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Design of Voltage fluctuation and Arc fault Protection for home appliances

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ABSTRACT

Power surges and arc fault tripping can occur simultaneously and can happen both at the same time. Nowadays, there are only few devices that can protect one at a time. The objective of this study is to design and develop a prototype where a surge protector and an arc fault interrupter can be integrated into a single device. The main components to develop this device are power surge protector and AFCI. To further support this study, the researchers conducted thorough data analysis and testing. The data analysis conducted by the researchers has three (3) phases. The first phase is to determine if the surge protector is working given its function. At a voltage of 180-265 volts, the surge protector reacted at an average of 1 minute and 34 seconds to normalize the flow of voltage. The second phase of testing is to determine if AFCI is working given its function based on different scenarios such as touching a test probe to a wrong surface, worn or loose connection, gaps in insulation, and corrosion. Finally, the last phase is to integrate power surge protector and AFCI where a simple parallel connection was successfully used.

Keywords: *Voltage Fluctuation, Arc Fault Protection*

1. INTRODUCTION

During power grid switching, power surges might come from an electric utility business. They can also happen if a neighbouring transformer or transmission line malfunctions. Lightning strikes can cause some of the most intense power surges on the planet. Within the home, power surges can also occur. A lesser power surge can occur when high-powered electrical equipment, such as an air conditioner or refrigerator, is turned on or off. Because the motors and compressors in these appliances consume so much energy to turn on and off, the transient power demand disrupts the electrical system's steady voltage flow. The power that flows through a standard wall outlet is 120 volts of AC power. However, the voltage is not always delivered at 120 volts; it can range from 0 to 169 volts. The voltage exceeds 169 volts during a dangerous power surge. This study focuses on the combination of a power surge protector and an arc fault circuit interrupter (AFCI) that can help in modern life. It is usually used in old appliances as protection against power fluctuations, and a good surge protector, also known as a surge suppressor or surge diverter, can help protect your home from damage caused by power surges. (Crank, 2016).

Arc fault circuit interrupters (AFCIs) safeguard a home against electrical fires and power fluctuations. They protect against fire-causing arcing in the same way that ground fault circuit interrupters (GFCIs) protect against stray current. When an arc is spotted, the circuit's power is cut off. Damaged or worn wires, faulty wiring, and loose or wet connections are only a few of the causes of arcing. Newer AFCIs can tell the difference between dangerous arc faults and routine arcing induced by fluorescent lighting, dimmers, and switches. Mike Holt, a certified electrician, electrical inspector, educator, and proprietor of Mike Holt Enterprises, a provider of training resources to individuals in the electrical profession and associated disciplines, states that AFCIs provide excellent fire protection in homes with older wiring. AFCI breakers are required by the National Electric Code for circuits providing electricity to bedrooms, living rooms, family rooms, and other common areas in new construction(Hardy, 2020).

As studied by Kolker et al. (2007), There is still obtained data that is used to create trip times for 120 volts and it is rated AFCI despite a very limited number of tests (195). However, the expansion of AFCI application is still continuous from the house's living room up to its bedrooms, and it requires more knowledge about the ignition characteristics at 240 V so that it can be classified as

the times that are needed to clear arcing faults with V AFCIs. In addition, Lee et al. (2012) mentioned that a new generation of residential electrical branch circuit breakers has been introduced, which includes technology for detecting and mitigating the impacts of arcing failures. The invention of the arc-fault circuit interrupter for the prevention of residential electrical fires is reviewed, as well as fire loss estimates attributable to electrical wiring. As mentioned by Engel (2012), Arc Fault Circuit Interrupter (AFCI) protection for bedroom outlets was first introduced to the National Electrical Code (NEC) in 2002. Designers and UL claim that a cut in the cord conductor is dangerous, and that a combination of AFCI, will respond to prevent any injuries or danger, whether inside or outside the home. The author believes the argument is unproven, and explains why the AFCI branch/feeder is not authorised because it provides the most safety at home and is the most affordable. Ground Fault Circuit Interrupters (GFCIs) and Arc Fault Circuit Interrupters (AFCIs) are the two types of electronic protection specified by the Code for all residential development branch circuits (AFCIs). The garage, kitchen, bathroom, and other areas fall into this category. To avoid accidents, the GFCI must be shielded, while AFCIs must be installed throughout the residence. Cruz and Alvin (2011) stated that one of the most important things to consider in analysing a power system is surge protection in any electrical system that can cause us damage.

