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Smart Distributor System for Micro Grid Control

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ABSTRACT: A smart distributor system for controlling a micro grid has been developed in this work. The system switches ON different generators one after the other as the consumer load demand increases or switches them OFF one after the other as the consumer load decreases. This was achieved using a microcontroller, current and voltage transformer. The microcontroller was programmed using embedded C-language to communicate with the current and voltage transformers to give necessary output signals to activate or deactivate the generators. In this design, the maximum load demand of each generator was placed at 60W-100W (Generator 1), 100W-160W (Generator 2), 160W-220W (Generator 3), 220W-280W (Generator 4) and 280W-340W (Generator 5). The system was developed and tested by connecting seven 220V AC, 60W bulbs in parallel to the output of the generators. When the first generator having a capacity of 60KVA is switch ON, the Liquid Cristal Display (LCD) reads 0KVA meaning that no load is connected to the generator. As the generator is loaded by connecting each of the lamps to it, the LCD displays the total load connected to the generator. When the total load exceeds a certain amount (100W decided in this experiment as reflecting the maximum capacity of the first generator) the micro-controller sends a signal to activate another generator to accommodate the load demand. This system continues to automatically add generators to the grid as the load demand increases. Also, as the load connected to the generator decreases, the micro-controller sends signal to deactivate the generators one after the other.

1.0 INTRODUCTION

The design goal of electric power distribution systems is primarily to efficiently and reliably deliver power from substations to customers. The efficient delivery and the reliability of the service provided are crucial in determining the performance of distribution systems. However, extreme events can threaten the reliable delivery of the service provided by distribution systems, and this usually costs huge amounts of money. In most power stations, it will be found that the power is supplied from several smaller units (generators) operating in parallel rather than from a single large unit capable of taking care of the maximum peak loads. The increasing demand for electrical energy has compelled many electrical utility companies to plan towards increasing their generating capacity at regular intervals (Gupta, 1981). Since it is not economical to discard serviceable alternators in favor of larger ones, when load demand increases, alternators are therefore operated in parallel or the load is subdivided and fed from multiple isolated systems (Gupta, 1981). Among these two available options, parallel operation of alternators is preferred. Parallel operation of alternators does not require major changes in the existing system and provides greater reliability, improved efficiency, facilitate repairs and maintenance and make supply of load possible when it exceeds the capacity of the largest units available (Gupta, 1981).

When load demand is increasing or decreasing, power distribution is controlled by increasing or decreasing the electrical power available among all its customers based on the load demand and power generators available. By planning the controlled switching off of parts of the network, the system maintains stability throughout the day since the impact of the increasing load demand is spread over a range of customers.

A microgrid is an energy system that is self-sufficient. It serves a discrete geographic area such as a university campus, business center, etc. A microgrid in most cases uses one or more distributed energy sources such as solar panels, fuel cells, combined heat and power, gas or diesel generators, wind turbines, etc. to produce its power. Some microgrids presently contain energy storage using batteries and electric vehicle charging stations.

The epileptic nature of power supply from the national grid experienced by industries in Nigeria is very alarming. Most parts of Nigeria depend on power generators as an alternative source of power supply. In most cases, industries in Nigeria have more than one generator supplying power to different units within the industry. Sometimes, these generators are not loaded up to 50% of their rated capacity and when load drops the system still runs at that level, thus creating a lot of financial loss to these industries. To reduce the high cost spent by these industries in running their generators on petrol or diesel, there is need to connect these generators in parallel thus forming micro grids with the industries. This therefore creates the need to only switch them ON automatically with respect to load demand.

Thiswork focuses on developing a system (a smart power distributor (SPD)) within an industry that will supply power to end users effectively by either increasing or decreasing connected generators from source supply depending on the consumer load demand. The greater the consumer load, the more the system is being prompted to switch on the reserve generators to accommodate the load demand.

The developed system should be able todetect an increase or decreases in load using the micro-controller, automatically switch ON and OFF the generators as the load demand increases or decreasesand reduce the running costs on the generators. This will help to increase system reliability and automation of the smart power distribution, prevent the frequent breakdown of generators due to excessive load, ease fault tracing in the system, reduce the financial burden of many industries and facilitate quick restoration of electricity after power disturbances.

