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# DESIGN AND FABRICATION OF A 5.5KW GENERATOR FOR A PKS-FUELLED MICRO-POWER PLANT

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## ABSTRACT

The move to green energy has become the focus of the 21st century, although the energy needs of the world have been on the increase, the need is now more urgent than ever to do away with fossil fuel. This study tackles these problems through the design and fabrication of a vital part of a comprehensive micro power plant, the electric generator. The design of the 5.5kW Induction generator involved the application of recycling, through the recycling of a discarded scrap motor, designed and rewound to give an output of 5.5kW, included in this study are the procedures, calculation leading up to the fabrication of the 5.5kW 3-phase Induction generator. The study was carried out in a way scaling up for higher outputs are possible through the use of the provided procedures and formula.

**KEYWORDS:** energy, fabrication, electric generator, power plant.

## INTRODUCTION

Electricity is as important to human economic activity as oxygen is to human existence; our dependence on electric power has been on the rise ever since the industrial revolution with the most of these coming from fossil fuels. Whitney (2008) defines fossil fuels as energy-rich substances that have formed from long-buried plants and microorganisms; these include petroleum, coal, and natural gas which provide most of the energy that powers modern industrial society. The many negative effects of fossil fuel consumption is a major reason for research into alternative ways of power generation. Acid rain and global warming are two of the most serious environmental issues related to large-scale fossil fuel combustion. Other environmental problems, such as land reclamation and oil spills, are also associated with the mining and transporting of fossil fuels (Whitney, 2008). Beyond the worldwide dependence on fossil fuels, Nigeria

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

has two major ways of power generation; there are currently two main types of power plants operating in Nigeria: (1) hydro-electric and (2) thermal or fossil fuel power plants. With a total installed capacity of 8457.6MW (81 percent of total) in early 2014, thermal power plants (coal or gas-fired plants) dominates the Nigerian power supply mix (Premium Times, 2017). With the increasing population of Nigeria, one of the ways of solving the power supply problem is the creation of micropower plants that are renewable energy based.