Some devices nowadays can only perform one of two functions: power surge protection or arc fault circuit interrupter. According to Cruz and Alvin (2011), surge protection in any electrical system that can cause us damage is one of the most critical things to consider when examining a power system. Also, Engel (2012) said in his study that UL claims a cut in the cord conductor is dangerous and that a combination of AFCI and UL will respond to prevent any injuries and danger, whether inside or outside the home. Where there is no device that can perform both functions on a single device, like when experiencing a power surge, a power surge protector will be triggered, but if an arc fault happens thereafter, nothing will detect it, which in many cases may result in an electrical fire or worse, household burning. As a result, the purpose of this research is to:

a. Develop a prototype of integrated Power surge protector and Arc fault circuit interrupter(AFCI)
b. Understanding the process of incorporating power surge protector and arc fault circuit interrupter on a single device.

2. METHODS

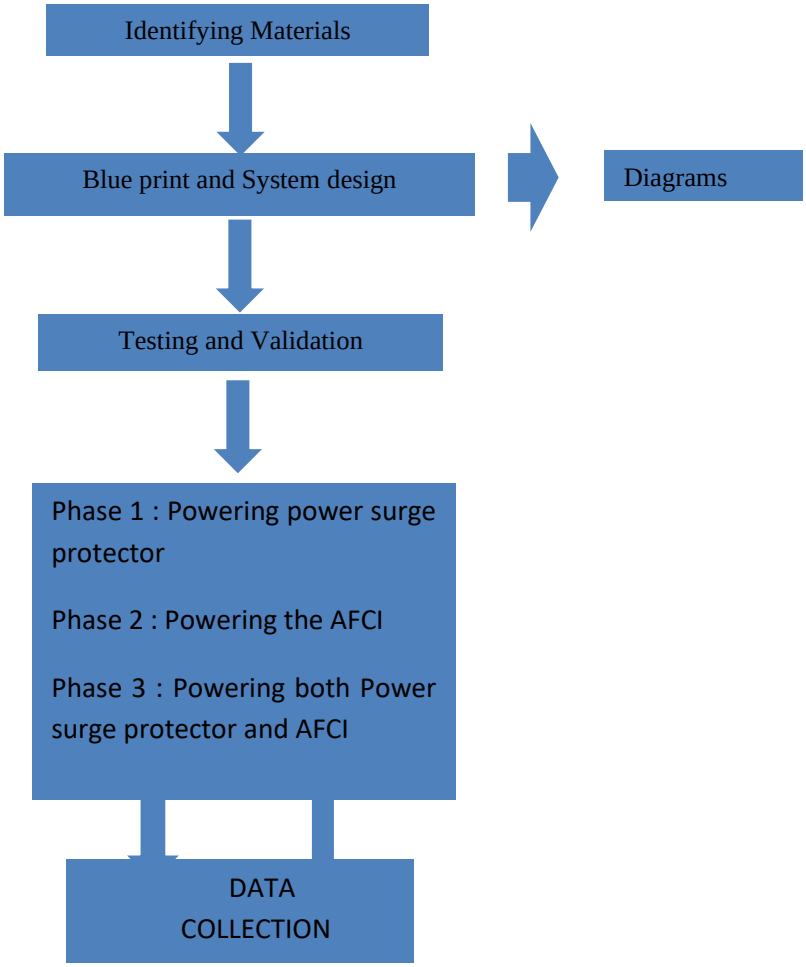

Figure 1. Research Framework

The methods used in this study includes proper selection of components, designing a blueprint, and testing and validation along with data collection and trial and error.

i. Identification of tools and materials to be needed.

The selection of components is important in this study as it would determine the proper setup of the device. Power surge protector and AFCI are the main components to achieve the objectives of this study.

The Power surge protector used in this study is a 15 ampere and can hold up to 3300 watts that is suitable for home appliances: television, refrigerator, audio player, mobile charger and electric fan. However, the power surge protector used by the researchers has a delay function of 2-4 minutes.

The AFCI used in this study is a Cutler-Hammer that has a 15 ampere capacity and can hold up to 10 kilo ampere interrupting capacity. The researchers also considered the availability of the device on the local and international market. However, the AFCI acquired by the researchers holds up to 120 volts capacity only instead of the expected 220 volts. Thus, to meet the capacity of AFCI a converter is used so it can step down the voltage from 220 volts to 120 volts.

