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The design of automatic three phases load balancing for dynamic electrical installation

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Abstract. This paper discusses the automatic design and simulation of The Three Phase Load Balancing in consumers' three-phase electrical installations with a single-phase load. This approach solves many constraints of load imbalance, which is installed as a three-phase source for the consumers. The process of manually changing an electrical installation and adding new loads is very difficult. This load imbalance causes a one phase voltage source to be overloaded, while the other voltage sources are still not fully loaded. Implementing the automatic system makes the electrical installation dynamic, so that changing installation and adding new loads will be easier. The Automatic Three Phase Load Balancing comprises two types of control that integrate with each other, namely Central Controller and Unit Controller. The Central Controller is used as a data processor for overall loads. Several Unit Controllers are used as switches connection among phases in each load group. Based on the simulation results with MATLAB Simulink, this system can manage loads so that a balance is achieved in each phase. The more the number of load groups in an electrical installation, the better the load balance is obtained.

1. Introduction

Consumers with large power consumption will be provided a three-phase power grid by the power company [1]. With this three-phase network, the consumers must independently manage the electrical loads installed, so that these three network sources are used equally. In fact, most consumers with three-phase sources only have single-phase load. This will raise a problem of complexity in installing loads. It is because it requires installing a clear data on the single-phase load, so that the loads do not collect in one of the wire phase that come out of the Kwh meter. In addition, changing the installation of the loads because of various reasons, have to reconfigure the other loads that have been installed previously. A poor management during installing the loads will cause the power used at the three-phase source from the Kwh meter, not maximal [2][3].

The designed and simulated Automatic Three Phase Load Balancing in this article is an automatic system that is expected to ease the installation of electrical loads with a three-phase source for the consumers[4][5]. In the realization of this design, the biggest challenge is the need for a communication system that is fast and real time. However, seeing the development of data communication technology that is getting faster and with increasingly affordable costs, it would no longer be a problem. With a data communication device that is fast and inexpensive, this design is very possible to be implemented at low cost and its durability.

In general, the development of this automatic device design lays on two types of data processing tools, namely: Central Controller and Unit Controller. Every installed three-phase Kwh meter requires



one Central Controller. While the required number of Unit Controller depends on the three-phase Kwh meter amount of power. The loads installed in an electrical installation at the consumer are grouped into several load groups, so that each load group must have one Unit Controller. The more load groups on the electricity installed at a consumer are, the more Unit Controllers are required. This Unit Controller has a duty to switch one of the wire phase that have been determined by the Central Controller.

This Automatic Three Phase Load Balancing design is simulated by using MATLAB Simulink. The controller was programmed with Stateflow. Simulink-Stateflow [6] is generally used for modeling, simulation, and controlling embedded design prototypes systems. Simulink is a block diagram used to model a continuous system, while Stateflow is for logical control and to model state-based system behavior. Simulink-Statflow is widely used to develop embedded safety systems.

2. Automatic Three Phase Load Balancing Diagram

The application of this design is for three-phase electricity consumer so that the installation can be dynamic. At a Kwh meter of the three-phase electricity consumer, there are four connected wires, namely: phase 1 wire, phase 2 wire, phase 2 wire, phase 3 wire, and neutral wire. The instantaneous voltage waveform in each of these cables are formulated as follows [7].

$$v_{wire1} = \sqrt{2}V_m \cos(\omega t + \phi) \text{ volt} \quad (1)$$

$$v_{wire2} = \sqrt{2}V_m \cos(\omega t + \phi - 120) \text{ volt} \quad (2)$$

$$v_{wire3} = \sqrt{2}V_m \cos(\omega t + \phi - 240) \text{ volt} \quad (3)$$

$$v_{wire_netral} = 0 \text{ volt} \quad (4)$$

From this formula it can be understood that the maximum voltage of each wire phase that comes out of the Kwh meter is different at the same time. With a frequency of 50 Hz, in each wire phase, 50 times of the positive peak voltage occurs, and 50 times of the negative peak voltage occurs in one second. When the voltage in the phase 1 wire is at a positive peak, the voltage in the phase 2 wire and in the phase 3 wire is at half negative peak. This indicates that the current pushed from the phase 1 wire to the load will enter the phase 2 and 3 wire, and not to neutral wire. Ideally, the loads connected to each wire phase are exactly the same, which is formulated as follows [8].

$$i_{wire_netral} = i_{wire1} + i_{wire2} + i_{wire3} \quad (5)$$

When the loads are attached to each wire phase equally and ideally, the flowing current in the neutral wire is zero. In this condition, the neutral wire does not actually need to be in the consumers' electrical installation. However, in reality this will never happen, because single-phase loads attached to each wire phase cannot possibly be exactly the same. Therefore, a neutral wire is needed as a current counterweight. The greater current entering or leaving the neutral wire, indicates that a load imbalance installed in a consumer is very large.