2.0 REVIEW OF PAST WORK.

Many research works have been done in the area of the design and construction of smart power distribution system. In **Amanyire et.al (2017),** an automatic power supply from four different sources were designed and implemented using a microcontroller. Continuous power was supplied to a load through one of the four sources of power supply namely: solar, mains, thermal, and wind when any one of them is available. It provided a practical solution in cases where power outages cannot be prevented. However, the system had some limitations which included lack of measurement of the power drawn by load and the output of the power supply and switching was done automatically but not with load variation.

Abhishek et.al (2016) worked on automatic transformer load distribution and sharing using microcontroller. In this approach of power distribution, slave transformers are brought into the network to share the load along with the main transformer when the load on the main transformer rises above its rated capacity. In this work a relay and comparator integrated circuits (ICs) were used for the automatic load distribution between the three transformers. The work of Abhishek et.al (2016) has an obvious limitation because the transformers do not automatically switch off as the load decreases.

Ribeiro et.al (2020) worked on a literature review of electricity distribution in smart grid scenarios. The authors asserted that the different ways of improving the distribution of electricity are linked to the application of smart grid so as to meet the uniqueness of each case. However, with regards to self-healing mechanism technologies, the requirements for connectivity proposed for electrical systems for the performance of smart grid limits the advancements of this application as proposed by Ribeiro et.al (2020) in their findings.

ABB Brochure (2019) asserted that the power distribution network is facing new challenges due to accelerating urbanization and evolving requirements for improving the reliability and availability of electric power supply. The increasing demand for installing new and intelligent technologies needed to ensure smart city infrastructures, requires an increase in automation throughout the network.

This work seeks to produce a smart distribution system that switches ON different generators one after the other as the consumer load demand increases, and also switches them OFF one after the other as the consumer load decreases. This is attainable since the output of each generator and also the power drawn by the load will be measured to ensure effectiveness.

3.0 MATERIALS AND METHODS

This system developed in this work is based on the principle of switching ON different generators one after the other as the consumer load demand increases and switching them OFF one after the other as the consumer load decreases. The system works with the aid of a microcontroller and a current and voltage transformer. For the micro-controller to work effectively, an embedded C-language programme is used to communicate with the current and voltage transformers in order to give necessary output signals to activate or deactivate the generators. When the total load exceeds the required load on a generator, the microcontroller sends a signal to turn ON an additional generator to accommodate the new load demand. Also, as the load connected to the generator decreases, the micro-controller sends signal to deactivate the additional generator thereby switching it OFF.

The block diagram of the entire system designed I this work is shown in Figure 1. The flow chart of the system developed in this work is shown in Figure 2. The circuit diagram of the entire system is shown in Figure 3.