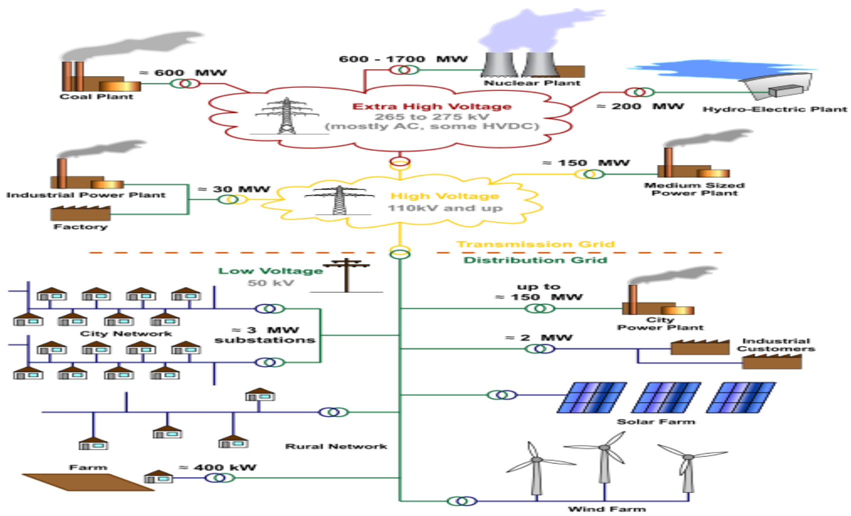



**Figure 0-1: General layout of electricity networks (TACS, 2016).**

Renewable energy is also known as Alternative Energy, is generally a form or forms of energy that are not based on fossil fuels but are either renewable or sustainable without depleting a finite resource. Examples of alternative energy are Biofuel; Biomass; Geothermal Energy; Solar Energy; Tidal Energy; and Wind Energy (Microsoft Encarta, 2009). Biomass is the total dry weight of a tree's leaves, branches, stem (trunk), and roots, (Briggs, 2009), energy generated from these is also called renewable energy. In the production of palm oil, biomass residues can be converted from being potential environmental pollutants to useful fuel for steam and electricity generation which are largely needed for industrial use (Sulaiman *et.al*, 2011). Nigeria, being the fifth largest producer of palm oil, accounts for about 1.5% (930,000 metric tonnes) of the global output. However, a huge quantity of oil palm residues which could otherwise be used for energy generation is being wasted (Izah *et.al*, 2016). Muhammad *et.al* (2014) report that about 30 tonnes of fresh fruit bunches /hr. produce from a few palm oil mills can be used to generate up to 20 - 35 MW of electricity. This can significantly reduce greenhouse gases and increase employment for the local population (Sulaiman *et.al* 2011). Generation of electricity for the most part involves combustion, the production of heat, conversion of form of energy from one to another (example: heat energy to mechanical energy); A typical power plant consists of a heat source, working fluid and generator that converts from mechanical energy to heat energy, for this study, the working material for the furnace

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

which is the heat source will be Palm Kernel Shells. Oladosu *et.al*. (2016) designed a CAD program that was used to design a palm kernel shell combusting furnace while using the standard design equations to size the furnace and its components, they were able to get results that showed generation of 5kW of electricity from palm kernel shell using the data: 5.5kW turbine, 3.1 m superheater, 3.8 m riser, furnace of 1.432 m height and 0.45 m3 volume considering power loss due to friction and others; the results were also used to size the appropriate boiler for the generation process. The power station of a power system consists of a prime mover, such as a turbine driven by water, steam, or combustion gases that operate a system of electric motors and generators. The specifications and foundations of this study will be based on the results of the study conducted by Oladosu et al. (2016), therefore the prime mover in this study is a 5.5kW steam turbine provided with steam from a boiler of determined specifications, the boiler is heated by a palm kernel shell-fuelled furnace. In the chosen study, micro-power plants are known to be auxiliary sources of power that support the main generation that exists in the power grid and thus can be of outputs of less than 100kW; they are mostly used in the renewable energy sector where input and output can vary and be small, The types of turbines used may vary based on the type of primary fuel or energy source, wind turbines with outputs of less than 100kW are examples of micropower plants so also hydropower plants or thermal plants of similar output.

## MATERIALS AND METHODS

The induction generator is designed to be self-induced using the capacitance in a capacitor; a typical generator is made up of two major parts: the rotor and the stator, the design of the induction generator involves the calculation of the parameters that transforms the 6.8kW scrap Induction generator into a working Induction generator of an output of at least 5.5 kW.

### Induction Generator design specifications

Based on the intended output, the specification of the available machine and proposed use, the following are the basic specifications for the design:

**Table 0-1: Table showing the available and proposed specifications of the induction generator**

| | Available | Proposed |
|---|---|---|

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

| **Type of Generator** | Scrap Induction generator | Asynchronous or Induction generator |
|---|---|---|
| **Method of excitation** | ----- | Capacitor banks |
| **Power Output** | 6.8 kW | 5.5 kW |
| **Number of phases** | 3-phase | 3-phase |
| **No of poles** | 4 poles | 4 poles |
| **No of slots** | 38 slots | 38 slots |
| **Power factor** | ----- | 0.86 |
| **Efficiency** | ----- | 85% |

**Design Calculations**

**Synchronous Speed**

The speed of an AC motor or generator is dependent on the number of poles it has and the line frequency of the power supply, not on its voltage. Common AC motor units are constructed with either two or four poles. A magnetic field is created in the stator poles that induces resulting magnetic fields in the rotor which follow the frequency of the changing magnetic field in the stator; the rotor will always rotate slower than the magnetic field of the stator and is playing a constant game of catch up. This produces the torque to get an AC motor running. The difference between the synchronous speeds of the stator and the actual operating speed is called slip (Encarta, 2009). Synchronous speed ($N_S$) is the speed at which the magnetic field rotates. Depending on motor design.

$$N_s = \frac{120f}{p} \quad ------1$$

Where: $N_s = Synchronous\ speed$

$f = frequency$

$p = no\ of\ poles$

$$(Engineering\ ToolBox, 2004)$$

$$N_s = \frac{120 * 50}{4}$$

$$N_s = 1500\ rpm$$

**Torque**

Torque: is a measure of the force that can cause an object to rotate about an axis. Just as force is what causes an object to accelerate in linear kinematics, torque is what causes an object to acquire angular

International Journal of Applied Science and Engineering Review

IJASER

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

acceleration. The driving force of an electric motor is torque - not horsepower. The torque is the twisting force that makes the motor running and the torque is active from 0% to 100% operating speed. The power produced by the motor depends on the speed of the motor and is zero at 0% speed, and normally and it's top at operating speed. Torque is represented using T (Engineering Toolbox, 2004).