The researchers used an Arduinno uno that has a limit of an input voltage of 7-12 volts, along with the AC current sensor, AC voltage sensor and LED sensor where the Arduinno uno is programmed to detect and read the amount of voltage and current flowing through AC current sensor and AC voltage sensor that will be shown on the LCD screen, while the LED indicates if it is normal, over voltage or under voltage.

ii. Components Layout and Diagram/Blueprint

The single line diagram shows direct connection of the device from the AC power source up to the load (appliances). It is a general concept of how the device works, wherein the power source is the AC source that will power the power surge protector up to the AFCI where the load or appliances are plugged in. While a grounding slot is available if the appliances plugged has grounding.

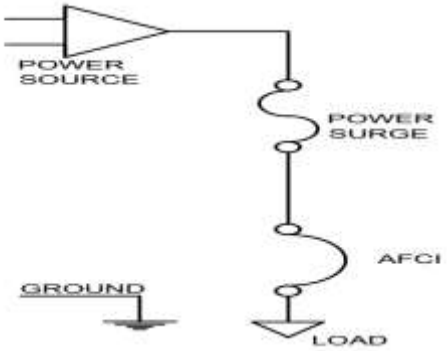

Figure 1.1 Single line Diagram

The wiring diagram shows the detailed connection of the device, where in the first box indicating the overload and underload protection serves as the Power surge protection. The second box shows the 220Vac to 110Vac converter where it step down the voltage coming out from the Power surge protection to meet the capacity of the AFCI which followed next after the second box. The diagram also shows Arduinno uno as an interacting device to monitor the current and voltage flow through AC current sensor and AC voltage sensor that will be shown on the LCD screen.

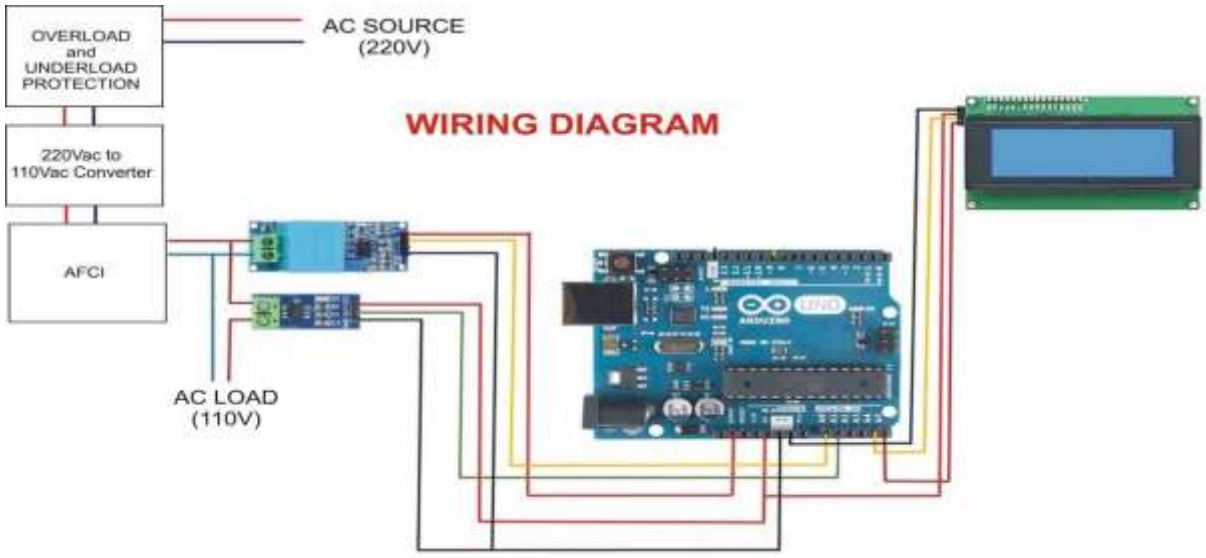

Figure 1.2 Wiring Diagram

iii. Testing and Validation

For the testing and validation of the device, the researchers test first the power surge protection if it's working properly by using an adjustable voltage power supply from 180 volts up to 265 volts as the limit of the power surge protector. Then the AFCI is tested by using different scenarios such us worn or loose connection, gap on insulation, dust, touching a test probe to wrong surface, and corrosion *(see page 6, section b for the details and discussion).*

3. RESULTS AND DISCUSSION

a. Powering up the Power surge

Table 1.0 Test Results for powering up the Power surge protection.