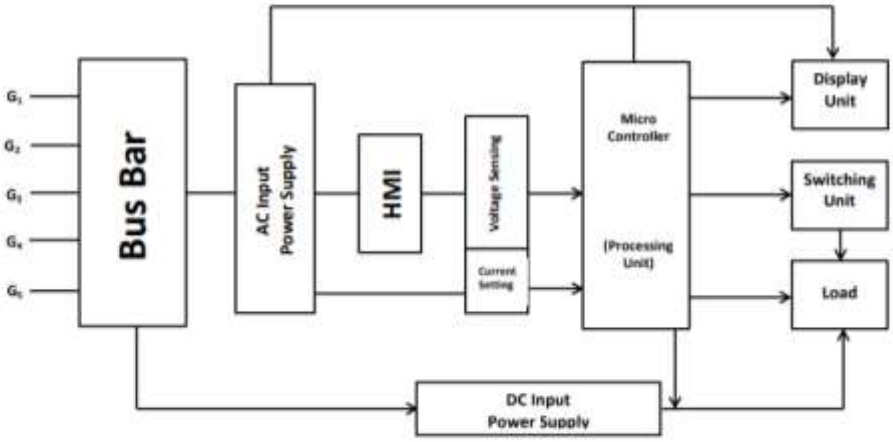

Figure. 1. System Block Diagram

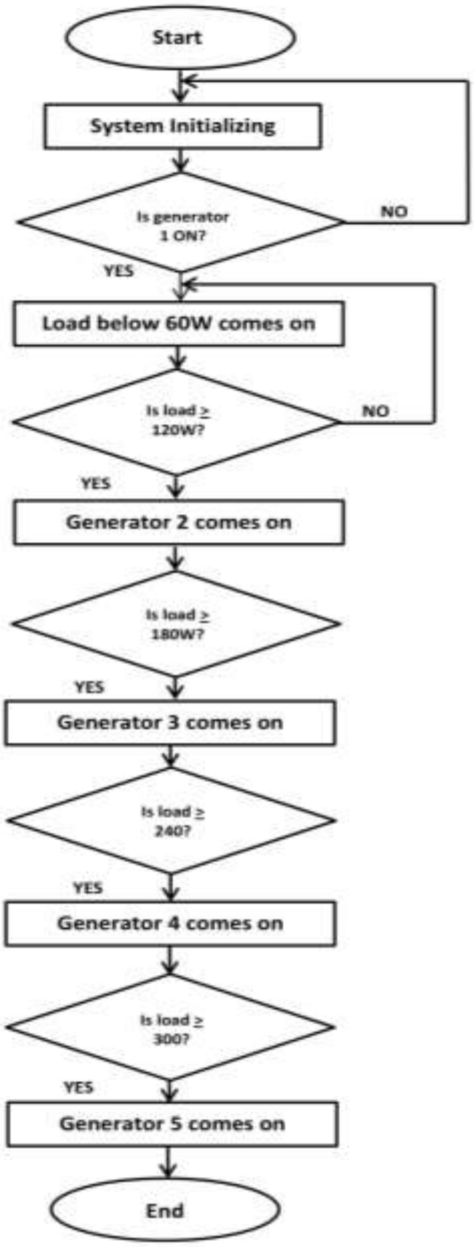

Figure 2. Flow chart of the developed System

Some basic assumptions were made in this work with respect to the conditions for the synchronization of two or more generators:

1. The voltage magnitude must be the same. (The phase voltage).
2. The phase angle and the phase sequences must be the same.
3. The frequency of generators must be the same.
4. The polarities of the generators must be the same.

This is to be accomplished by a synchroscope which is not part of this work. The synchroscope would be inserted between the generators and busbar to ensure they are synchronized for operation. All we are monitoring is the load and we use the value to either turn on or turn off the generators.

From figure 3, it can be seen that the developed system consists of the power supply unit, voltage sensing unit, current sensing unit, processing unit, display unit and the switching unit. The power supply units convert the power supply from the AC mains to a constants DC voltage supply that powers every part of the circuit. It takes 220-230VAC and converts it to 8-15Vdc with the help of a rectifiers circuit and a voltage regulators. The current sensing unit monitors the load current demand from the consumer while the voltage sensing unit monitors the input voltage and sends corresponding signals to the microcontroller. The microcontroller interfaces all other units of the circuit. A program is written and burnt into the microcontroller such that when it receives input signal from a particular point, it acts upon that input based on the stored program and gives out the necessary output for switching the generators. The control unit is made up of relays. It switches each of the generators depending on the load current from the current sensing unit.

The switching unit helps in distribution of the load among the generators. This unit is implemented with an NPN transistor (Tip41) and a DC relay. The relay switch is in contact position when they are energized. The TIP41 transistor (NPN type) consist of maximum collector power dissipation (PC) of 60W, maximum collector based voltage (Veb) of 40v, maximum emitter, base voltage (Veb) of 5v and the collector current of 6A.The relay consist of five terminals namely: common (com), normally close (NC), normally open (NO), T1 and T2. T1 and T2 are the energizing terminal of the relay.

In this work 12 relays were used to interface the load with the generators as shown in Figure 4. There are four bus-bars in the system which represents the four generators. The first three relay is used to interface between the generator (1) and generator (2), the second three relays are used to interface between generator 2 and generator 3, the third three relays are used to interface between generator 3 and generator 4 while the last three relay are used to interface between 4 and generator 5.