The torque (T) of the motor is given as:

$$T = \frac{60}{2\pi} * \frac{P * 1000}{N} \quad ------2$$

Where: $P = Expected\ Power\ output\ in\ kW$

$N = synchronous\ speed\ of\ machine\ in\ RPM$

$(Engineering\ ToolBox, 2004)$

$$T = \frac{60 * 5.5 * 1000}{2 * \pi * 1500}$$

$$T = \frac{330000}{3000\pi}$$

$$T = 35.014\ Nm$$

$$T = 35.014\ Nm * 0.102$$

$$T = 3.57\ Kgm$$

**Calculating the power (Real, Apparent and reactive)**

**Power:** this is the rate at which work is done; Power in an electric circuit is the rate of flow of energy past a given point of the circuit. In alternating current circuits, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow. However, in electric motors and generators there are three kinds of power namely: Active (Real or True) Power is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work; Apparent Power is measured in volt-amperes (VA) and is the voltage on an AC system multiplied by all the current that flows in it. It is the vector sum of the active and the reactive power; Reactive Power is measured in volt-amperes reactive (VAR). Reactive Power is power stored in and discharged by inductive motors, transformers and solenoids (Engineering Toolbox, 2004).

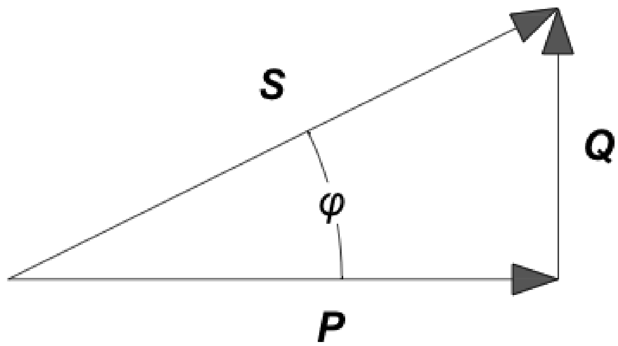



**Figure 0-2: Power Triangle showing the relationship between the kinds of powers and power factor (Engineering Toolbox, 2004).**

Where, $P = real\ power\ (kW)$

$S = apparent\ power\ (kVA)$

$Q = reactive\ power\ (kVAR)$

$\cos\emptyset = Power\ factor$

$\emptyset = Phase\ angle$

$$P = S\cos\emptyset$$
$$Q = S\sin\emptyset$$
$$S = \sqrt{P^2 + Q^2}$$

$(Engineering\ ToolBox, 2004)$

$$S = \frac{P}{power\ factor}$$
$$S = \frac{5.5}{0.86}$$
$$S = 6.395\ kVA$$
$$S\ (apparent\ power) = 6.4kVA$$

To calculate phase angle (∅)

$$power\ factor = \cos\emptyset$$
$$\emptyset = \cos^{-1}(p.f.)$$
$$\emptyset = \cos^{-1}(0.86)$$
$$\emptyset = 30.68°$$

International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

For the reactive power $Q = S \sin \emptyset$

$$Q = 6.395 * \sin 30.68°$$

$$Q = 3.263\ kVAR$$

3-Phase systems and Winding configurations types

Three-phase electricity consists of three AC voltages of identical frequency and similar amplitude. Each AC voltage phase is separated by 120° from the other (IAEIMAGAZINE, 2017). This system can be represented diagrammatically by both waveforms and a vector diagram.

