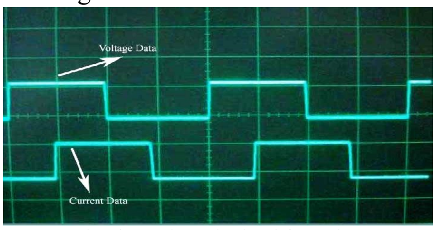

Fig. 3. The current and voltage data obtained from the ZCD

D. Microcontroller circuit

Zero-cross detector outputs a logic 1 signal when the current and voltage signals cross zero. These signals are applied at the inputs of the microcontroller. When the voltage signal crosses zero, the suitable TIMER0 timer of the PIC 18F452 microcontroller has been started and when the current signal crosses zero it has been 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 has been performed [7, 19]. Implemented circuit and the schematic of the microcontroller are shown in Fig. 4.

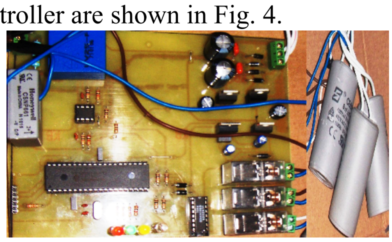

Fig. 4. Implemented microcontroller measurement circuit

E. Fuzzy Logic Control

The reactive power coefficient of the power drawn from the circuit is measured; all receivers are directed according to the amount of the reactive power, instead of passing through a single compensation component. This direction action is expressed linguistically as "*Very low-VL*", "*Low-L*", "*Medium-M*", "*High-H*", "*Very high-VH*" [20]. Taking into consideration that the phase difference used in determining the reactive power coefficient is 90 degrees and it completes a full period in 0,02 sec., for a portion of 5 degrees a delay of maximum 0,005 sec. is possible. As the compensation action will be carried out with 3 main components, this interval has been divided into 5 parts.

VL = Less then 1 ms (1)

L = Between 1 and 2 ms (2)

M = Between 2 and 3 ms (3)

H = Between 3 and 4 ms (4)

VH = High then 4 ms (5)

Fuzzy set of the direction action parameter is as follows.

VL = {1/0.5, 0.5/1, 0/1.5}; (6)

L = {0/0.5, 0.5/1, 1/ 1.5, , 0.5/2, 0/2.5} (7)

M = {0/1.5, 0.5/2, 1/ 2,5, 0.5/3, 0/3.5} (8)

H = {0/2,5, 0.5/3 , 1/3.5, 0.5/4 , 0/4.5} (9)

VH = {0/3.5, 0.5/4, 1/4.5} (10)

The graphic illustration of the above fuzzy set values is shown in Fig. 5.

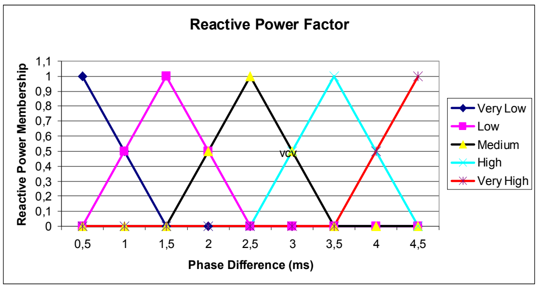

Fig. 5. The graphic illustration of the above fuzzy sets

Using the fuzzy input and output values, coding in C language is made into the microcontroller. The values used in the programming made for the microcontroller may change according to the characteristics of the device. Maximum saving and efficiency may be obtained using the changeable values.

IV. EXPERIMENTAL RESULTS

In the designed measurement circuit, making use of the time difference between the current and voltage signals that have been obtained in logical form, the reactive power coefficient has been determined by the microcontroller. In order to determine the reactive power coefficient, the current and voltage data taken from the sensors have been applied at the inputs of the PIC 18F452 microcontroller. By making use of the software written in the microcontroller, directing to saving has been achieved according to the reactive power coefficient. The waveform used in logical form to determine the reactive power coefficient is shown in Fig. 6 [9].

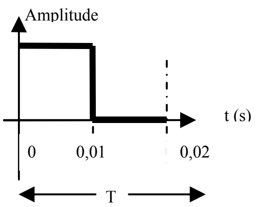

Fig. 6. The waveform used in logical

Here, T is defined as the period of the logic waveforms in unit time. According to the waveform in Fig. 6,

$T=20000\,\mu s$ (11)

$T=360^{\circ}$ (12)

Applying equations (11), (12) $1^{\circ} \cong 55.555556\ \mu s$ is 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 has been made.