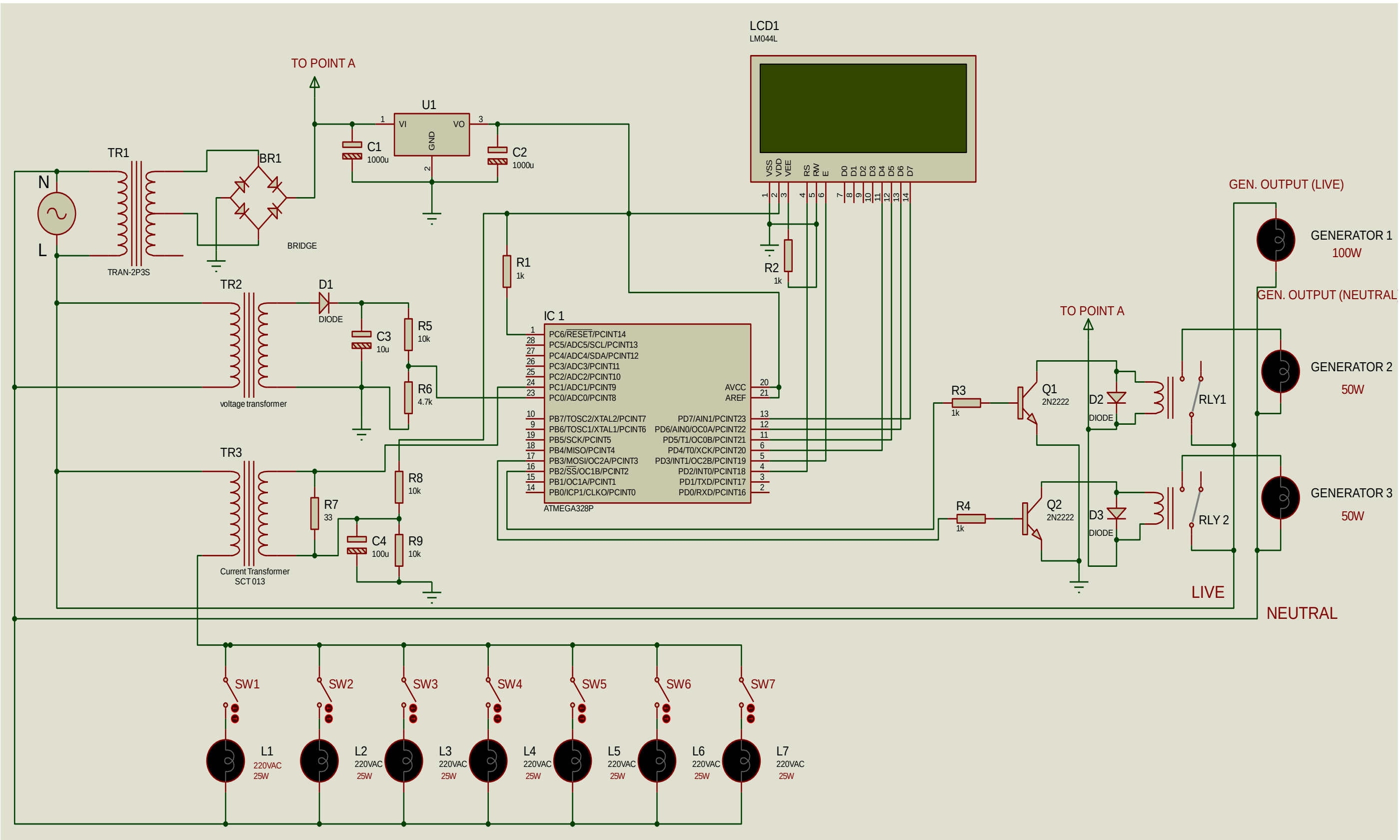

Figure 3. Circuit Diagram of the Smart Power Distributor System

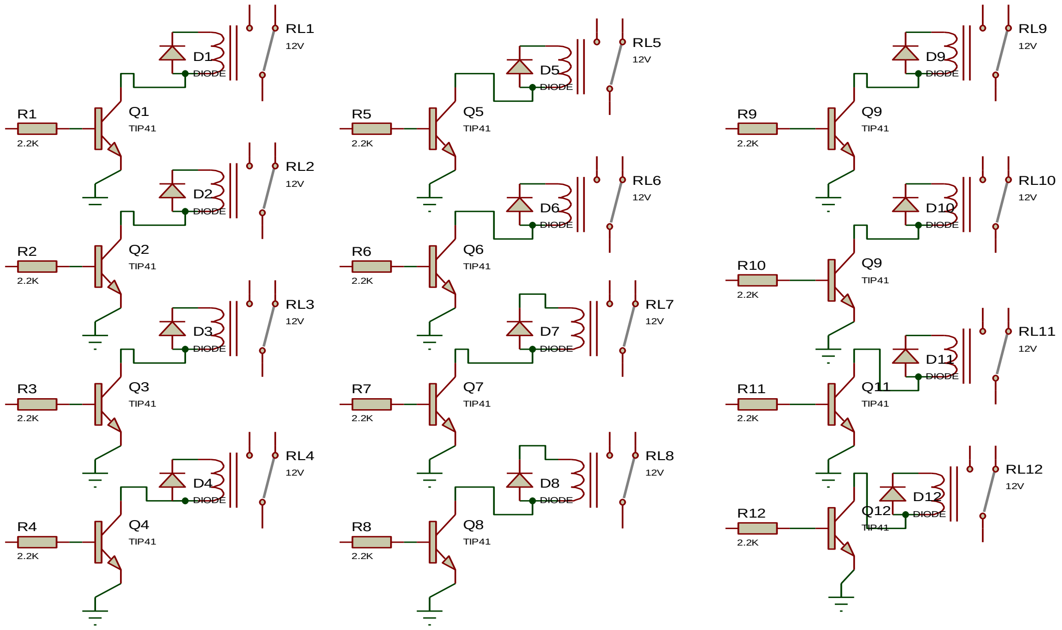

Figure 4. Circuit diagram of the relay connected to the transistors.

Since there are 12 relays in the switching unit, there are also 12 NPN transistors. The terminal (T1) of all the relays are tied together and connected to +12v power supply unit with a crystal diode (IN4007) connected across the T1 and the T2 of each relays. Also connected across T1and T2 is a l00uf electrolytic capacitor which will make the switching rapid. The T2 of the twelve relays are connected to the twelve collector terminal of the 12 transistors, with the emitter (E) of the 12 transistors connected to the ground as shown in Figure 4.The connection diagram of the transistor connected to the microcontroller is shown in Figure 5. The base of each transistor is connected to the microcontroller pin through a 2.2k resistor. Table 1 shows details of the connection between the transistor and the microcontroller. The relay is also connected to the bus bar. The bus-bar receives the power from each generator and distributes to other sub-stations. There are 6 bus-bars which represent live (1), live (2), live (3), live (4) and live (5) of each generator with the entire neutral tied together to the last bar (Neutral bar).For the first three relays, the normally close (NC) of the relay1, relay2 and relay3 are connected to the first bus-bar (generator1), while the normally open (NO) of relay1, relay2 and relay 3 are connected to the second bus-bar (generator 2) and the common (COM) of the three relays is connected to a connector load (OUTPUT) as shown in Figure 6.

