SYNCHRONIZATION OF SINGLE PHASE GENERATORS FOR DOMESTIC APPLICATION: RELIABILITY IN LOAD HANDLING

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Abstract
This study proves that synchronization can be realized using ordinary single-phase domestic generators. This was achieved first by developing a manual means of combining two or more generators for effective operations and design of electronic device that makes synchronization much easier and affordable for domestic users, secondly, an evaluation of the performance of the manual and electronic means of synchronization with a view of ascertaining their individual load handling capacities to set up a synchronized power system with high reliability in power delivery to domestic residents. It was observed that the output power of electronic designed single phase domestic generators is more stabilized and reliable to that of manual synchronization. It has been established that the design has come to solve the problem of the inability of some generators to single-handedly supply enough power to meet the demands of their users. Electronic method of synchronization should be adopted instead of manual synchronization method in single phase domestic generators.

Keywords
Synchronization, Single Phase Generator, Domestic Applications, Load Handling and Reliability.

Introduction

Synchronization of electric generators is the parallel operation of two or more generators in which case there is a matching of the speeds and frequencies of the machines involved. In many cases, consideration is given to synchronous generator which is alsoknown as an alternatorwhenever issues bordering on synchronization are discussed. This has made the experimental society to believe that single phase generators that are not of the alternating category cannot be synchronized.This study proves that synchronization can be realized using ordinary single-phase domestic generators. However, this exercise still conformed to the laid down rules of synchronization. According to Gupta (2008), synchronization of generators, otherwise known as parallel connection of generators, can only be possible when the following conditions are met:

(a) The generators must have the same output voltage rating.
(b) The rated speeds of the machines should be such as to give the same frequency.
(c) The generators should be of the same type in order to generate the same voltage waveforms.
(d) The shafts of the generators should have the same speed load characteristics which will help in loading the generators in proportion to their output ratings.
(e) The generators must have reactance in their armatures to enable operate in parallel successfully.

In these days of high demand for power, it is necessary to seek sufficient power to drive some domestic appliances at the most economic rate. The usual practice has been to dedicate different generators to different loads. Most of the times, the result is that those generators end up not powering the heavy load appliances because the generators are operating independently. The contribution in this paper is the idea of combining two or more generators in a parallel mode to enhance the power delivery and hence serve all the appliances in the building economically and reliably.

Research Task

The paper is a product of the laboratory experimentation on synchronization. This is aimed atdeveloping a manual and electronic means of synchronizing single phase generators for domestic application with the following objectives:

- To develop a manual means of combining two or more generators for effective operations.
- To design an electronic device that makes synchronization much easier and affordable for domestic users.
- To evaluate the performance of the manual and electronic means of synchronization with a view to ascertaining their individual load handling capacities.
- To set up a synchronized power system with high reliability in power delivery to domestic residents.

Conceptual Ideas

Thompson (2012) highlighted that synchronizing a generator to the power systemmust be done carefully to prevent damage to the machine anddisturbances to the power system. Traditionally, in the industry where synchronization is widely used, power plants are designed to include a synchronizing panel to indicate what adjustments theoperator should make to the governor and exciter and when it isacceptable for the operator to close the breaker. In most of the systems,the process is automated using an automatic synchronizer withmanual control available as a backup. A recent technology is the use of protective-relay-grade microprocessor devices which significantly improves manual and automatic synchronizingsystems. This paper compares with that of Thompson (2012) in the sense that they both talk about manual and automatic systems.While the researcher laid emphasis on the industrial application of synchronization, this paper dwells on domestic application.

Recently, a similar view was that of Johnson, *et al* (2013) who worked on synchronization with a view of enhancing the power delivered by single-inverters. They employed electronic means that emulated the phenomenon of networks of coupled oscillators. As a result of the electrical coupling between the inverters, they synchronize and share the load in proportionto their ratings. The experimentalresults were those from a system of three inverters demonstrating power sharing in proportion to power ratings for both linear and nonlinearloads.This is similar to this paper because the design was tailored towards improving power in a system by connecting the power supply units in parallel just as the generators experimented in this paper were connected in parallel. However, the power supply units in the other paper were single-phase inverters while the power supply units in this paper were single-phase generators.