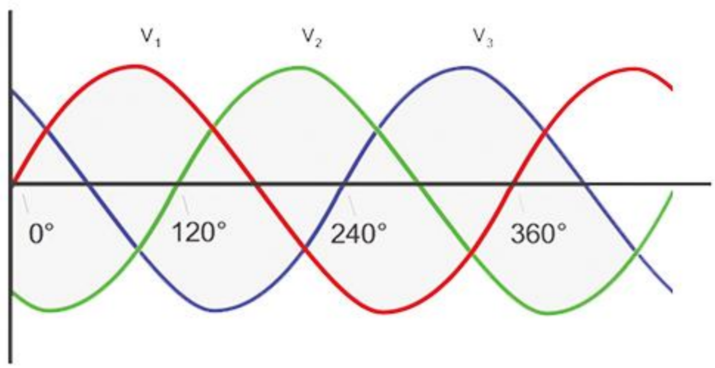



**Figure 0-3: Three-phase voltage waveform (IAEIMAGAZINE, 2017).**

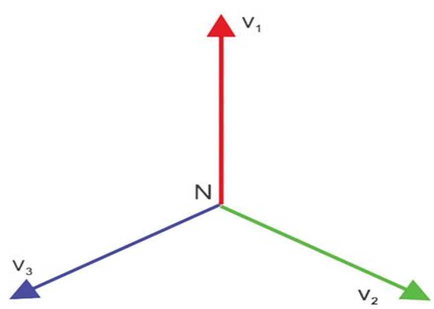



**Figure 0-4: Three-phase voltage vectors (IAEIMAGAZINE, 2017).**

In connecting 3-phase circuits and machines, there are mainly two winding configurations: the star or wye and the delta.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

**Wye or Star connection**

A three-phase system with a common connection is known as a "wye" or "star" connection. The common point is called the neutral point. This point is often grounded at the supply for safety reasons. In practice, loads are not perfectly balanced, and a fourth neutral wire is used to carry the resultant current

For "Y" circuits:

$$V_{line} = \sqrt{3} V_{phase}$$
$$I_{line} = I_{phase}$$

$(allaboutcircuits, 2018)$

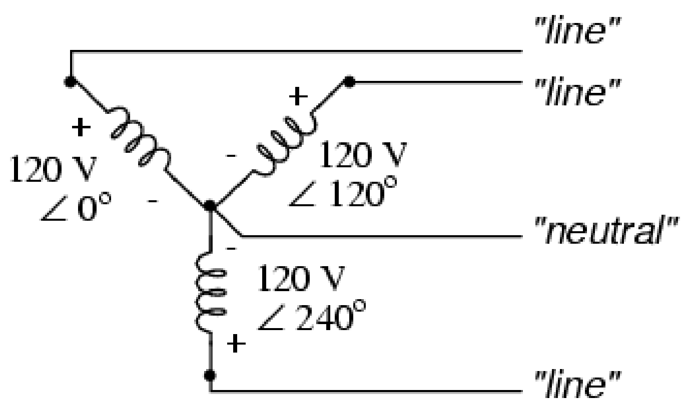



**Figure 0-5: Three-phase, four-wire "Y" connection uses a "common" fourth wire (allaboutcircuits, 2018).**

**Delta connection**

Three single-phase supplies could also be connected in series. The sum of the three 120° phase shifted voltages at any instant is zero. If the sum is zero, then both endpoints are at the same potential and may be joined together. The connection is usually drawn as shown below and is known a delta connection after the shape of the Greek letter delta, Δ.