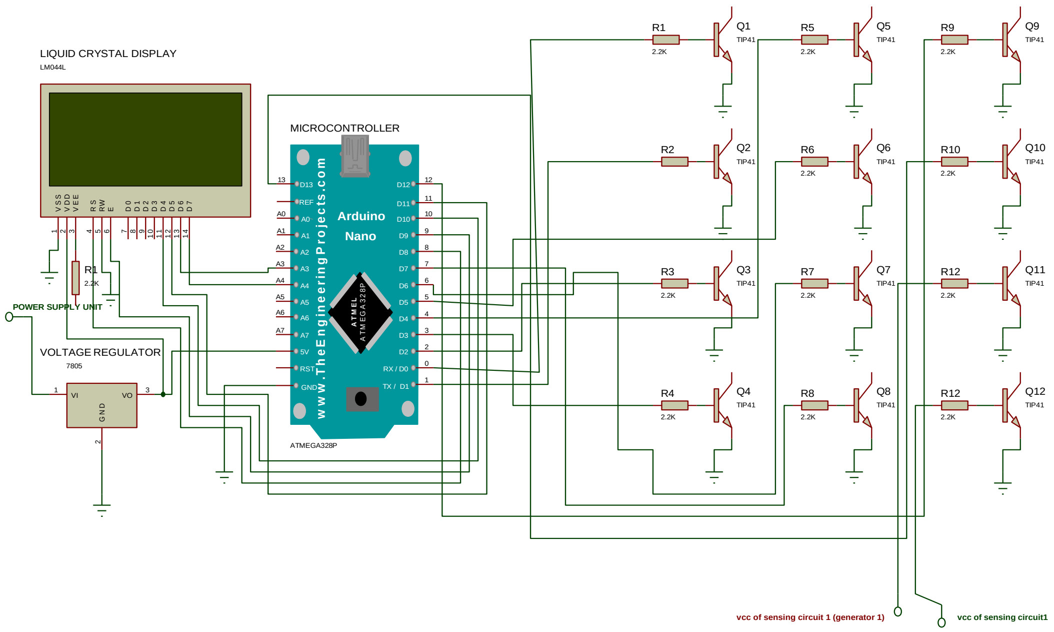

Figure 5. Connection diagram of the transistor connected to the microcontroller.

Table 1: Connection of the transistors to the microcontroller

Microcontroller	Transistors
Digital pin (0)	Transistor (T_1)
Digital pin (1)	Transistor (T_2)
Digital pin (2)	Transistor (T_3)
Digital pin (3)	Transistor (T_4)
Digital pin (4)	Transistor (T_5)
Digital pin (5)	Transistor (T_6)
Digital pin (6)	Transistor (T_7)
Digital pin (7)	Transistor (T_8)
Digital pin (8)	Transistor (T_9)
Digital pin (9)	Transistor (T_{10})
Digital pin (12)	Transistor (T_{11})
Digital pin (13)	Transistor (T_{12})

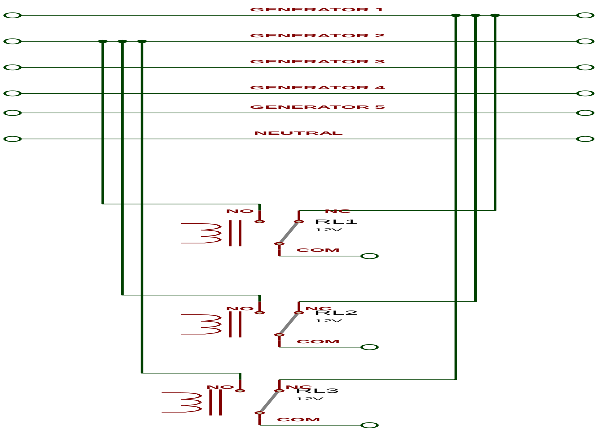

Figure 6. Connection diagram between the relays and the bus-bar

The sensing unit helps in monitoring the load applied to each generator. The variation of the voltage and current as the load is applied to any of the generators, the sensing unit senses those variations and compares them with the value of the microcontroller in either integer or floating format during the programming of the system operation. To make the system very sensible to too much load application, a rectifier and a filter circuit through a step-down transformer is connected across each generator. There are four (4) sensing circuits in the sensing unit. Also in the sensing unit, each generator is connected to each generator bar. The first sensing circuit is used to switch between generator 1 and generator 2, the second sensing circuit is used to switch between generator 2 and generator 3, the third sensing circuit is used to switch between generator 3 and generator 4, while the last sensing unit is used to switch between generator 4 and generator 5.The sensing circuit one is implemented using a 12v, 300mA step-down transformer, and IN4007 diode and 100uf capacitor. The figure 7 shows the circuit diagram of the sensing circuit one.