Another recent innovation by (Hadjidemetriou*et al,* 2016) involves the synchronization of single phase inverters and tying them to the grid. It makes use of Multi-Harmonic Decoupling Cell, in which case if the synchronized system witnesses a slight phase shift in the waveforms of the voltages of the individual inverters, the Multi-Harmonic Decoupling Cell device will harmonize and synchronize them within some fractions of a second of its operation (Hadjidemetriou*et al,* 2016). In the design presented in this paper, the manual method of synchronization did not take the issue of harmonization of signals into consideration but the electronic method did and that makes the entire design novel.

Researchers' ideas on this topic of synchronization however seems to vary from person to person but one aspect that remains constant is the target of combining the required generators without any phase shift in the waveforms of their output voltages. A system was developed using Peripheral Interface Controller (PIC) to determine when the waveform of one alternator is at zero level so that the second one would be synchronized to start delivering power at the zero level also. This system requires that one alternator should first start delivering power while the PIC microcontroller monitors when it is about to cross the zero point for the second one to join. This monitoring is made possible by means of program running on the PIC microcontroller chip and a potential transformer connected externally to the chip to form a zero crossover detector (Ingle &Halmare,2014).

Patil *et al* (2015) described a synchronization system that makes use of a synchronizing panel. The panel is made up of many components including lamps and a synchro scope. The synchro scope is the main detecting device. It has a pointer which shows when the alternators are out of phase and in phase. It shows very accurately the exact instant of synchronism.The pointer rotates clockwise when an alternator is running fast and counterclockwise when an alternator is running slow. When the pointer is stationary, pointing upward, the alternators are synchronized.

In his work, Daniel (2015) departed from manual method and the use of ordinary electronic components and went into the use of PLC to achieve synchronization of a power system. The system was programmed using ladder diagram which is the programming language of the PLC. The system realized in this case was very reliable and accurate in synchronizing the generators involved because of the program which was able to correctly determine the signal sequence of the power generators involved.

Sen*et al* (2014) employed the services of the microcontroller and opto-coupler to achieve automatic synchronization of generating sets. This system, though a three-phase system, used single phase connections through the opto-couplers to the microcontroller. In this system, the microcontroller used the code embedded in it to monitor when the voltage of the generator was at the peak and otherwise. The microcontroller is able to capture either the peak state or the zero state depending on the condition given in the code, and match the generator with the next one at the same point. By so doing, synchronization of the individual generators would be achieved.

In the case of the design in this paper, the main active components used are operational amplifiers configured in comparator mode. It is actually different from all the methods reviewed above. The voltages of the individual generators are compared and linked within a window of the waveform so that all the generators will easily synchronize to run as one unit.

Materials and Methodology

Materials and Tools

(e) Generator 2.2KVA (2 numbers)
(f) Energy Bulb 200W (3numbers)
(g) Cables(Single Core 2.5mm^2)
(h) Voltmeter(3numbers)

(i) Ammeter(3numbers)
(j) AC Connectors
(k) Centre Tap Transformer 220/12V(2 numbers)
(l) Diode 1N4001(10 numbers)
(m) Voltage Regulator 7808(1number)
(n) Switch(100A double pole – 1 number)
(o) Transistor PNP(2numbers)
(p) Resistor 1KΩ(2numbers) and Potentiometer 10KΩ(4numbers)
(q) Capacitor 22µF(1number)
(r) Relay 12V (3numbers)
(s) OperationalAmplifier LM741 in a Comparator Mode(4numbers)
(t) Tachometer (1number)

Methodology

The above listed components and materials were practically put together to realize this design. This experimental block is an illustration of how the components were combined at each stage

