

Energy Saver System for Residential Application

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Abstract

When compared to energy use in other construction sectors, house buildings have one of the highest levels of energy consumption. The overall yearly energy consumption of houses is between 1,800 and 4,300 kWh per year depending on the size of the building, usage of technology and electrical appliances. The heating and cooling systems, lighting systems, ventilation systems, and house equipment consume the majority of energy in house buildings. The goal of this research is to investigate strategies to save electrical energy in the house by examining the impact of power factor improvement on the electrical appliances by installing capacitor to the electricity bill. Plenty of electrical companies are trying to improve the power utility by studying the usage of power which can be more efficient for the consumers. This technical research work is to design and stimulate the energy saver system that can be apply to a single phase 240 V resident. This work use NI Multisim Analog Device after the design and calculation process.

1. Introduction

This outline is being carried out in order to create a workable system that will improve the power factor in a home application. This project will improve energy efficiency while also enhancing power quality given to customers. It also benefits both utilities and consumers. In order to have an efficient system, the power factor should be as near to unity [1]. This demonstrated that the focus will be on improving the power factor because it causes an issue for neither utilities nor consumers.

Enhancement of the power factor involves understanding the inefficiencies associated with electrical systems and the possible advantages of boosting power factor is characteristic of energy saver projects [2]. Power factor in an electrical system is the ratio of real power to apparent power (the total power provided to the system). When there is a discrepancy between the amount of real power required and the total apparent power provided to the system, a low power factor arises. As a result of this mismatch, energy consumption increases, system efficiency decreases and power bill rise [3]. Advantages of incorporating this device into the electric system are that it can resolve the power factor issue for multiple levels of connected load in that specific residence. Even if numerous loads alter over time, the system will continue to fix the power factor. The power factor corrector system worked by computing the power factor for each connected load and determining the usual capacitor values that might be used in parallel with the load [5]. The same technique is considered here. Furthermore, knowing the type of power measured by the utility provider to the user is required.

Keeping the power factor near to unity, a bank of capacitors should be deployed via the network. The capacitor must be connected in parallel with the load or system. Because industrial loads are often inductive which also have low lagging power factor, installing a capacitor bank will be advantageous [4]. When the capacitor bank is

connected to the network, the reactive power from the capacitive load is added to the system's initial power triangle. This system can be used as an energy saver which acts as a power factor control system.

2. Methodology

Energy-saving techniques in residential houses using capacitors can be implemented through a systematic approach that aims to achieve efficient energy consumption. The working principle behind these techniques involves power factor correction and voltage regulation.

2.1 Power Factor Correction

Power factor is a measure of how effectively electrical power is being used. Inefficient power usage can result in increased energy consumption and higher electricity bills. Capacitors can be used to improve power factor by compensating for the reactive power in an electrical system. Reactive power is the power consumed by inductive loads, such as motors, transformers, and fluorescent lights. It causes the current to lag behind the voltage waveform, resulting in a lower power factor. Capacitors can be connected in parallel to these inductive loads to offset the reactive power, thus improving the power factor. This correction reduces the overall current drawn from the electrical supply, leading to lower energy losses in the distribution system.

2.2 Voltage Regulation

Another aspect of energy-saving techniques involves voltage regulation. In some cases, the voltage supplied by the utility company may be higher than necessary, which can lead to energy wastage and premature failure of electrical appliances. Capacitors can be used to regulate voltage by storing excess electrical energy when the voltage is higher than required, and releasing it when the voltage drops below the desired level. This process helps to maintain a stable voltage level within the optimal range, ensuring efficient operation of electrical appliances and reducing energy waste.

2.3 Study Principle

The systematic approach to implementing energy-saving techniques using capacitors in residential houses typically involves the following steps:

1. Energy audit: Conduct an energy audit of the house to identify areas of energy inefficiency and determine the power factor and voltage requirements.
2. Load analysis: Identify the inductive loads that contribute to low power factor and excessive voltage. This may include appliances like motors, fluorescent lights, and transformers.
3. Capacitor sizing: Calculate the appropriate capacitor size required for power factor correction and voltage regulation based on the load analysis. Proper sizing ensures efficient compensation without overcorrection.
4. Installation: Install capacitors at strategic points in the electrical system, typically near the inductive loads or at the main electrical panel. Ensure proper electrical connections and safety measures are followed during installation.
5. Monitoring: Regularly monitor the power factor and voltage levels to ensure the capacitors are functioning correctly.