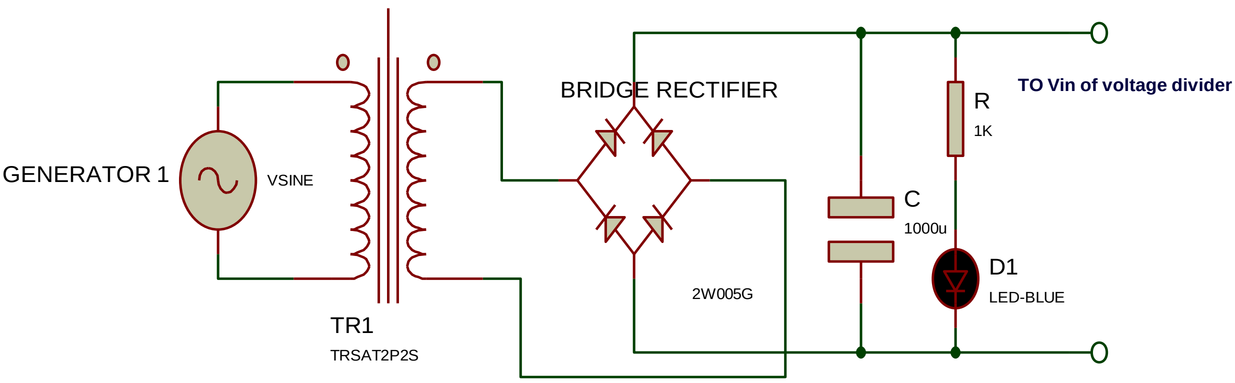

Figure 7. The circuit diagram of the sensing circuit

The first terminal of the primary winding of the transformer is connected to the first bar (generator 1), while the other terminal of the primary winding is connected to the neutral bar. The pulsating direct voltage of the rectifier is applied across the capacitor and it charges the capacitor and it also supplied current to the load. At the end of quarter cycle, the capacitor is charged to the peak value $V_m$of the rectifier voltage. A blue light Emitting diode (LED) through a resistor is connected across the output of the rectifier for indication. Before connecting the sensing circuit 1 to the microcontroller, it is important to note that the microcontroller does not and cannot accept a voltage greater than 5v. Since we have 14.3vdc from the supply vcc, there is a need to employ a voltage divider network. This network is achieved by connecting two resistors in series across the rectifier output of the sensing circuit as shown in Figure 8.

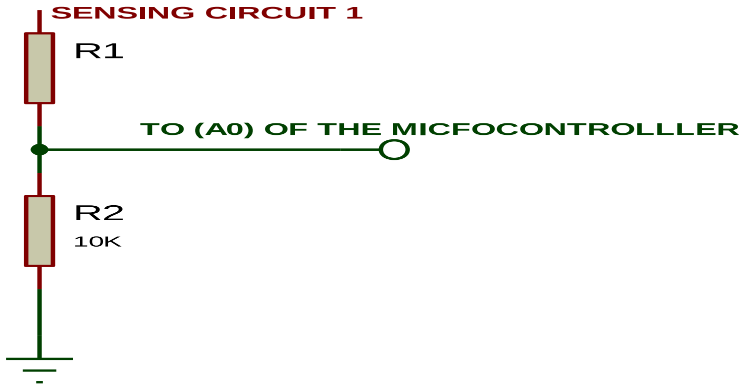

Figure 8: Circuit diagram of the potential divider network

$$\text{Vout} = \frac{Vin\ R1}{R1+R2} \quad \ldots\ldots\ldots\ldots 1$$

Where, Vin is the supply voltage, while R1 and R2 represent the value of the resistors.

R1 is given as 10K = 10000 ohms, Vin =14.3v

Since we need Vout=5v from the network, there is a need to calculate the value of R2.