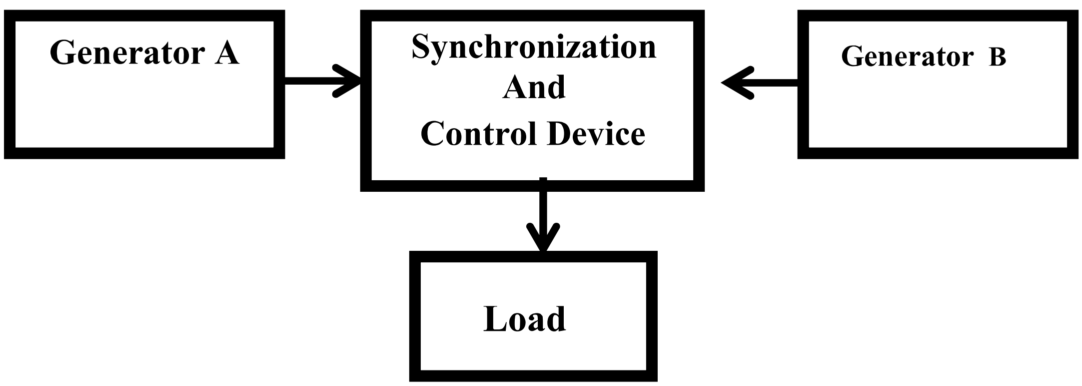

Figure 1: Block diagram of Single Phase Generators Synchronization for Domestic Application

Pre-design Consideration

In order to ascertain the actual current delivered to the load during synchronization exercise, the **following considerations were made using the diagram in figure 2:**

- In an ideal condition, when all the synchronization conditions are met,there will be no loss in power but this is practically impossible.
- With the design running on noload

  $I_{gA} = I_{gB} = 1.4A$ - - - (1)

  For the

  $L_1 = L_2$ and $V_{dB} = V_{dA} = 0.5V$. The power loss along $GA = (I_{gA} \times V_{dA})$ and $GB = (I_{gB} \times V_{dB})$ - - - (2)

  But the Total Minimum Power Loss during synchronization on no load $P_L = (I_{gA} \times V_{dA}) + (I_{gB} \times V_{dB}) = 0.7W$ - - - (3)

- According to KCL : $I_{gA} + I_{gB} = I_L$ but the maximum allowable current for each of the identical generators is given by

  $I_{max} = \frac{P_{Max}}{The\ rated\ output\ Voltage} = \frac{2200}{220} = 10A$; - - - (4) Therefore the Maximum load current =20A.

- From figure 2, the load was connected upto 4000W, $I_{gA} = I_{gB} = 9A$ this led to the addition of more loadsto get 20A as the synchronization current in figure 3.
- Therefore the total power in the system is given by

  $$\mathrm{T_T} = Total\ Power\ loss\ on\ Max\ load + (\text{Maximum load current} \times \text{Maximum load Voltage})$$

