DEVELOPMENT OF PLC-BASED OVERLOAD PROTECTION SYSTEM VIA AUTOMATIC LOAD TRANSFER

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Abstract — **Electrical connection is one of the top three fire originating causes based on Bureau of Fire Protection (BFP). Overloading, electrical arcs, and short circuit are the common electrical fault causes in a system. Load distribution is a common practice used in industries to prevent such accidents, which uses technologies like PLC, Arduino, SCADA, etc. In line with that, industries using high voltage have delicate equipment which are not meant to be interrupted. The project is a development of a system that provides protection against overloading through load distribution without interrupting normal operation. It uses a PLC that receives signals from the Arduino, which communicates with the Power Analyzers that read the current and power that is being used by an outlet. An Arduino-based system was developed to distribute the loads, irrespective of where it is connected. The touchscreen LCD is used to operate the machine, whose functions are to monitor the loads, adjust parameters, and provide an easy-to-use user interface. The results gathered shows that the developed overloading protection system can distribute loads to other outlets through the PLC-Arduino system without interrupting the operation and will only turn off in case of an addition of a load that surpasses the allowable load per outlet. The study used the prototyping method which verified the feasibility of the desired process and output. It underwent various tests and evaluation process from the initial to its final iteration.**

Keywords—*Overloading, Load distribution, Programmable Logic Controller, Arduino-based load transferring, Load balancing, Load switching, Load monitoring*

I. INTRODUCTION

Overloading happens when there is a load on a circuit that draws more power or current than what the system can handle, which is a common electricity-related cause of fire. Based on studies conducted by the Fire Statistics of the Philippines over 57% of fire break outs in the Philippines were caused by electrical connections. Machine repairs, interrupted systems, equipment replacements, among others, were the usual result of overloading in a system. Due to the magnitude of the problem, various devices were created to counter it, such as circuit breakers, fuses, and manual and automatic load transfer switches. These equipment's were widely used in the industry for the sole purpose of protecting a circuit or machine. Although it provides protection to systems, it lacks the ability to transfer loads to more areas or to avoid the interruption of certain loads.

The project aims to protect electrical systems from overloading. This will provide continuous protection for the machines and has a wide range of applications in residential, commercial, or industrial systems. It can also be utilized for monitoring and controlling of the factors affecting the system's loads.

II. METHODOLOGY

A. Project Design

The construction of the project is divided into three main parts: the main frame, the shelves with the equipment's and the programming. The materials were available in the market, making the project construction more straightforward. Through research and understanding of the project concept, all the necessary information about the projects including its capabilities, limitations, price and efficiency, which will be needed in making the project were gathered. The main assembly or the frame of the whole project is composed of the cabinet with shelves. The foundation of the main frame is made using aluminum steel bars, fastened with stainless steel bolts and nuts. The walls are made by parts with acrylic for the front and upper walls, and marine wood for the side walls installed with DC fans on both sides. The drawers used are roll-out types for all the shelves excluding the lower base area. The equipment installed are consist of PLC and Transistor Switches on the top shelf. The middle shelf is consisted of SSR's and Current Transformers. The lowermost level is consisted of 12V DC Power Supply, CB, Arduino and Power Analyzer. The machine is supplied using 230VAC which will be converted into 5 and 12VDC which will power the Arduino and SSRs. The PLC is the one that will trigger the SSRs to open and close the lines which are protected by circuit breakers, connected to the outlets. Each outlet wire has its own power analyzer which will send the signal to Arduino to measure the current for each line. The signal will be analyzed and balanced in the Arduino and the status will be shown on the LCD touchscreen and sent the signal to the PLC for triggering.