Therefore,

$$5 = \frac{14.3 * 10000}{10000 + R2} \ldots\ldots\ldots\ldots 2$$

R2= 18.6k ohms

This same calculation is applicable to other sensing circuits. Any variation of the input, also affects the dc output voltage. The second sensing circuit is connected to analog pin (A1) from the network, while the third sensing circuit is connected to analog pin (A2) of the Microcontroller from the third network and the last sensing circuit is connected to analog pin (A5) of the microcontroller from the fourth network.

There are 5 outputs from the system, which are connected to 60W electric bulbs. As earlier mentioned, each generator consists of 3 outputs. The prototype system is designed such that it cannot handle a load greater than 100 watt per generator.

Since we are using 5 electric bulbs of 60W per generator, we have

P_T =300W

The maximum voltage =230v

Recall

$$P = IV \ldots\ldots\ldots\ldots 3$$

Therefore;

I = P/V = 300/230

I = 1.3A

This means that when the applied load gets to 0.44A, any load that will be added to that same generator will automatically be switched to the next generator.

At 60W load, we have the current I;

I = 60/230

I = 0.26A

The above expressions only function when the input load is less than 100W.

This is also applicable to one generator.

At 100W load, we have the current I;

I = 100/230

I = 0.44A

At 160W load, we have the current I;

I = 160/230

I = 0.69A

This is also applicable to two generators.

At 180W load, we have the current I;

I = 180/230

I = 0.78A

This is also applicable to three generators.

At 240W load, we have the current I;

I = 240/230

I = 1.04A

This is also applicable to four generators.

At 280W load, we have the current I;

I = 280/230

I = 1.21A

This is also applicable to five generators.

4.1 Tests, Results and Discussion

The result obtained after testing is tabulated in Table 2-4.

Table 2. Voltage level at each sections of the circuitry.

Input voltage to the bridge Rectifier	Output of the bridge Rectifier	Output of the voltage regulator	Input into the microcontroller (Vcc)
220-230V	**8-12VDC**	**≈5.0VDC**	**≈5.0VDC**

Table 3. Switch and LED status of load demand

LED Status for the respective generators	Load (W)
Generator 1 ON	60W-100W
Generator 1&2 ON	100W-160W
Generator 1, 2 &3 ON	160W-220W
Generator 1, 2, 3 & 4 ON	220W-280W
Generator 1, 2, 3, 4 & 5 ON	280W-340W

Table 4. Performance Test Result

S/N	Description of Load	Voltage Rating of Load	Maximum Load for Generator Activation
1	60W	220V	Only Generator (1) is ON for power less than 100W
2	15W added	220V	
3	25W added	220V	
4	25W added	220V	Increase in load exceeding 100W, Generator (2) turns ON to join Generator (1) from 100-165W
5	25W added	220V	
6	15W added	220V	
7	25W added	220V	Generator (3) turns ON to join Generator (1 and 2) at 210W
8	15W added	220V	
9	15W added	220V	
10	15W added	220V	Generator (4) turns ON to join Generator (1,2,3) at 275W
11	25W added	220V	
12	25W added	220V	
13	25W added	220V	Generator (5) turns ON to join Generator (1,2,3 and 4) at 325W. All generators are turned on
14	25W added	220V	

The system was tested with appliances having different current ratings as shown in Table 4. As the load demand increased, the system automatically turned ON the generators corresponding to the load demand as shown in Table 4. Also, as the load demand decreased, the system automatically turns off the corresponding generators. The system provides information on the wattage drawn from the consumers end and switches OFF the generators accordingly, whenever the load consumption power is been reduced. It supplies power based on consumer's demand thereby increasing cost savings and efficiency.

5.0 CONCLUSION AND RECOMMENDATION

The future scope of this project is particularly in generating stations. During the peak hours there is a need for the operation of additional generators to supply the additional load requirement. This work automatically turns on the generators under critical loads. Thus, there is no need to operate all generators under normal loads, particularly during off peak hours. Thus power is shared intelligently with the generators connected in parallel. The major limitation of the study is that it does not take care of the need for the generators to be synchronized. It assumes that the user must install a synchroscope between the generators and the bus bars to ensure generator synchronization for the system to function effectively.

CONFLICT OF INTEREST.

We have no conflict of interest to declare

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