  $$\mathrm{T_T} = P_L + (I_L \times V_L) \quad - \ - \ - \ - \ - \quad (5)$$

  $$= (10 \times 3 + 10 \times 3) + 20 \times 216 = 4380W$$

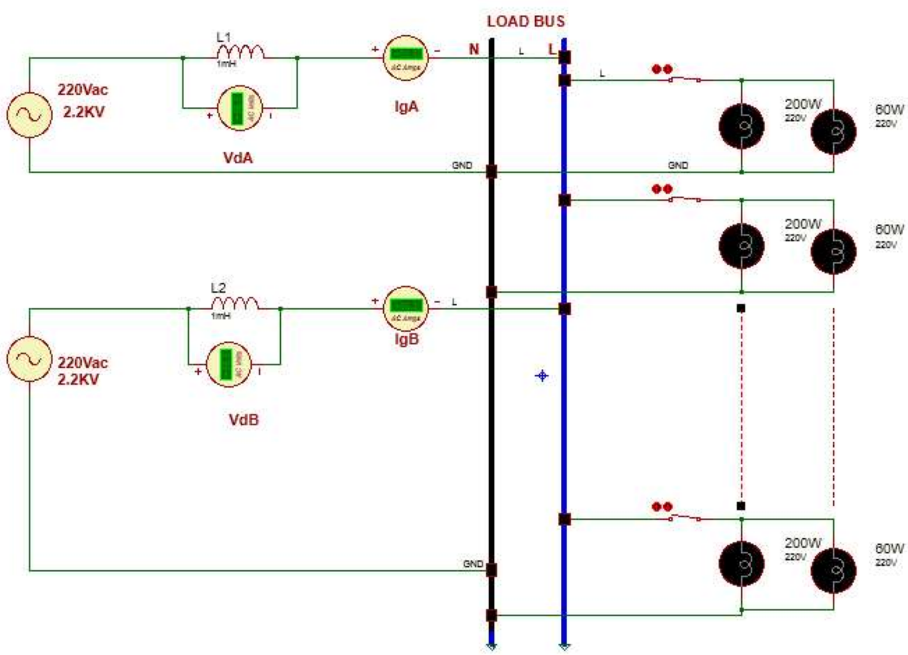

Figure 2: Circuit diagram of the pre-design of the system synchronization of the Single-Phase generators

Design Circuitry and Procedural Approach

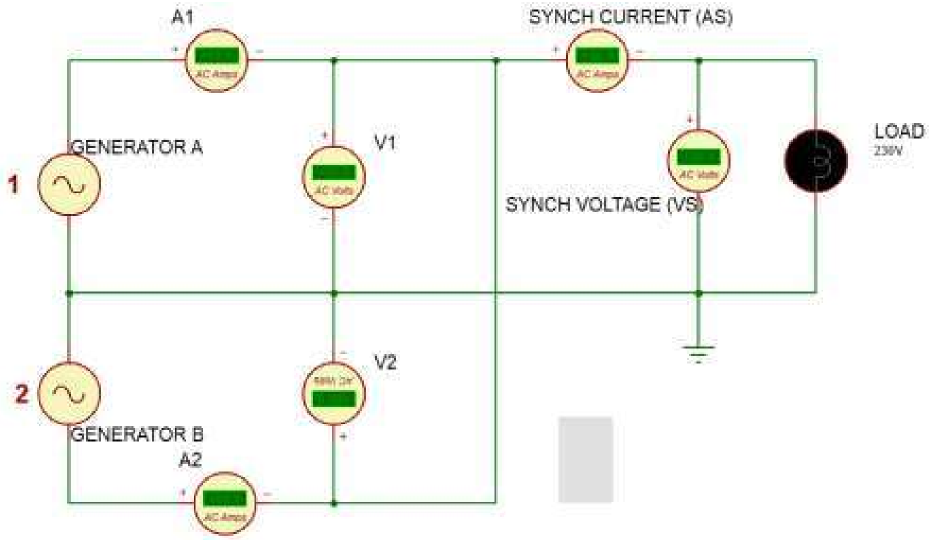

Figure 3: Circuit diagram of the manual method of synchronizing Single-Phase generators

Procedure 1

(a) The generators A&B was check to ensure thatthey conform to the general synchronization requirements.

(b) The generatorswere again checked to ensure that they were operationally ready.

(c) The generators were startedand allowed to run for about 3 minutesand their individual speeds were measured.

(d) A voltmeter and an ammeter were connected to generator A and a load of 200Wbulb was connected to the output. The values of the voltage and current were recorded as shown in table1.

(e) Another voltmeter and ammeter were connected to generator Band a load of 200W bulb was also connected to the output. The values of the voltage and current were also recorded as shown in table1.

(f) Yet another voltmeter and an ammeter were connected tothe synchronized generators A & B and 200W bulb was connected to their common output. The synchronized voltage and current were measured and record as V_s and $A_s$in the table1.