By implementing these energy-saving techniques using capacitors and following a systematic approach, residential houses can achieve efficient energy consumption, leading to reduced energy costs, improved power quality, and a more sustainable living environment.

3. Result and Discussion

This section discusses the research's results and analysis. This chapter will essentially go through all of the details of the simulation part. In general, that electronic design automation software that allow load flow analysis, making it a valuable tool for determining equipment loading and voltage levels throughout the circuit. Electronic design automation software is commonly used for visual simulation in the power system industry.

3.1 Theoretical of Power Factor Correction

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3.2 Inductive Load Circuit

An inductive load refers to a load that stores magnetic energy upon being connected to a power source. The impedance of an inductive load includes both resistance and inductance arranged in series. Examples of typical inductive loads suitable for operation with Smart High Side Switches include relays, motors, and solenoids. When these loads are turned off, they have the potential to produce a transient negative voltage reaching several hundred volts due to the magnetic energy stored in the inductance. This transient voltage has the potential to cause significant harm to the driving circuitry.

3.3 Calculation for Clothes Dryer's Inductive Loads Circuit (before adding capacitor)

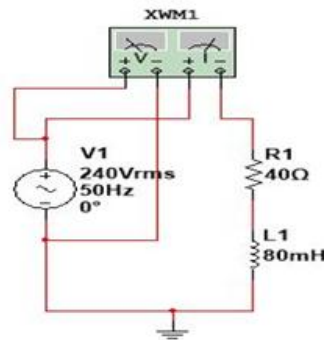


Fig.1 Circuit of clothes dryer as a load

$R = 40\Omega$, $L = 80\text{mH}$, $V = 240\text{V}$, $f = 50\text{Hz}$

Table 1 Calculation for clothes dryer's inductive loads circuit

Before adding capacitor	After adding capacitor
$Z = R + jX_L$	$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(50\text{Hz})(35.2\mu\text{F})}$
$Z = 40 + j25.13 @ 47.23\angle 32.14^\circ$	$X_C = 90.43\angle -90^\circ$
$I = \frac{240\angle 0^\circ}{47.23\angle 32.14^\circ} = 5.08\angle -32.14^\circ$	$Z_C = \frac{(47.23\angle 32.14^\circ)(90.43\angle -90^\circ)}{(47.23\angle 32.14^\circ) + (90.43\angle -90^\circ)} = 55.77\angle 0.66^\circ$
Power factor, $\text{PF} = \cos\theta = \cos(32.14) = 0.85$	$I = \frac{V}{Z} = \frac{240\text{V}}{(55.77\angle 0.66^\circ)} = 4.30\angle -0.66\text{A}$
Calculation of capacitor value for power factor correction,	New power factor, $\text{PF} = \cos\theta = \cos(0.66) = 0.9993$
True Power = P $P = 1036.32\text{W}$ Apparent Power = S $S = 1219.2\text{VA}$ Reactive Power = Q $Q = 642.25\text{VAR}$ $X = \frac{(240)^2}{642.25} = 89.7$ $C = 35.49\mu\text{F}$	

3.4 Simulation Result for Clothes Dryer

Fig. 1 illustrates the initial power factor value before the correction process. To determine the power factor, a wattmeter in the NI Multisim software is employed. On the right side of the image, the power factor is measured using a wattmeter. After constructing the inductive load circuit, which simulates a load similar to a clothes dryer, the power and current are measured. To ensure the correction is effective, a voltage check is performed at 240V AC using both a wattmeter and a multimeter to measure the current and power factor. Power factor of the circuit increased significantly from 0.85 to 0.99 as computed in Table 1 as well as Fig. 2.