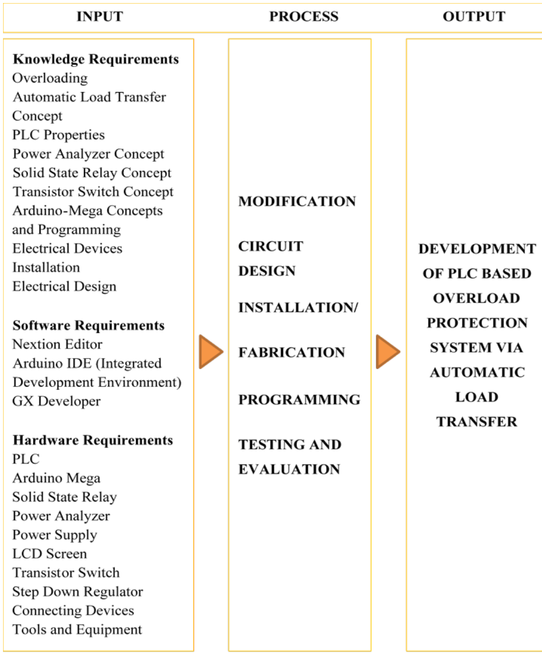

Fig. 1. *Conceptual Model of the Study*

B. Circuit Design

I. System Flowchart

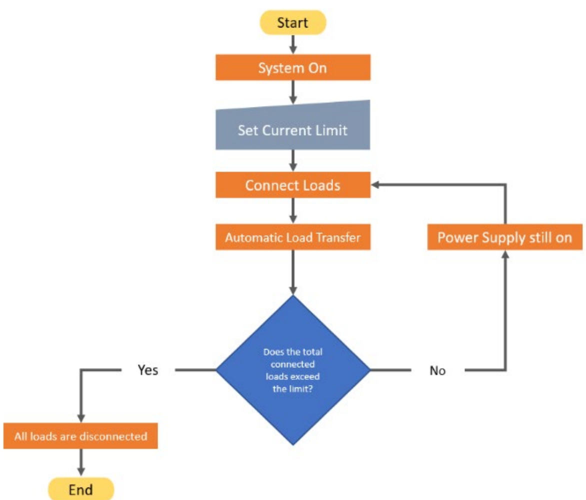

Fig. 2. *Conceptual Model of the Study*

II. Schematic Diagram

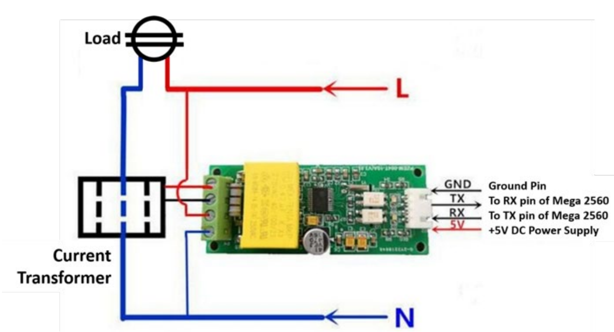

Fig. 3. *PZEM-004T-100A Connection Diagram*

The figure shows how the power analyzer, which is rated for 100A, is connected to the machine. There are 2 parts of the power analyzer: the measuring side, composed of the current transformer that is placed on the one line of the supply conductors that measures the current, and the integrated circuit that reads the voltage; and the logic part which is the board containing the integrated circuits that process the information given by the current transformer and integrated circuit. There are 6 power analyzers used in the machine, all of which are located near the Arduino. The current transformers encompass one line of the supply conductors.

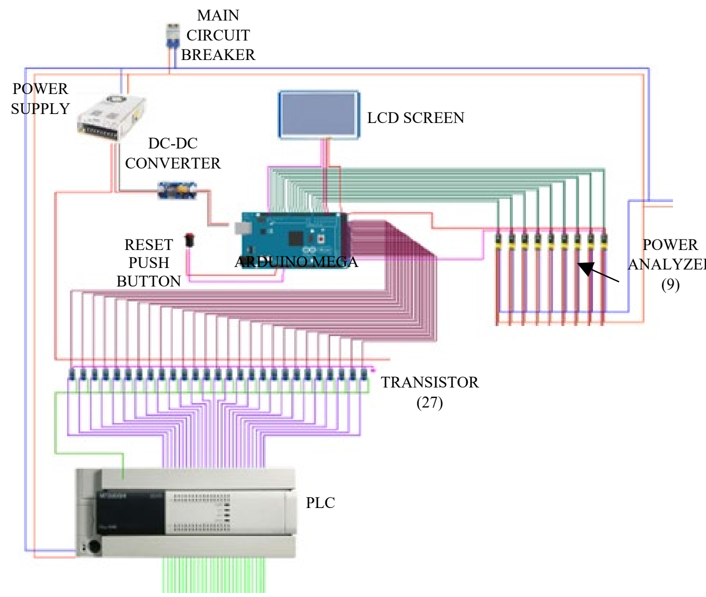

Fig. 4. *Schematic Diagram of the Project (Part 1) (Main Breaker, Arduino, PLC, Power Analyzers, LCD Screen, and DC Power Supplies)*