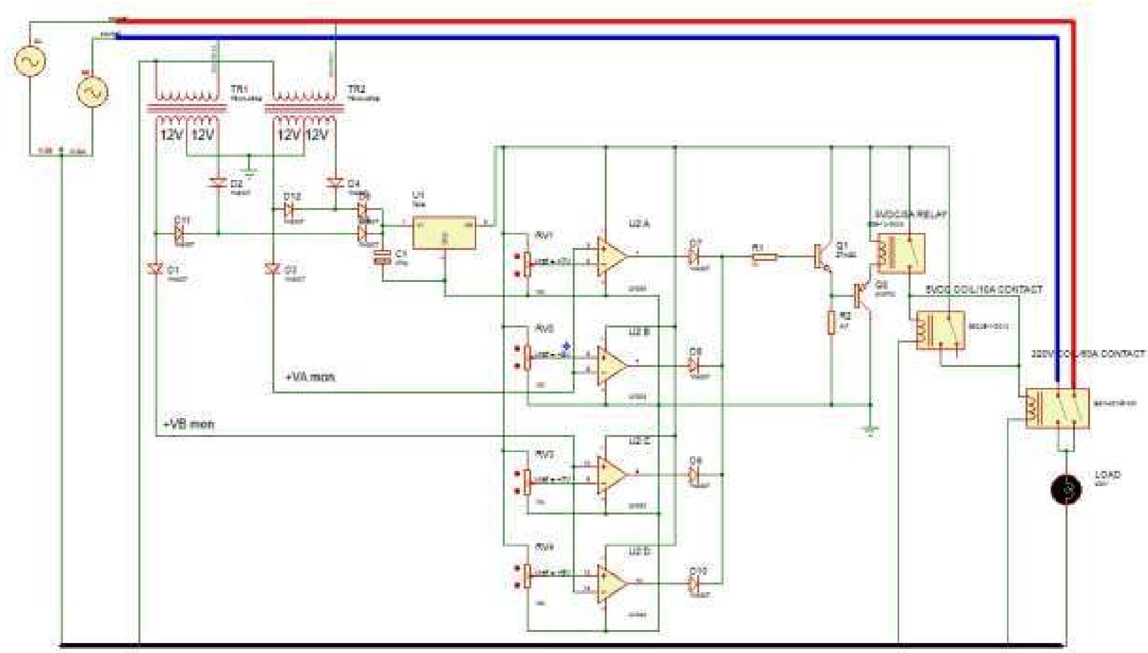

Figure 4: Circuit diagram of the electronic method of synchronizing Single-Phase generators

Procedure 2

- The Live lines of the two generators were connected to their individual bus as shown in figure 4.
- Similarly, the neutral of the two generators were connected to the neutral bus.
- The load was connected through the switch to the output of the system with all the metering devices.
- The Generator G_A was first engaged and later G_B. The system scans for some fractions of a second before synchronizing them.
- The load switches ON and produces all the results.

Principle of Operation

The operation of this design is such that the neutral of the first generator (G_A) and second generator (G_B) are connected together to the ground bus. Generator $G_A$is made to start running and delivering power to the load first.

Whenever the voltage at the non-inverting terminal of the comparator is higher than the voltage at the inverting terminal, the output voltage of the comparator becomes high and vice versa.

Each of the two transformers is connected to one generator and each of the generator output voltages is stepped down and rectified in the full wave rectification mode.One more diode from each of the transformers (D_1 from TR_1 and D_3 from TR_2) delivers a half-wave rectified signal to two comparatorsU2:A and U2:B (see figure 5 below).

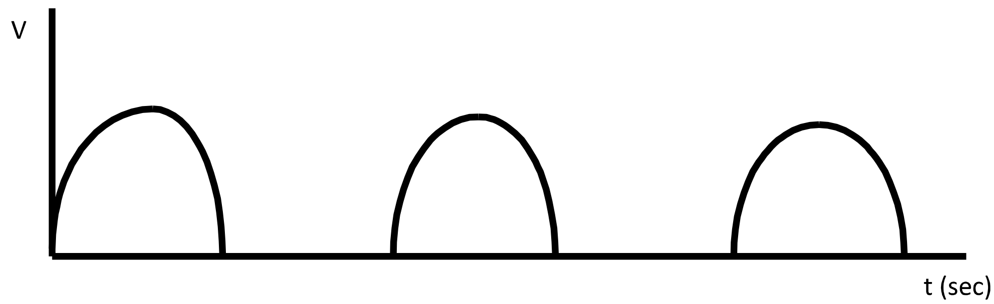

Figure 5: Half-wave rectified signal from D_1 or D_3 (i.e. $+VA_{mon}$ or $+VB_{mon}$)

The two diodes just before the voltage regulator are connected in the OR gate arrangement to ensure that even when only one generator is running, power would be supplied to the electronic components.