For "Δ" circuits,

$$V_{line} = V_{phase}$$
$$I_{line} = \sqrt{3} I_{phase}$$

$(allaboutcircuits, 2018)$

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

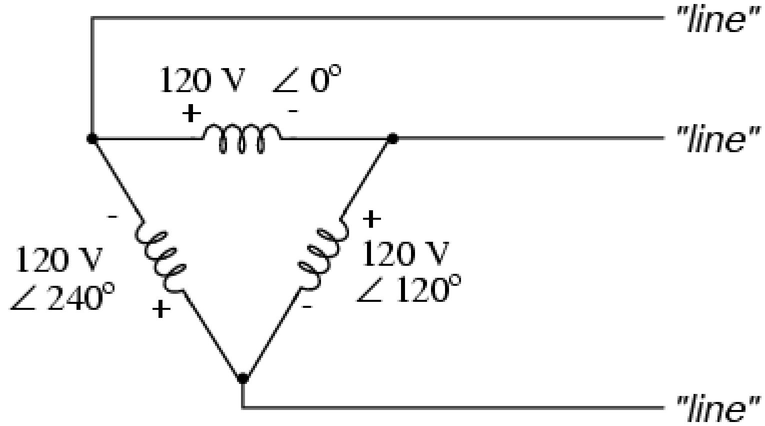



**Figure 0-6: Three-phase, three-wire Δ connection has no common (allaboutcircuits.com, 2018).**

**To calculate Phase and Line voltage of Alternator**

Since it's a star connection,

$$V_L = V_{ph} * \sqrt{3}$$

Where: $V_L = Line\ to\ line\ voltage\ at\ 415V$

$$V_{ph} = \frac{415V}{\sqrt{3}}$$

$$V_{ph} = 239.6V$$

**Current**

Electric current produces a magnetic field. The magnetic field can be visualized as a pattern of circular field lines surrounding the wire that persists as long as there is current. Magnetism can also produce electric currents. When a changing magnetic field is applied to a conductor, an Electromotive force (EMF) is produced, and when there is a suitable path, this causes a current. Electric current can be directly measured with a galvanometer, but this method involves breaking the electrical circuit, which is sometimes inconvenient. Current can also be measured without breaking the circuit by detecting the magnetic field associated with the current. Devices used for this include Hall Effect sensors, current clamps, current transformers, and Rogowski coils (Horowitz and Hill, 2015).

$$P(in\ kW) * 1000 = \sqrt{3} * I_{ph} V_l \cos\emptyset * \eta$$

Where, $P = real\ power\ (kW)$

$I = Current\ (Ampere)$

$V_L = Line\ to\ line\ voltage\ at\ 415V$

$\cos\emptyset = Power\ factor$

$\eta = Efficiency$

$(Engineering\ ToolBox, 2009)$

International Journal of Applied Science and Engineering Review

IJASER

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

$$I = \frac{P * 1000}{\sqrt{3} * V_l \cos\emptyset * \eta}$$

$$I = \frac{5.5 * 1000}{\sqrt{3} * 415 * 0.86 * 0.85}$$

$$I = 10.467\ ampere$$

**Required capacitor's capacitance**

In order to generate electricity, the capacitor must be connected to the winding of generator. The capacitors serve as the excitation source for the induction generator. The selection of an excitation capacitor is very important for voltage regulation of the three-phase induction generator.

$$C(F) = \frac{1000 * Q(kVAR)}{3 * 2\pi f * {V_{ph}}^2}$$

$$C(F) = \frac{1000 * 3.263}{3 * 2 * \pi * 50 * 239.6^2}$$

$$C(F) = \frac{3263}{54105916.11}$$

$$C = 6.0307 * 10^{-5} Farad$$

$$C = 60.307 \mu F$$

**Number of turns for each phase winding**

In generators, increasing number of coils increases generated EMF or the voltage. a way to increase or vary the number the number of coils is to vary the no turns wound for the slots. To get the number of turns needed to get the desired output of 5.5kW based on the available specifications of the 6.8kW induction generator.