The figure represents the monitoring and logic side of the schematic diagram, how everything, from the LCD screen, PLC, and Power Analyzers are all connected to the Arduino. The data gathered by the analyzers are transferred to the Arduino, which then translates the data to numerical value that is displayed in the LCD. The current limit can be changed using the LCD, and when the current limit is changed, the Arduino checks whether or not that the current at the moment does not exceed the newly set limit, if the new current limit is exceeded, the Arduino disconnects all the outlets from the grid. Otherwise, the machine operates as normal.

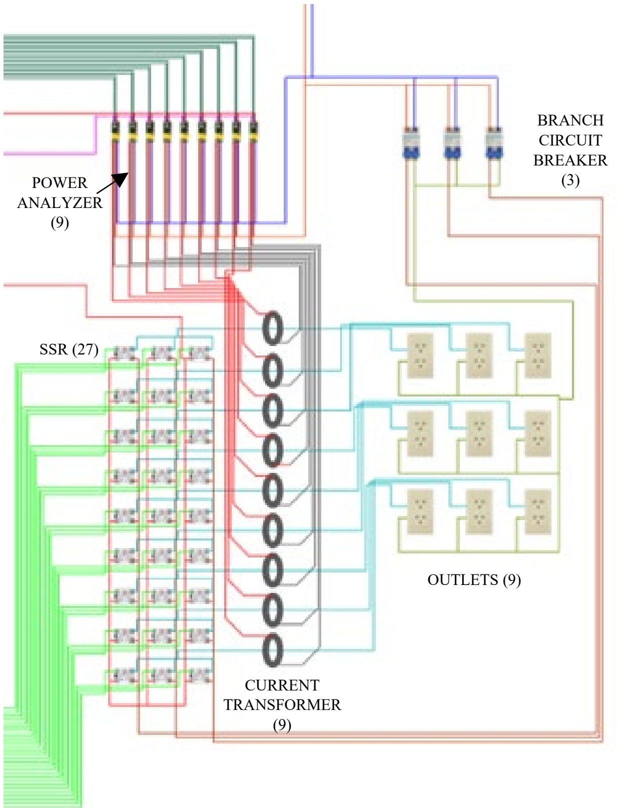

Fig. 5. *Schematic Diagram of the Project (Part 2)*
(Solid State Relays, Power Analyzers, Branch Breakers, and Convenience Outlets)

As the current limit is set on the LCD, once a circuit gets overloaded, the Arduino sends a signal to the PLC to disconnect all circuits from the grid. Each Solid State Relay (SSR) is connected to a terminal in the PLC, each outlet is connected to 3 SSRs, and 1 SSR per outlet is connected to one of the three branches. Each outlet has a current transformer connected to it to measure the current being drawn on it and sends it to the Arduino. That data helps the Arduino balance, control, and monitor everything. The SSRs that are each connected to a branch circuit, allows us to control which branch the outlet will be connected to, and allows us to achieve effective load transfer and balancing. While all of this is happening and as long as the current limit is not being exceeded, the Arduino constantly balances the three branches of the loads that are currently being drawn from them, and re-balances every time a new load is connected. In the case of an overload or if the current limit is exceeded, all of the outlets are disconnected. In order to restore operation of the machine, simply disconnect some, or all, loads, and reset the machine via the button next to the LCD or reset the breakers if they trip.