The functionality of this system is based on the configuration of the comparators. Comparator U2:A and U2:Bcheck the output voltage of G_A while U2:C and U2:D check the output voltage of G_B. Their reference voltages are drawn from the 8V voltage regulator and set by the preset resistors.

The +Vcc pins of the comparators are connected to the stabilized +8V while their -Vcc pins are connected to ground. The mode of operation of comparators U2:A and U2:B is the same with that of U2:C and U2:D.

Looking at U2:A and U2:B, RV_1 was set to 7V while RV_2 was set to 5V. If $+VA_{mon}$ oscillates until the instantaneous voltage gets to +5V, the outputs of the two comparators become low (that is, logic 0). It is only within this window of +5V and +7V that these two comparators give outputs of low. Outside this window, they give outputs of high (that is, logic 1).

In the same vein, comparators U2:C and U2:D monitors the waveform of $+VB_{mon}$ to also capture generator G_B within the same window. When this is achieved, the outputs of the four comparators become low. This logic 0 keeps transistor Q_1 non-conducting thereby also outputting logic 0 at the emitter and so biasing Q_2 into conduction since it is a PNP transistor. This leads to the relay on its emitter being energized just momentarily and immediately de-energized due to the comparators quickly seeing themselves out of the window, owing to the instantaneous nature of the pulsating $+VA_{mon}$ and $+VB_{mon}$. At the same time, the second relay latches thereby energizing the final relay which has two throws. These throws are then closed simultaneously to combine the two generators G_A and G_B. This is how synchronization of the two generators is achieved by electronic means and greater amount of power is thereby delivered to appliances for a better load management.

Results and Discussions

Result 1: Summary of manual method of synchronization of generator A and B

Table 1: Manual Synchronization

	Generator A		Generator B		Synchronized Results	
	Current(A)	Voltage(V)	Current(A)	Voltage(V)	Current(As)	Voltage(Vs)
Exercise 1	0.68	230	0.66	226	4.17	224
Exercise 2	0.68	230	0.66	226	3.7	224
RatedPower	2.2KVA		2.2KVA			
Speed	1300 rpm		1200 rpm			

Table 1 shows the results gotten from the manual method of synchronization. The two generators were labeled A and B with power rating of 2.2KVA. Each of the generators was loaded with a 200-W incandescent bulb and it registered currents of 0.68A and 0.66A respectively. After the first synchronization exercise, the total synchronized output voltage was 224V while there was a current loss of 4.17A. The system was not very stable. Initially the two generators were vibrating vigorously but after some time it stabilized. However, by the output values of current and voltage, it was obvious that the system was not well synchronized.

The second exercise gave almost the same result. The only difference is that the current loss in this case came down a little to 3.7A. This shows that the system was a bit more successfully synchronized this time than in the first case.

On the whole, the power delivery was not enhanced because the system was not well synchronized in either case.