This statement needs to be straightened out by looking at the scope of the attached loads. As the Kwh meter is not an installed generator (only as a current sensor), while a wire phase is also connected to other consumers, the current in the neutral wire from the Kwh meter cannot be used as an indicator of consumers' load imbalance. Based on this, the proposed design does not do a sensor on a neutral wire, but only installs the current sensors in each wire phase which come from the Kwh meter [9]. To determine the load balance of the consumers, it can be done by comparing the currents in three wire phase. The waveform that represents the amount of instantaneous current in each wire phase is as follows:

$$i_{wire1} = I_p \sin(\theta - \phi) \text{ Ampere} \quad (6)$$

$$i_{wire2} = I_p \sin\left(\theta - \frac{2}{3}\pi - \varphi\right) \text{ Ampere} \quad (7)$$

$$i_{wire2} = I_p \sin\left(\theta - \frac{4}{3}\pi - \varphi\right) \text{ Ampere} \quad (8)$$

$$i_{wire_netral} = \text{can not be defined} \quad (9)$$

The waveform of the current in each wire phase has different characteristics from the waveform of voltage. A voltage waveform is not affected by load size and the type of load, while the waveform of the current is affected by load. The amount of load will affect I_p (peak current), while the type of load will affect φ (phase angle). Loads that are purely resistive will have a phase angle of zero. The amount of I_p (peak current) for non-resistive load is as follows.

$$I_p = \frac{V_p}{|Z|} \quad (10)$$

$$Z = Ze^{j\varphi} \quad (11)$$

The average current is used to determine the amount of current in each wire phase, not the peak current. The reason for using this average current is based on the concept that all electrical devices, whether it is Kwh meter or breaker, have inductive and capacitive values. With this value, the maximum current limit of a device is not determined by the instantaneous peak current value, and yet by the amount of the current over the range of time. A device that has a capacitive value circuited in parallel will slow down the time of the current flows through the device.

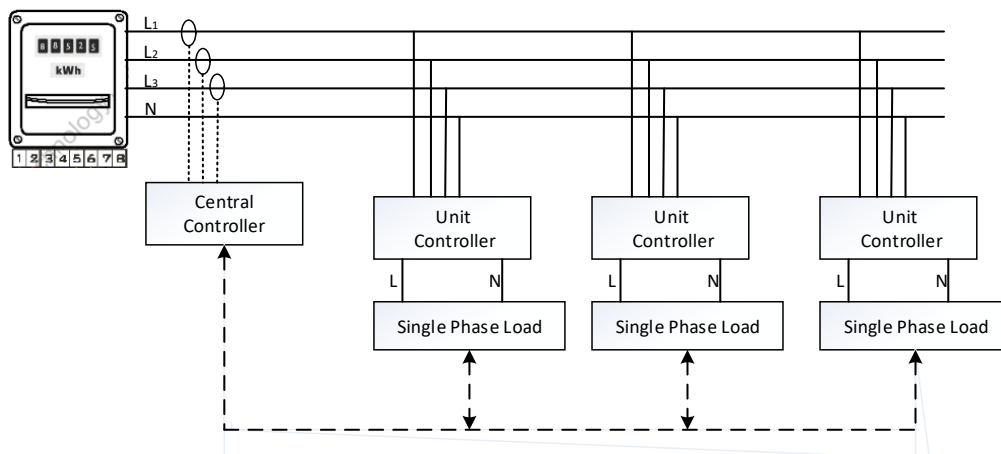


Figure 1. The schematic diagram of Automatic Three Phase Load Balancing that is proposed in this research.

This Automatic Three Phase Load Balancing model consists of two types of controllers, namely: Central Controller and Unit Controller. Three current sensors for three phase cables is used as input signals to the Central Controller. The number of unit controllers required in one installed Kwh meter depends on the customer needs. At a 3000 Kwh meter Watt power, where each phase will be capable of 1000 Watt, the number of installed Unit Controllers can be up to 6 units. The more the number of Unit Controllers installed, the smaller the load that is covered by a group. Therefore, the phase balance that will be obtained is greater. All Unit Controllers can communicate with the Central Controller.