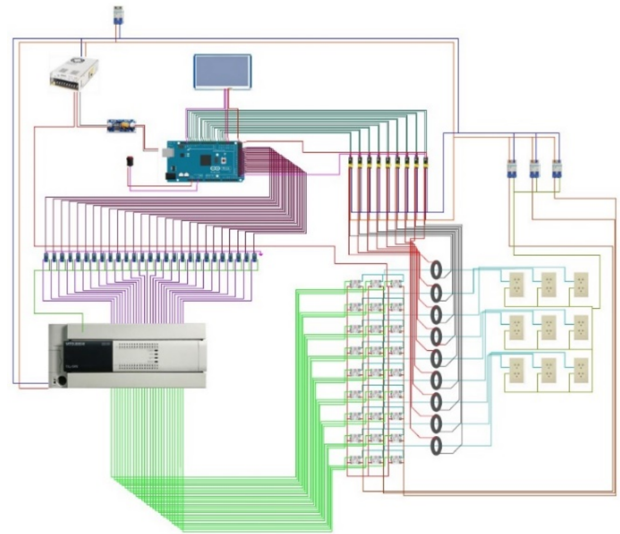

Fig. 6. *Schematic Diagram of the Project (Whole)*

The diagram shown is the whole schematic diagram of the system.

C. Main Assembly

Fig. 7. *Frame*

The main body of the project was made of steel as its main skeleton, with walls made of acrylic glass and wood. The skeleton has a dimension of (750 x 950 x 500mm). The acrylic sheets were measured after the construction of the skeleton.

Device Installation in Shelves

The inside shelves are made of aluminum sheets to maintain high heat dissipation and structural integrity. The layout of the measurement ensured that the wires passing at the front and back of the aluminum are able to pass with enough space. The 9 outlets are layout at the acrylic walls at the front of the project. The dimension used for this is the measurement of the back of the outlets, so it will fit in the acrylic walls evenly. The equipment to be placed, which are, 27 solid state relays, a PLC, Arduino, etc., all measured and placed strategically in the aluminum sheets, together with the DIN rails and screws.

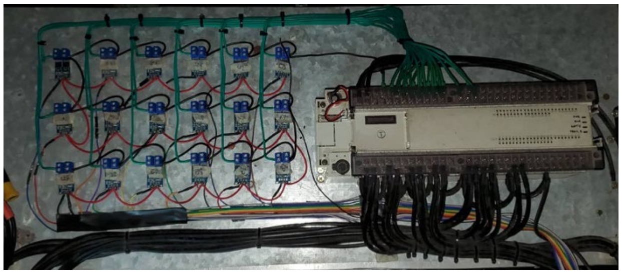

Fig. 8. *Top Shelf (PLC with Transistor Switches)*

The top shelf consists of PLC and transistor switches. The transistor switches send signals to the PLC for the Solid State Relay to switch on/off and to which circuit the load must be distributed.

Fig. 9. *Middle Shelf (PLC with Transistor Switches)*

The middle shelf is composed of current transformer coils and the Solid-State Relay. The current transformer is the one that monitors the changes in current in the outlet and sends this data to the power analyzer and to the Arduino for further analysis. When the Arduino has processed this data, it will send a signal to the transistor switch to trigger the PLC to send a signal in which the circuit must distribute its load.

Fig. 10. *Lowest Shelf (Power Analyzer, Circuit Breakers, Power Analyzers, and Arduino)*

The bottom shelf consists of It is composed of three branch circuit breakers with a capacity of 20A. A power supply is a very crucial piece of equipment as it is the one that provides a 12V DC supply for the PLC; add a DC-to-DC step down converter to provide a 5V DC supply for the LCD, Arduino, and power analyzers to work properly; power analyzers that receive signals from their current transformer that will be delivered to the Arduino for processing and analyzing data; and lastly, the Arduino, wherein all the data is processed and analyzed.

Fig. 11 & 12. *Actual image of the Project*

Programming

I. Nextion Editor

This application is used for the LCD screen to display variety of images, information, control parameters and etc., for users to have a brief introduction of who made the project or what is the function of the project, this application help us set-up, sets of controls to help users select the current limit for our designed system, this enabled us to summarize the important info we need to determine if the system is working properly.

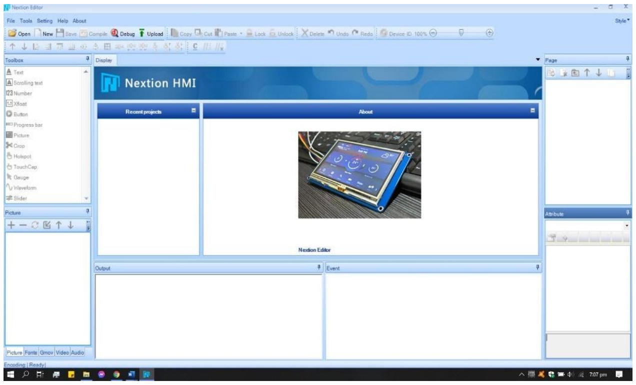

Fig. 13. Nextion Editor

II. Arduino IDE (Integrated Development Environment) Application

This application is the core of the project, without this the project wouldn't work properly. This application is the appropriate one to use, for it is the best choice among the other compatible applications, as it is ready made along with the component used in the project. It is used for making codes to control the process of the system automatically.