***Result 2*:** Oscilloscope from electronic method of synchronization of generator A and B

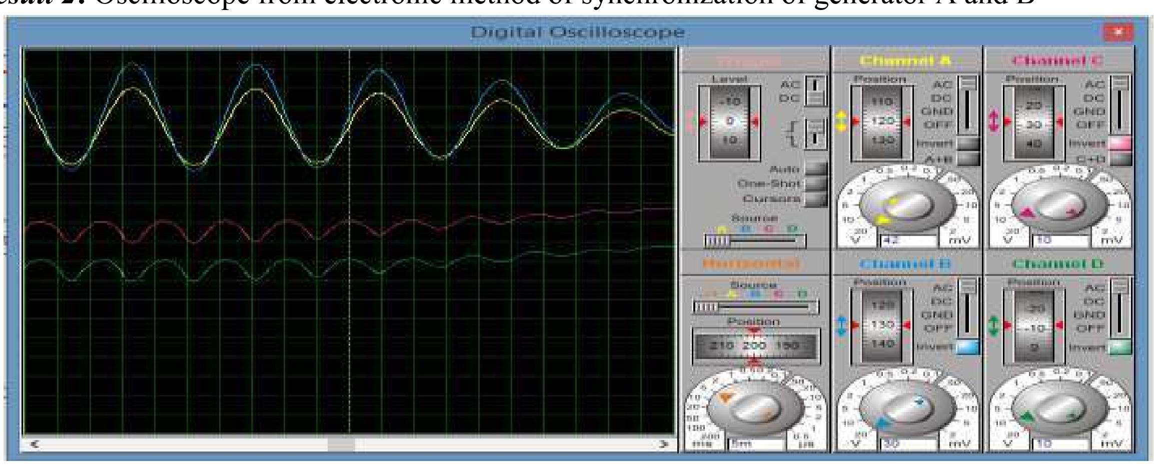

Figure 6: Waveforms from electronic method of synchronization

The oscilloscope in figure 6 shows the results gotten from the electronic arrangement of the synchronization of the two generators. The two waveforms at the lower part of the screen are the pulsating dc voltages immediately after rectification of the output voltages of the generators.

Above them are the waveforms of the synchronized system. The blue trace (that is, the waveform with slightly higher amplitude) is the output voltage of generator A while the other one is the output voltage of generator B. As can be seen, the two waveforms were made to start at about the same time, rise at the same pace and fall at the same pace also. This shows that the frequency and phase were actually successfully synchronized by the electronic method. The only little imbalance was found in the case of the individual output voltages of the generators. Nevertheless, the system still worked well as the difference between the voltages was practically manageable.

Design Implementation Results and Comparison

The electronic design circuit was implemented with the Generators A and B giving an output power of $4380W$.This is as a result of losses due to the synchronization.

The manual synchronization loss was significant therefore the maximum power was difficult to ascertain. Similarly, the simulation result actually conforms to the implementation data with slight difference.

S/N	ITEM(S)	QTY	UNIT PRICE	PRICE
1.	Bulb 200W	3nos	200	600
2.	Cables(Single Core 2.5mm^2)	10yards	250	2500
3.	Voltmeter	3nos	7000	21000
4.	Ammeter	3nos	8000	24000
5.	AC Connectors	4nos	250	1000
6.	Centre Tap Transformer 220/12V	2nos	1200	2400
7.	Diode 1N400	10nos	20	200
8.	Voltage Regulator 7808(1number)	1no	100	100
9.	Switch (100A double pole)	1no	1500	1500
10.	Transistor PNP	2nos	150	300
11.	Resistor 1KΩ	2nos	20	40
12.	Potentiometer 10KΩ	4nos	100	400
13.	Capacitor 22μF	1no	150	150
14.	Relay 12V	3nos	250	750
15.	Operational Amplifier LM741 in a Comparator Mode	4nos	200	800
16.	Tachometer	1no	10000	10000
			TOTOAL (N)	65740

Table 2: Bill of Engineering Measurement and Evaluation of electronic design for single phase generators Synchronization

NB The justification to choose this design is as follows:

I. The design is more reliable.
II. The design is more stable.
III. The design is more economical.

Conclusion

The use of electronic method improved synchronization of single phase generators for domestic application. As a matter of practical fact, the design in this paper has come to solve the problem of the inability of some generators to single-handedly supply enough power to meet the demands of their users. Combining many generators in a residential building leads to generation of greater amount of power that will be able to serve every resident. However, this practice had not been explored. Both the manual and electronic methods of synchronization demonstrated the possibility of realizing this feat. Moreover, this paper advocates the use of the electronic method over the manual method due to its accuracy, stability, safety and efficiency. Generally, a successfully synchronized system has a higher load handling capability.

Recommendations

Since engineering design is an endless journey, further work could be done with a view to increasing the output power by synchronizing higher power generators (e.g. 3.5KVA generators and above) or synchronizing more than two of the type of generators used in this study.

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