3. Simulink Design

Simulations on SIMULINK are as shown in Figure 2. In the Central Controller, the current sensor is used to measure the amount of current that comes out of each voltage source. The specifications of the three voltage sources are that each voltage source has a peak voltage of 311 volts resulting in an effective voltage of 220. Each voltage source has an alternating current frequency of 50 Hz. Each voltage source has a different frequency phase by setting the first voltage source in 0 degrees, the second is 120 degrees, while the third is 240 degrees.

Central Controller requires an input from three current sensors and data communication to each Unit Controller. The signals that are transferred and received from this data communication are signals that instruct the Unit Controller to disconnect and connect the breaker. Each load group will have three breakers. Each breaker's terminal will be connected to each three-wire phase. Then the three breaker outputs are combined into one and then go to the load. Through the control terminal, whether this breaker will be connected or not to the wire phase, is determined by the Unit Controller. The Central Controller, through data communication, will receive a signal in the form of the current being consumed by each load group sent by the Unit Controller.

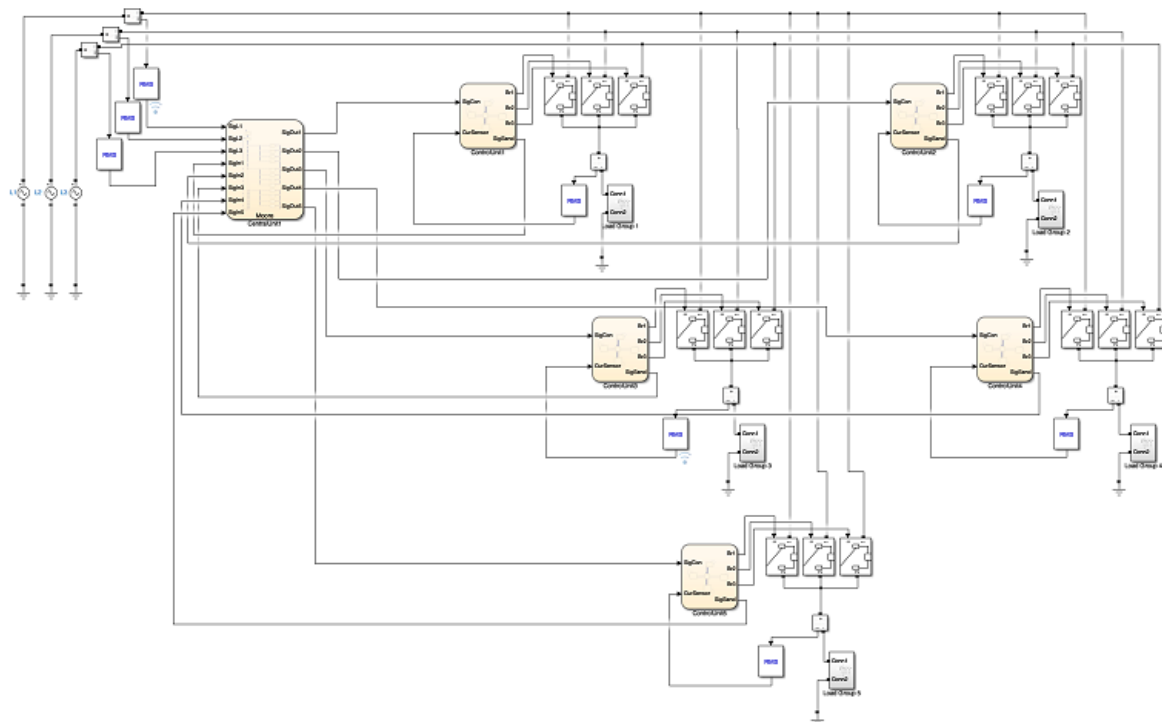


Figure 2. The simulation of Automatic Three Phase Load Balancing at Simulink.

4. Load Group Design

To represent the real load on a consumer, this simulation will create a load variable. This load variable is a load group form as in reality. In fact, a load group consists of several loads. These loads are turned on or off depending on the user, thereby the amount of current from one load group differs from time to time. Generally there is more than one load group in the electrical installation installed at a consumer.



Figure 3. A group of electrical loads on a consumer.