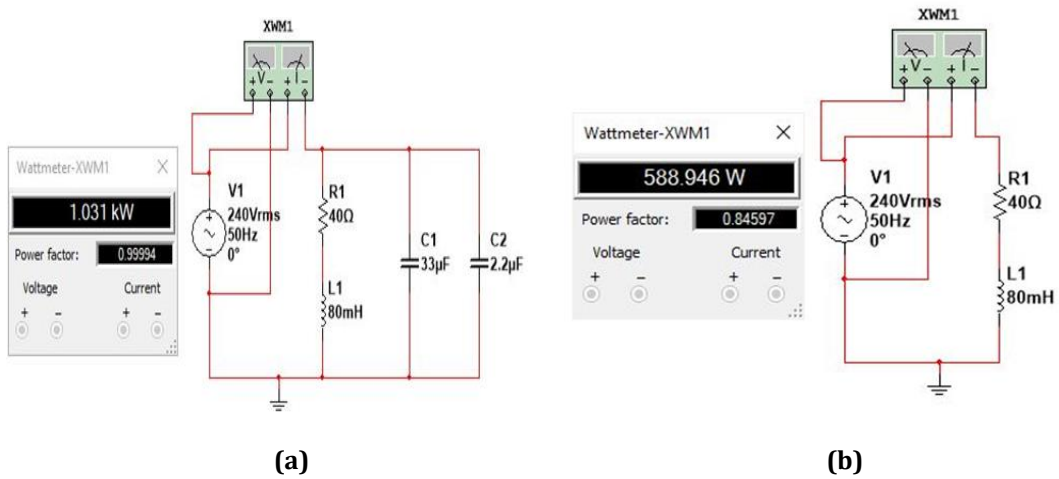


Fig. 2 Power factor of clothes dryer circuit (a) before adding capacitor; (b) after adding capacitor

Two parallel capacitors have led to a reduction in the circuit's current output from 5.08 A to 4.29 A as demonstrated in Fig. 3. The decrease in current indicates improved efficiency and reduced power consumption in the circuit.

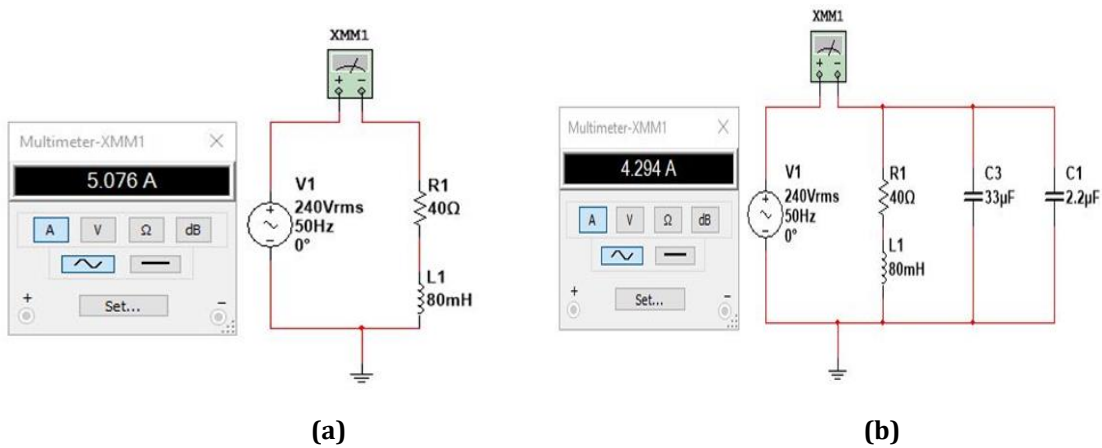


Fig. 3 Current of clothes dryer circuit (a) before adding capacitor; (b) after adding capacitor