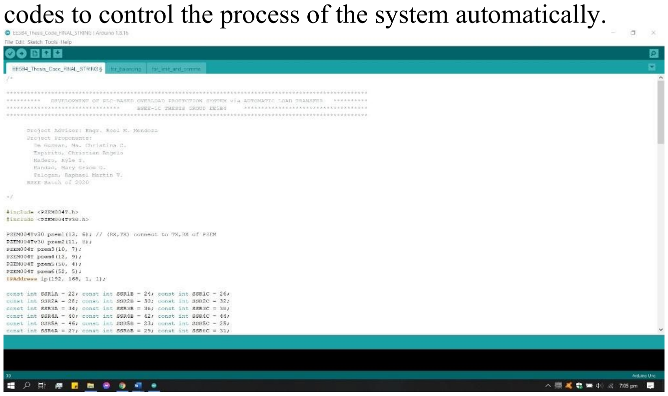

Fig. 14. Arduino IDE

III. Gx Developer

This application is used for the PLC (Programmable Logic Circuit) to function properly. It is a program that controls how the component will control the circuit/system. This application is ready made along with the component used for our project.

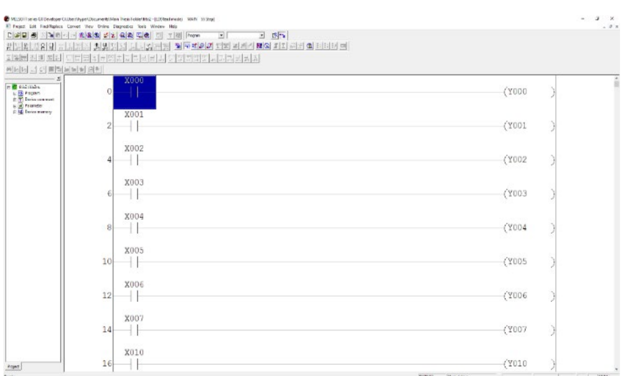

Fig. 15. GX Developer

Testing Procedures

To test the functionality and limits of the equipment, three different tests are conducted; Functionality Test, Stress Test, and Simultaneous Load Test. Functionality Test is a series of test with different scenarios possible when operating the equipment to see if it gives the result expected from how it was designed and programmed. Stress Test is a test if it can protect the system from short circuit current. And lastly, Simultaneous Load Test is a series of test with different time delay per second when two simultaneous loads are plugged-in to the device and still work on how it was designed.

III. RESULTS AND DISCUSSION

FUNCTIONALITY TESTING

Test 1: Adding in an initially no-load machine

CURRENT LIMIT: 2A		
	BEFORE	AFTER
LINE A	0 A	0.23A
LINE B	0 A	0 A
LINE C	0 A	0 A

Summary: 2A load is given to load 1 which is connected to line A. Line B is set for the next load.

Test 2: Adding in a one-line machine

CURRENT LIMIT: 2A		
	BEFORE	AFTER
LINE A	0.23A	0.23A
LINE B	0 A	0.11A
LINE C	0 A	0 A

Summary: A load is given to load 2, and it connects to line B, so the load transfer is successful while line C is set for the next load.

Test 3: Adding in a two-lines machine

CURRENT LIMIT: 2A		
	BEFORE	AFTER
LINE A	0.23 A	0.23 A
LINE B	0.11 A	0.11 A
LINE C	0 A	0.17 A

Summary: A load is given to load 3, and it connects to line C and line B is set for the next load.