TESTING	VOLTAGE (V)	CURRENT (A)	POWER (W)	DELAY	LED SENSORS
1	265	0.23	60.95	1 minute and 36 seconds	Over Voltage
2	265	0.23	60.95	1 minute and 40 seconds	Over Voltage
3	180	0.33	59.4	1 minute 20 seconds	Under Voltage
4	265	0.23	60.95	1 minute 43 seconds	Over Voltage

During testing the researchers used adjustable voltage power supply as a surge maker to verify if it works properly and the LED sensors will show if the voltage is under (180-199 volts), normal (200-250 volts) and over voltage (251-265 volts). The researchers specifically conducted four (4) trials. On the first trial, at 265 volts with a current of 0.23 and 60.95 watts the surge protector reacted at 1 minute and 36 seconds to normalize the voltage, thus resulted to over voltage. On the second trial, at 265 volts with a current of 0.23 and 60.95 watts the surge protector reacted at 1 minute and 40 seconds to normalize the voltage, thus resulted to over voltage. On the third trial, at 180 volts with a current of 0.33 and 59.4 watts the surge protector reacted at 1 minute and 20 seconds to normalize the voltage, thus resulted to under voltage. Lastly, at 265 volts with a current of 0.23 and 60.95 watts the surge protector reacted at 1 minute and 43 seconds to normalize the voltage, thus resulted to over voltage. The data shows that the average time for the surge protector to react in normalizing the voltage with range of 180-265 volts is 1 minute and 34 seconds.

b. Powering up the AFCI

For Arc Fault Circuit Interrupter (AFCI)

Table 1.1 Test Results for powering up the AFCI.

TESTING	VOLTAGE (V)	CURRENT (A)	WATTS (P)
By touching a test probe to wrong surface	111.53/227.3	0.41	45.73/93.19
Worn or loose connection	112.4/227.1	0.51	57.32/115.82
Gaps in insulation	111.6/229.3	0.61	68.08/139.87
dust	114.9/231	0.71	81.58/164.01
corrosion	111.9/229.1	0.59	66.02/135.17

The researchers used the following items to generate the various scenarios for powering up the AFCI: 4 meters of no.12 solid type wire, no.12 extension cord, an old male plug soaked in salt water to serve as corrosion, and a convenience outlet with dust or dirt. The live and neutral wires were peeled with a little distance to generate arc flash or arc faults that will manifest smoke, and the outlet wire has a connection where the crank of the screw is not tight enough to show that it is a loose connection.

It is advisable that when performing this experiment, a personal protective equipment (PPE) must be used for safety and precaution purposes.

c. Powering up the AFCI and Power surge protection

Testing both AFCI and Power surge protector.

Table 1.2 Test Results for powering up both Power surge protection and AFCI.

	VOLTAGE (V)	CURRENT (A)	WATTS (P)	STARTING DELAY
1	229.5	0.56	128.52	3 seconds
2	228.1	0.49	111.75	2 minutes and 15 seconds
3	231.2	0.61	141.03	3 minutes and 25 seconds
4	229.7	0.57	131	1 second

This table shows the data of powering both power surge protection and AFCI on different input, and also shown the delay of powering up both devices in the same time. Where the researchers found out different time interval of starting delay depends on how long the device rested after being used.

The device can hold a maximum load of 15 ampere or 1,800 watts as shown on the product description. Hypothetically we can assume that the device can support approximately 58 laptop chargers that has a maximum capacity of 31 watts.

31 watts x 58 laptops charger=1,798 watts

4. FINAL PROTOTYPE

The experiment was originally made and conducted by the researchers.

Figure 1.3 Final Prototype

Our daily lives rely heavily on electricity and the power it provides to our cities, homes, appliances, gadgets, and other technologies. Electricity is a type of energy that we cannot see, hear or smell but do you know how to ensure your safety? We have to be aware of the hazards it can pose to us and the environment. Electrical connection issues have been the top cause of fires in Metro Manila, constituting an average of 53.85% of the total fires yearly. Of the 338 recorded residential fires in Manila, 123 (36.39%) of these were due to electrical ignition caused by arcing, loose connection, overloading, pinched wire, and/or overheated home appliances. Arcing is when electricity jumps from one connection to another, usually caused by a damaged cable or overloaded circuits. (Anonymous, 2007)

Device installation process

1. place the device near the outlet and appliances. make sure that the surface is flat to maintain proportion to the ground. the surface should also be dry to avoid being grounded and possible corrosion.
2. plugged-in the device to the outlet.
3. plugged-in the appliances to the device. the device can hold more than one appliances provided that the total load does not exceed to 1800 watts.