To implement this actual state into SIMULINK simulation, six load groups are created. The more load groups there are at the same power quantity, the better the three-phase load balance. This shows that each load group has a smaller maximum power. The load used in SIMULINK can represent the type of load, whether the load is purely resistive, contains a capacitive value, and an inductive value [10]. Lights are represented by purely resistive loads, Aircon is represented by a combination of resistive and inductive loads, computers are represented by a combination of resistive, inductive and capacitive loads. The life time of each load is designed using a controller made in the form of a Flowstate.

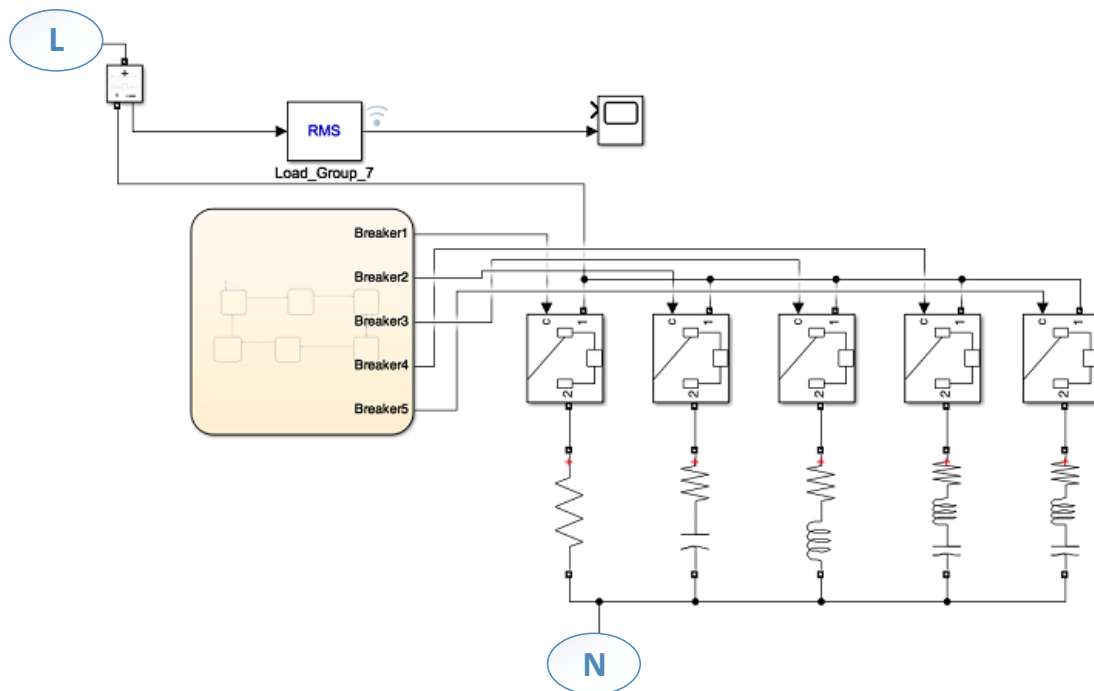


Figure 4. Design of a group of loads in Simulink.

5. Flowstate Design

Central Controller (CC) and Unit Controller (UC) which are used as data processor, communication, and decision maker have been designed in Stateflow. The input of this Stateflow is the amount of current in the phase1 wire, phase2 wire, phase3 wire from Kwh, and the current from all load groups in an electrical installation at a consumer. Whereas the output is a control signal to each load group that latter can be used to determine which breaker should be connected. The flow of the Stateflow algorithm from CC begins by checking the smallest current of the three wire phase. Then check the current on each installed load group. When there is a large current imbalance in the three wire phase, CC will look for

the smallest current from the load group. If the size of a current that is the smallest of a load group is found, then we know the position of the load group. If the large current imbalance between the wire phase is greater than the current in a load group, the load group connection must be transferred to another wire phase.

The state flow of the Unit Controller is shown in Figure 5. This Unit Controller (UC) is used to control the breaker in each load group. In the hardware, each load group will use three breakers, each connected to each wire phase. All three of these breakers will be controlled by the output of the Stateflow. In controlling these three breakers, there can only be one breaker in contact with the wire phase, if this condition is not met, a short circuit will occur. The current from one wire phase will enter the other wire phase. Therefore, the software control system must be made as reliable as possible. The use of the Stateflow guarantees the program in a certain state at a time. There are four states, namely (1) a state that turns off all breakers, (2) a state that only turns on breaker1 while the rest must be off, (3) a state that only turns on breaker2 while the rest must be turned off (4) the state that turns on breaker3 while everything else must be off.