Example 1. A refrigerator with an inductive motor inside is used as the receiver. Consumption and measurement device has been connected to the refrigerator, the current and voltage data from the mains have been read out and the phase difference between them has been determined (Fig.7). From this phase difference, the reactive power coefficient has been found using equations number (11), (12).

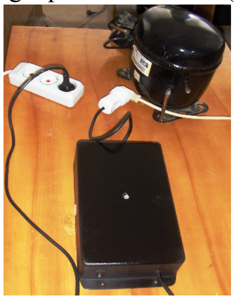

Fig. 7. Application of the measurement circuit on refrigerator

Under normal conditions, experimental setup and measurement device have been connected to the refrigerator for 3 hours and test results have been obtained. These results are given in Table 1.

TABLE I. TEST RESULTS OF THE IMPLEMENTED CIRCUIT ON REFRIGERATOR

Refrigerator	cos φ	kwh	Saving%
Implemented circuit not connected	0,56	0,46	0
Implemented circuit connected	0,95	0,32	29

According to the obtained results, it has been 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 has been brought to around (cos φ) ~0,95 and average 29% saving has been achieved. Compensation system with fuzzy logic control has been tested with other electrical devices in the house; values have been recorded for open and closed positions. Test results are given in Table 2.

According to the test results, net savings have been obtained in devices which are known to consume reactive power. Very low savings have been obtained in devices such as wired electrical heaters, pressing irons, incandescent light bulbs, hair drying machines, toasters, etc. as they do not consume reactive power. However, taking into consideration that the quality of the electrical power and efficiency are increased and the effects of the harmonics are reduced, the cost of their adverse effects should be taken as a form of saving, also.

Portability feature of the compensation system with fuzzy logic control makes is possible to use it individually for all devices or for more than one device at the same, using multiplexers. Home electrical devices are grouped according to their types and their test results are given in Table 3.

TABLE II. TEST RESULTS OF COMPENSATION CIRCUIT IN ELECTRICAL DEVICES

No	Device name	h	Power (w)		cos φ		Saving %
			Off	*On*	*Off*	*On*	
1	Refrigerator	3	4600	3266	0,56	0,95	29
2	Air condit.	2	3000	2160	0,54	0,95	28
3	Washing ma.	2	4400	3432	0,68	0,94	22
4	Dishwasher	2	4400	3476	0,69	0,94	21
5	Vacuum clea.	1	1600	1312	0,80	0,94	18
6	Fans	2	100	83	0,89	0,95	17
7	Combi boiler	3	36000	28080	0,71	0,94	22
8	Computer	2	1000	755	0,61	0,95	24,5
9	Television	2	400	311	0,60	0,95	23,5
10	Turbo oven	1	1500	1185	0,70	0,94	21
11	Electric heat.	1	3000	2972	0,98	0,99	1
12	Iron	2	3000	2972	0,98	0,99	1
13	Wire lamp	3	300	297	0,98	0,99	1
14	Fluo. lamps	3	60	35,4	0,49	0,95	41
Mean Savings%							19,2

TABLE III. SAVING RATIOS OF HOME ELECTRICAL DEVICES IN GROUPS

No	Group name	Group content	Saving rate %
1	White goods	Refrigerator, washing machine, etc.	23,25
2	Heaters	Heaters, iron, kettle, combi boiler etc.	1
3	Lighting	Wire lamp, Fluorescent lamps etc.	21
4	Motor	Vacuum cleaner, Fans, Air con. etc.	23
5	Electronic	Television, computer systems etc.	24

V. CONCLUSION

At the present, the existing compensation systems used in small-scale enterprises and residences started to be produced individually according to the features used in the electric device and make compensation without making a reactive power coefficient measurement.. As these compensation systems are fixed top 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 do 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 4.

Of various existing models of compensation systems, the devices connected permanently to the fuse provide approximately factor of 5-25% 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 is measured and effect of unnecessary capacitive loading of the system is reduced when only those devices which do not consume reactive power are operated or no electrical devices are operated at all. It has been taken into account that due to the time loss caused by the program waiting time and time loss caused by the relays at the performed experiment and test phases, an error factor of 1% may be present. In cases when the reactive power is increased, the compensation ratio is also increased, thus a saving of factor of 1-41% has been achieved. Furthermore, the implemented system has the advantages of reducing the effects of the harmonics, increasing the quality of the electrical power and efficiency, thus prolonging the service lives of the compensation components and devices.

TABLE IV. SAVING RATIOS OF EXISTING DEVICE TYPES AND THEIR ADVERSE EFFECTS ON THE MAINS

Existing device types	Saving rate %	Adverse effect %
Fixed on the fuse	5-25	20
Plugged into the nearest outlet	5-25	15
This Method	5-41	1

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