Test 4: Adding in a three-lines machine

CURRENT LIMIT: 2A		
	BEFORE	AFTER
LINE A	0.23 A	0.23 A
LINE B	0.11 A	0.47 A
LINE C	0.17A	0.17 A

Summary: A load is given to load 3, and it connects to line B

Test 5: Adding overload in a three-lines machine

CURRENT LIMIT: 2A		
	BEFORE	AFTER

LINE A	**0.23 A**	**1.91 A**
LINE B	**0.47 A**	**1.87 A**
LINE C	**0.17 A**	**1.92 A**

Summary: 4A load is given to load 4 and load 4 is automatically disconnected from the system and the system needs to reset to start adding load.

Test 6: Removing loads

CURRENT LIMIT: 2A		
	BEFORE	AFTER
LINE A	1.91 A	1.91
LINE B	1.87A	1.87
LINE C	1.92A	1.08

Summary: Load at load 3 is removed and set as the lowest value and ready for the next load.

STRESS TEST RESULT

TEST 1: No Load

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	TRIPPED
LINE B	0A	0A
LINE C	0A	0A

Summary: After shorting an outlet, Main breaker of Line A tripped.

TEST 2: Line A has one load

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	2.45A
LINE B	0A	BREAKER TRIPPED
LINE C	0A	0A

Summary: After shorting an outlet, Main breaker of Line B tripped.

TEST 3: Line A and Line B have one load

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	2,45A
LINE B	0A	1.51A
LINE C	0A	BREAKER TRIPPED

Summary: After shorting an outlet, Main breaker of Line C tripped.

FUNCTIONAL LOAD TEST

TEST 1: Simultaneous similar loads at outlet 1 and outlet 2

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.53A
LINE B	0A	0A
LINE C	0A	0A

Summary: Both loads were set into line A and still reads in line A only.

TEST 2: Simultaneous similar loads at outlet 1 and outlet 2 with a 1 second interval

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.53A
LINE B	0A	0A
LINE C	0A	0A

Summary: Both loads were set into line A and still set in line A with 1 second interval.

TEST 3: Simultaneous similar loads at outlet 1 and outlet with 2 seconds interval

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.26A
LINE B	0A	0.26A
LINE C	0A	0A

Summary: The loads are separated into Line A and Line B with 2 seconds interval and reads separately with line A and B.

TEST 4: Simultaneous similar loads at outlet 1 and outlet with 3 seconds interval

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.26A
LINE B	0A	0.26A
LINE C	0A	0A

Summary: The Loads were set into line A and line C with 3 seconds interval and reads with line A and B.

TEST 5: Simultaneous similar loads at outlet 1 and outlet with 4 seconds interval

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.26A
LINE B	0A	0.26A
LINE C	0A	0A

Summary: The loads are separated into Line A and Line B and reads also separately with line A and B.

TEST 6: Simultaneous similar loads at outlet 1 and outlet with 5 seconds interval

CURRENT LIMIT: 20A		
	BEFORE	AFTER
LINE A	0A	0.26A
LINE B	0A	0.26A
LINE C	0A	0A

Summary: The loads are separated into Line A and Line B and reads separately with line A and B.

Summary of Findings

In summary, when it has equal or no loads, the project will prioritize loading form line A to line C in that order. The project always prioritizes the line with lowest load. When a line is overloaded, it will automatically disconnect the outlet where the last load is added. All tests have been able to prove that the machine is able to protect the system from overloading and able to transfer load automatically.

Conclusions

Therefore, using the results, the researchers were able to conclude that by adding a load or loads to the machine will automatically distribute the load to the lowest available current rating between the three-branch circuit with respect to the order in which the loads were connected. The parameters: voltage, current and, power is accurately monitored by the power analyzers and is shown to the LCD to guide users in using it. The limit of 20 Amps per branch circuit can be utilized for single-phase loads only. through our tests we see that by setting the current limit the machine responds accordingly to the set limit. The set limit can vary from 1-20 amps, depending on the intended usage. Overloading and a short circuit in the system won't affect the loads that are already connected in the machine, as the last load added that can cause overload will be automatically cut-off in case that the set limit is exceeded. The machine takes 2-4 seconds based on the test results to respond before being able to balance the next load.

Recommendations

The following recommendations are suggested to achieve maximum capabilities of the project.

I. To make the project more flexible to three phase loads.

II. Make the electrical equipment put as wall mounted to it easier to wire, troubleshoot and change equipment when an electrical equipment failure occurs.

III. Make the frame as small as possible to lessen the weight of the project.

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