3.5 Calculation for Refrigerator's Inductive Loads Circuit (before adding capacitor)

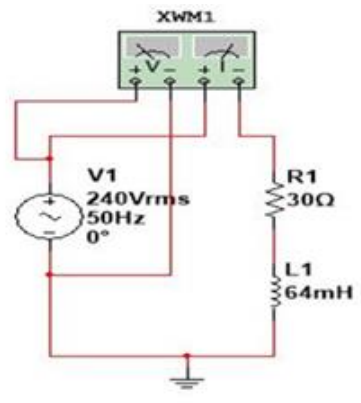


Fig.4 Circuit of refrigerator as a load

$$R = 30\Omega, L = 64\text{mH}, V = 240\text{V}, f = 50\text{Hz}$$

Table 2 Calculation for refrigerator's inductive loads circuit

Before adding capacitor	After adding capacitor
$Z = R + jX_L$	$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(50\text{Hz})(48.7\mu\text{F})}$
$Z = 30 + j20.11 @ 36.12\angle 33.84^\circ$	$X_C = 65.36\angle -90^\circ$
$I = \frac{240\angle 0^\circ}{36.12\angle 33.84^\circ} = 6.64\angle -33.84^\circ$	$Z_C = \frac{(36.12\angle 33.84^\circ)(65.36\angle -90^\circ)}{(36.12\angle 33.84^\circ) + (65.36\angle -90^\circ)} = 43.47\angle 0.29^\circ$
Power factor,	$I = \frac{V}{Z} = \frac{240\text{V}}{(43.47\angle 0.29^\circ)} = 5.52\angle -0.29\text{A}$
$\text{PF} = \cos\theta = \cos(33.84) = 0.83$	New power factor,
Calculation of capacitor value for power factor correction,	$\text{PF} = \cos\theta = \cos(0.29) = 0.9998$
True Power = P	
$P = 1322.69\text{W}$	
Apparent Power = S	
$S = 1593.6\text{VA}$	
Reactive Power = Q	
$Q = 888.85\text{VAR}$	
$X = \frac{(240)^2}{888.85} = 64.8$	
$C = 49.12\mu\text{F}$	

3.6 Simulation Result for Refrigerator

Fig. 4 illustrates the initial power factor value of refrigerator before the correction process. To determine the power factor, a wattmeter in the NI Multisim software is employed. On the right side of the image, the power factor is measured using a wattmeter. After constructing the inductive load circuit, which simulates a load like a clothes dryer, the power and current are measured. To ensure the correction is effective, a voltage check is performed at 240 VAC using both a wattmeter and a multimeter to measure the current and power factor. Power factor of the circuit increased significantly from 0.83 to 0.99 as calculated in Table 2 and successfully simulated in Fig. 5.

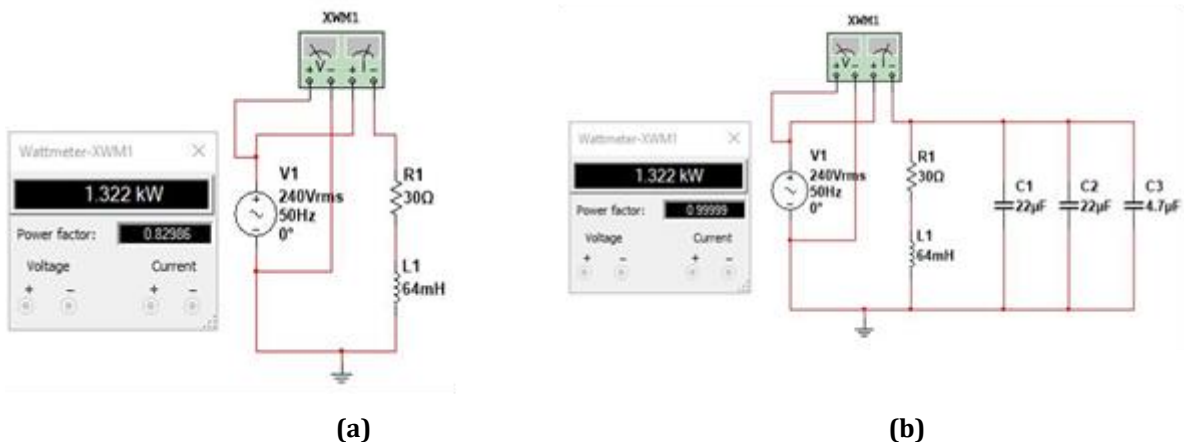


Fig. 5 Power factor of refrigerator circuit (a) before adding capacitor; (b) after adding capacitor