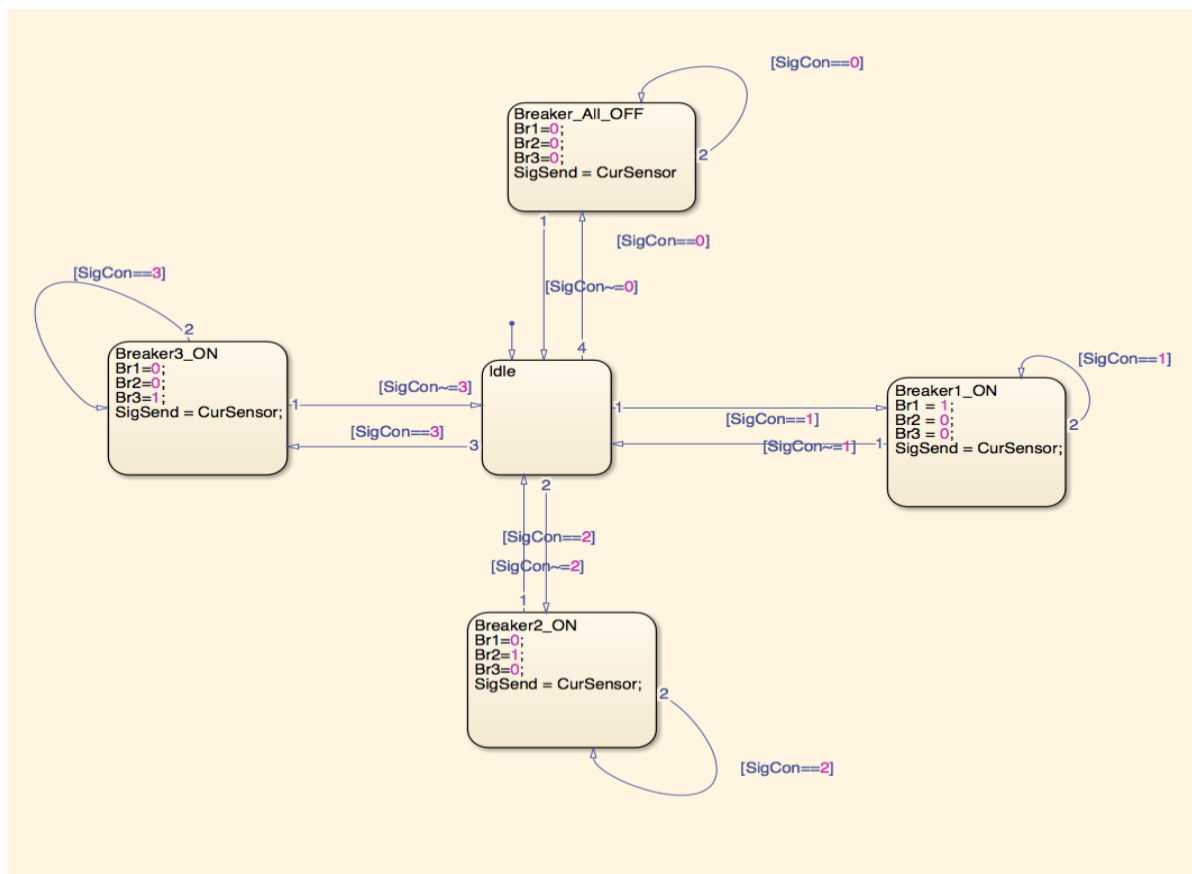


Figure 5. Stateflow of Unit Controller

6. Simulation Results

With a maximum load of 3000 Watts on a consumer electrical installation, two experiments were simulated, namely (1) by creating load groups of 5 groups, and (2) by creating load groups of 6 groups. From these two experiments, each of them is presented in tables. I_{wire1} , I_{wire2} , I_{wire3} are respectively the amount of current that flows on the Kwh wire of phase1, phase2, and phase3. Whereas T_1 to T_{10} are time samples from the experimental time span of 10 seconds. I_{LG1} to I_{LG5} shows the number of load groups

where if all of these load groups consume the maximum limit, the total power consumed by all load groups from three-phase sources with a maximum power for every 1000 watts is 3000 Watts.

Table 1. Testing with 5 load groups with a maximum power of 3000 Watts.