Features of the device

1. Light Indicator Green Light - the device is successfully functioning without any problem Red Light - the device indicates warning that a power surge or arc fault happened.
2. Reset Button A switch used to reset the afci when arc fault happened.
3. LED Screen Displays the amount of current, watts and voltage running on the device indicating if it is normal, under or over voltage.

Caution

TO REDUCE THE RISK:

- Use only in dry locations and only indoors.
- DO NOT shake the device.
- DO NOT plugs an appliances that exceeding 1800 watts.
- DO NOT Plug 220 volts appliances when its converter switch in 220 volts - 110 volts DO NOT use for medical or life support purposes.
- This device features is use for protection of a devices and appliances, but it will keep unprotected power to the load for the rest of its functional life. Note: You can plug different appliances not exceeding 1800 watts.

Note: You can plug different appliances not exceeding 1800 watts

Economical Analysis

Statistical record shows that electrical failure caused by arc faults and power surge cost $1.5 billion in direct property damage a year. Arcing served as the highest record source of home fire incidents in 2015-2019 according to Richard C. (2022).

As of now, the existing home electrical protection devices can only perform either surge protection or Arc fault interrupter. For instance, you may have a surge protection installed to an outlet to avoid damages it may cause on your appliances but a sudden arc fault tripping within household wiring cannot be prevented, likewise an arc fault interrupter vis-a-vis to a power surge, respectively.

Surge protector and AFCI combined only cost at a total of ₱ 4,234.00, the AFCI cost a total of ₱ 3,963.00 that has a capacity of 15 ampere and 10 kilo ampere interrupting capacity, the power surge protector cost a total of ₱ 790.00 with a capacity of 15 ampere and voltage range of 180 volts (under voltage cut off), 220 volts (normal voltage) and 265 volts (over voltage cut off).

Table 1.2 Advantage and Disadvantage of Power surge protection.

Device	Advantage	Disadvantage
Power surge Protection	● Can protect your device from power surge or voltage fluctuations such us lightning surge, black out and etc. ● Small and easy to use.	● Cannot protect your home appliances from arc faults that may occur after a power surge.

Table 1.2 Advantage and Disadvantage of AFCI.

Device	Advantage	Disadvantage
Arc Fault Circuit Interrupter	● Can protect your appliances from arc faults that caused by short connections, loose connections, and gaps in insulations.	● Cannot protect your home appliances from power surge.

Table 1.2 Advantage and Disadvantage of integrated Power surge and Arc faults protection..

Device	Advantage	Disadvantage
Integrated Power surge and Arc Fault protection	● Can perform both power surge and arc fault protections especially when arc fault occur after power surge happens. ● Can plug up to 15 ampere load of appliances. ● Can protect your home from fire caused by electrical malfunctions. ● Requires minimal length of wiring.	● Little bit pricy compared to a power surge protector and AFCI. ● Little bit bulky compared to AFCI and Power Surge Protection.

5. CONCLUSION

Combination of power surge protection and Arc Fault Circuit Interrupter (AFCI) is imperative in maintaining and protecting appliances and devices. This device can be effectively used to prevent damages caused by electrical overload, faulty wiring, lightning strikes, and sudden restoration of power after a power outage or blackout, arcing faults and loose connection. The increase of devices and appliances plugged-in to an outlet has the higher chance of power surge and arc faults to happen which also a common cause of fire.

With several testing conducted, the result shows that this device can work when the appliances are plugged-in to it. Based on the testing and data produced, the device starts after an average delay of 1 minute and 40 seconds. The amount of voltage, current, and watts are usually displayed on the screen of device.

This device is the first of its kind made by researchers. However, certain improvement and innovation must be done so it can be used effectively and install at home safely. Moreover, the required components for this device are not available locally so the researchers had to purchase it outside the country. The AFCI acquired by the researchers has a capacity of 120 volts only thus, a converter was used to match the voltage required. But it is highly recommended that AFCI per so should have a 220 volts capacity to avoid the use of converter and minimize the required components. During testing & validation, when the two protecting devices are triggered, there is a delay of 1-2 minutes due to the capacitors, resistors, and the converter had to be discharged and rest for a certain period of time. Also, the AC Sensor Type used on the device is generic which could perhaps explain why the value of voltage and current displayed on the screen is not accurate. It is therefore recommended to use a quality product for an accurate output.

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