3.7 Calculation for Hair Dryer's Inductive Loads Circuit (before adding capacitor)

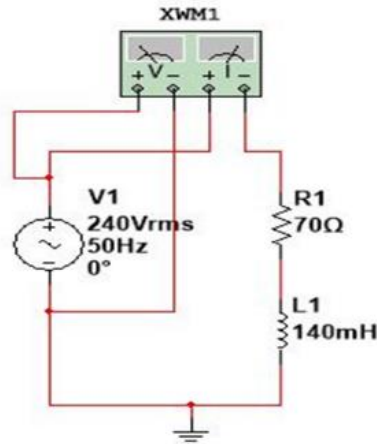


Fig.6 Circuit of hair dryer as a load

R = 70Ω, L = 140mH, V = 240V, f = 50Hz

Table 3 Calculation for hair dryer's inductive loads circuit

Before adding capacitor	After adding capacitor
$Z = R + jX_L$	$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(50\text{Hz})(20\mu\text{F})}$
$Z = 30 + j43.98 @ 82.67\angle 32.14^\circ$	$X_C = 159.15\angle -90^\circ$
$I = \frac{240\angle 0^\circ}{82.67\angle 32.14^\circ} = 2.90\angle -32.14^\circ$	$Z_C = \frac{(82.67\angle 32.14^\circ)(159.15\angle -90^\circ)}{(82.67\angle 32.14^\circ) + (159.15\angle -90^\circ)} = 97.55\angle 0.85^\circ$
Power factor, PF = $\cos\theta = \cos(32.14) = 0.85$	$I = \frac{V}{Z} = \frac{240V}{(97.55\angle 0.85^\circ)} = 2.46\angle -0.85A$
Calculation of capacitor value for power factor correction, True Power = P P = 591.6W Apparent Power = S S = 696VA Reactive Power = Q Q = 366.64VAR $X = \frac{(240)^2}{366.64} = 157.10$ C = 20.26μF	New power factor, PF = $\cos\theta = \cos(0.85) = 0.9998$

3.8 Simulation Result for Hair Dryer

Fig. 6 shows the circuit of hair dryer as a load and initial power factor value before the correction process. To determine the power factor, a wattmeter in the NI Multisim software is employed. On the right side of the image, the power factor is measured using a wattmeter. After constructing the inductive load circuit, which simulates a load similar to a clothes dryer, the power and current are measured. To ensure the correction is effective, a voltage check is performed at 240 VAC using both a wattmeter and a multimeter to measure the current and power factor. Table 3 explains the power factor of the circuit increased significantly from 0.85 to 0.99 and the same figures demonstrated in simulation result shown in Fig. 7.

Two parallel capacitors have led to a reduction in the circuit's current output from 2.9 A to 2.454 A. This can be seen from Fig. 8 and the drop in current indicates improved efficiency and reduced power consumption in the circuit.

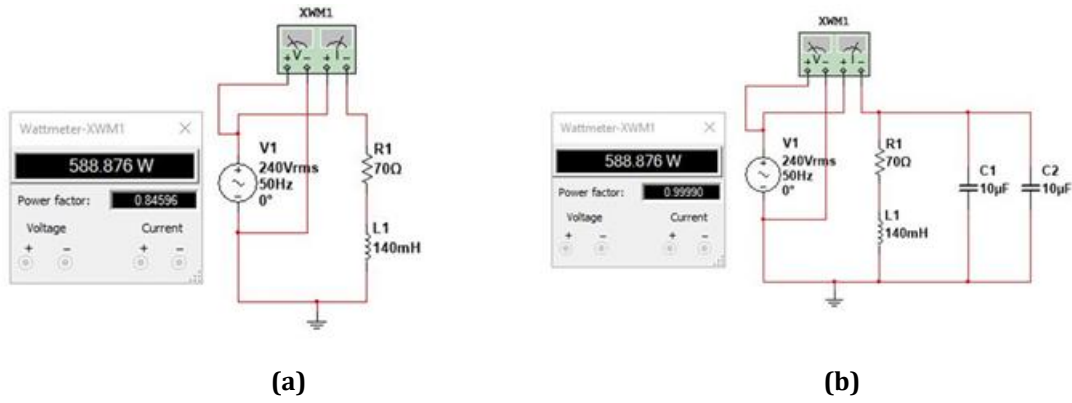


Fig. 7 Power factor of hair dryer circuit (a) before adding capacitor; (b) after adding capacitor



Fig. 8 Current of hair dryer circuit (a) before adding capacitor; (b) after adding capacitor

3.9 Total Loads

All the loads that been analysis above are assemble in one circuit as depicted in Fig. 9. This represents the appliances in daily use of the consumers. Two major point that will be analyze are the value power factor and current using wattmeter and multimeter for before and after adding capacitor. The value of power factor and current of the circuit improve significantly after capacitor been added to the total loads circuit. The power factor of the circuit increases and near to unity while the value of current decrease.