	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀
I _{wire1}	3.74A	2.20A	4.42A	3.67A	2.2A	5.95A	2.95A	2.95A	2.2A	2.2A
I _{wire2}	1.46A	3.74A	3.74A	3.67A	5.2A	3.7A	3.7A	4.4A	2.25A	2.25A
I _{wire3}	2.20A	3.65A	2.20A	3.75A	3.75A	2.90A	5.12A	5.12A	2.3A	2.1A
I _{LG1}	0A	0.75A	0.75A	1.45A	2.2A	2.2A	2.95A	2.95A	1.45A	1.45A
I _{LG2}	3.74A	3.74A	3.74A	1.45A	1.45A	2.25A	0.75A	1.45A	2.25A	2.25A
I _{LG3}	1.46A	2.20A	2.20A	3.75A	3.75A	2.90A	2.90A	2.90A	1.46A	0.74A
I _{LG4}	0.75A	1.45A	1.45A	2.22A	3.75A	3.75A	2.22A	2.22A	0.75A	1.45A
I _{LG5}	1.45A	1.45A	2.22A	2.22A	0A	1.45A	2.95A	2.95A	0.75A	0.75A

Based on the test with 5 load groups, as shown in Table 1, the greatest load occurs at T₆ with current of 5.95A in the phase1 wire. Current of 5.95A with a voltage of 220V will produce 1309 watts of power. In this condition, the phase1 wire will be overpowered so that the Kwh meter in the costumer will automatically turn off. From this condition, it shows that the algorithm applied is still not reliable, it is known by direct observation that the maximum current should be 4.45 so that the power is 979 Watts. Various intelligent algorithms such as Genetic Algorithms[4] or Particle Swarm Optimization Algorithm[11] can be applied for automatic load balancing applications. However, overall of this system has managed the power so that there is no large imbalance of the load current which is very far between the wire phase.

Based on the test with 6 load groups, as in Table 2, it shows that the minimum current is 2.95A and the maximum current is 5.92A. Compared with the previous experiment with 5 load groups which have a minimum current of 1.46A and a maximum current of 5.95, the second test shows better results because the range of differences in the minimum current and maximum current is smaller. The smaller the difference between the drawn current in one wire phase and the maximum current in the other wire phase indicates that the load balance at the three-phase source in a consumers' electrical installation is getting better. In this second experiment, the load balance obtained is getting better due to the use of more load groups compare to the previous experiment.

Table 2. Testing with 6 Load Groups with a maximum power of 3000 Watts.

	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀
I _{wire1}	3.74A	4.42A	4.42A	4.44A	5.1A	5.92A	5.17A	5.17A	2.95A	3.64A
I _{wire2}	3.66A	3.74A	3.74A	3.75A	3.75A	5.1A	2.95A	5.17A	3A	2.95A
I _{wire3}	2.95A	4.42A	4.42A	5.12A	3.75A	3.75A	5.87A	4.35A	3.66A	3A
I _{LG1}	0A	0.75A	0.75A	1.45A	2.2A	2.2A	2.95A	2.95A	1.45A	1.45A
I _{LG2}	3.74A	3.74A	3.74A	1.45A	1.45A	2.25A	0.75A	1.45A	2.25A	2.25A
I _{LG3}	1.46A	2.20A	2.20A	3.75A	3.75A	2.90A	2.90A	2.90A	1.46A	0.74A
I _{LG4}	0.75A	1.45A	1.45A	2.22A	3.75A	3.75A	2.22A	2.22A	0.75A	1.45A
I _{LG5}	1.45A	1.45A	2.22A	2.22A	0A	1.45A	2.95A	2.95A	0.75A	0.75A
I _{LG6}	2.95A	2.95A	2.22A	2.22A	1.45A	2.22A	2.22A	2.22A	2.95A	2.95A

7. Conclusion

Based on both simulation experiments testing the performance of the Automatic Three Phase Load Balancing system, it shows that this system can balance the load on three-phase sources installed in consumer electrical installations. The second simulation experiment produces a better load balance than the first simulation experiment. This is due to the use of a different number of load groups, where the

second experiment uses six load groups while the first experiment uses five load groups. The algorithm of load balancing can still be improved to get better load balance results. For further research, in realizing this design, the real time data communication factor with a maximum time requirement of about 1 ms must be met. Apart from this, the mechanical switching speed of a breaker needs to be considered into this system.

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