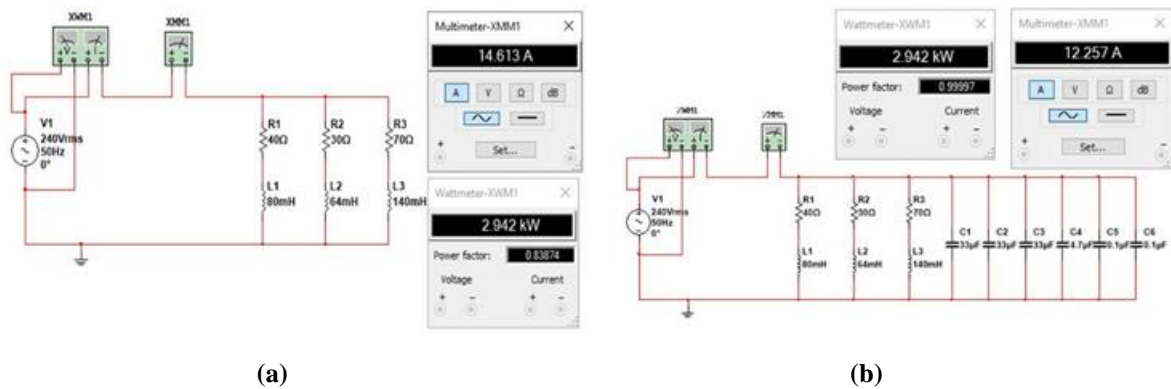


Fig. 9 Value of power factor and current for total loads circuit (a) before adding capacitor; (b) after adding capacitor

3.10 Total Loads

The simulation results are summarized in the Table 4 below, demonstrating all the improvements made to bring the power factor closer to unity.

Table 4 Table for result of simulation

Load	P (W)	Q (VAR)	S (VA)	I (A)	PF	I (A)	PF
Clothes Dryer	1036.32	642.25	1219.2	5.08	0.85	4.30	0.9993
Refrigerator	1322.69	888.85	1593.6	6.64	0.83	5.52	0.9998
Hair Dryer	591.6	366.64	696	2.90	0.85	2.46	0.9998
Total Load	2950.61	1897.74	3508.8	14.61	0.84	12.26	0.9997
Before PFC Installation						After PFC Installation	

4. Conclusion

Based on the conducted study, power factor correction devices find extensive usage in commercial and industrial sectors. However, they are not commonly employed or well-known among residential power users. The primary reason for this disparity is that commercial and industrial users face charges based on their low power factor, while residential users are not penalized for having a low power factor. The research findings indicate that the installation of an effective power factor correction device can result in a reduction in line losses and cost savings on electricity bills. This is attributed to the fact that a corrected power factor enhances electrical efficiency within the electrical system. The experiments conducted during the research revealed an increase in power factor upon connecting an appropriately sized capacitor. Overall, this research project has provided valuable insights into power factor and power factor correction devices, offering a better understanding of their significance and potential benefits.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors attest to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

References

- [1] Tony. R, Kuphaldt, John, H. (2020, June 1). *Power Factor Correction*, Iastate.pressbooks.pub, iastate.pressbooks.pub/electriccircuits/chapter/power-factor-correction/.
- [2] Storr, W. (2016, August 10). Power Triangle and Power Factor in AC Circuits. *Basic Electronics Tutorials*. <http://www.electronics-tutorials.ws/accircuits/power-triangle.html>.
- [3] Solomon, Ermias (2010). AT Load Power Factor Correction Final Report. *Www.academia.edu*, http://www.academia.edu/36464489/AT_LOAD_POWER_FACTOR_CORRECTION_FINAL_REPORT_AUGUST_2010.
- [4] Ararso ,T. (2018). Design And Simulation Of Automatic Power Factor Correction For Industry Application, 5(2), *International Journal of Engineering Technologies and Management Research*.
- [5] Patilkhede, D., Sairaj, G. (2017). Automatic Power Factor Correction Using PIC Microcontroller. *Www.academia.edu*, https://www.academia.edu/31011342/Automatic_Power_Factor_Correction_using_PIC_Microcontroller_January_2017