$$no\ of\ turns = \frac{phase\ voltage}{E_o}$$

Where, $E_o = L * B * 4.44 * 1.02 * f * 10^{-6}$

And,

$L = length\ of\ stator, 220mm$

$B = breadth\ or\ diameter\ of\ stator, 190mm$

$f = frequency, 50Hz$

$$E_o = 220 * 190 * 4.44 * 1.02 * 50 * 10^{-6}$$

$$E_o = 9.465192$$

International Journal of Applied Science and Engineering Review

IJASER

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

Phase voltages for each phase and colour coding

Phase 1 (L1) = 220V Red

Phase 2 (L2) = 230V Yellow

Phase 3 (L3) = 240V Blue

$$For\ L1: \quad No\ of\ turns\ for\ L1 = \frac{220}{9.465192}$$

$$No\ of\ turns\ for\ L1 = 23\ turns$$

$$For\ L2: \quad No\ of\ turns\ for\ L2 = \frac{230}{9.465192}$$

$$No\ of\ turns\ for\ L2 = 24\ turns$$

$$For\ L3:$$

$$No\ of\ turns\ for\ L3 = \frac{240}{9.465192}$$

$$No\ of\ turns\ for\ L3 = 25\ turns$$

Stator Lap winding configuration

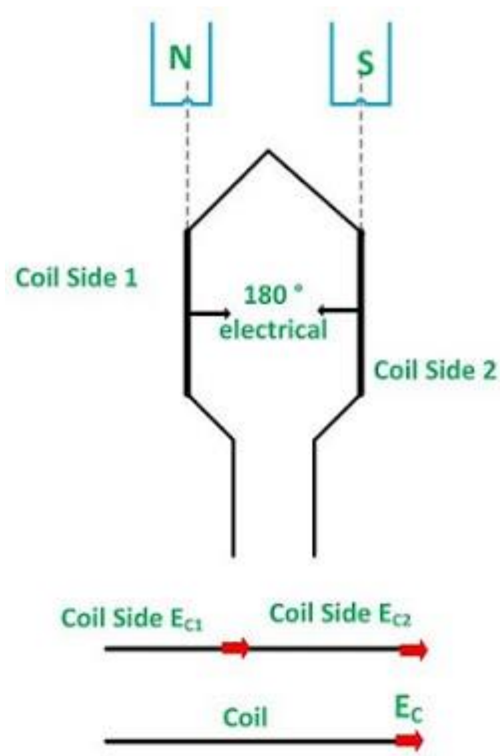



**Figure 0-7: A coil having a span equal to 180 electrical degrees is called a full pitch coil (cg, 2017)**

Coil of a rotating machine is made up of one turn or multi turns of the conductor. If the coil is made up of

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

a single turn or a single loop of conductor, it is called single turn coil. If the coil is made up of more than one turn of a conductor, we refer it as a multi-turn coil. A single turn coil will have one conductor per side of the coil whereas, in multi turns coil, there will be multiple conductors per side of the coil. Whatever may be the number of conductors per side of the coil, each coil side is placed inside one armature slot only. That means all conductors of one side of a particular coil must be placed in one single slot only. Similarly, conductors of opposite side of the coil are placed in another single armature slot.

**The pole pitch** is defined as the peripheral distance between centres of two adjacent poles in the rotating machine. This distance is measured in term of armature slots or armature conductor come between two adjacent pole centres. Pole Pitch is naturally equal to the total number of armature slots divided by the number of poles in the machine. If there are 96 slots on the armature periphery and 4 numbers of poles in the machine, the numbers of armature slots come between two adjacent poles centres would be 96/4 = 24. Hence, the pole pitch of that machine would be 24. As we have seen that, pole pitch is equal to total numbers of armature slots divided by total numbers of poles, we alternatively refer it as armature slots per pole (Electrical4u, 2012).

$$Slot\ number\ of\ start\ of\ R - phase\ (R_S) = 1$$

$$Slot\ number\ of\ start\ of\ Y - phase\ (Y_S) = 1 + \frac{120°}{slot\ angle\ in\ electrical\ degrees}$$

$$Slot\ number\ of\ start\ of\ B - phase\ (B_S) = 1 + \frac{240°}{slot\ angle\ in\ electrical\ degrees}$$

$$Slot\ angle\ in\ electrical\ degrees = \frac{180°}{Coil\ span}$$

$$Since\ it's\ full\ pitched, Coil\ span = pole\ pitch = \frac{number\ of\ slots}{number\ of\ poles}$$

$(Engineering\ ToolBox, 2009)$

To get the winding configuration, we need to calculate the following data

$Number\ of\ slot = 38 (36\ used, 2\ unused)$

$Number\ of\ poles = 4$

$Number\ of\ phases = 3$

$$Coil\ span = \frac{36}{4}$$

$$Coil\ span = 9\ slots$$

$$Slot\ angle = \frac{180°}{9}$$

$$slot\ angle = 20°\ electrical$$

International Journal of Applied Science and Engineering Review

IJASER

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

Starting slot for the winding for each of the phases:

$$R_S = 1$$

$$Y_S = 1 + \frac{180°}{20°} = 1 + 6 = 7$$

$$B_S = 1 + \frac{240°}{20°} = 1 + 12 = 13$$

$$Slots\ per\ pole\ per\ phase = \frac{36}{3 * 4}$$

$$Slots\ per\ pole\ per\ phase = 3$$

**Coil span** is defined as the peripheral distance between two sides of a coil, measured in term of the number of armature slots between them. That means, after placing one side of the coil in a particular slot, after how many conjugative slots, the other side of the same coil is placed on the armature. This number is known as coil span (Electrical4u, 2012).

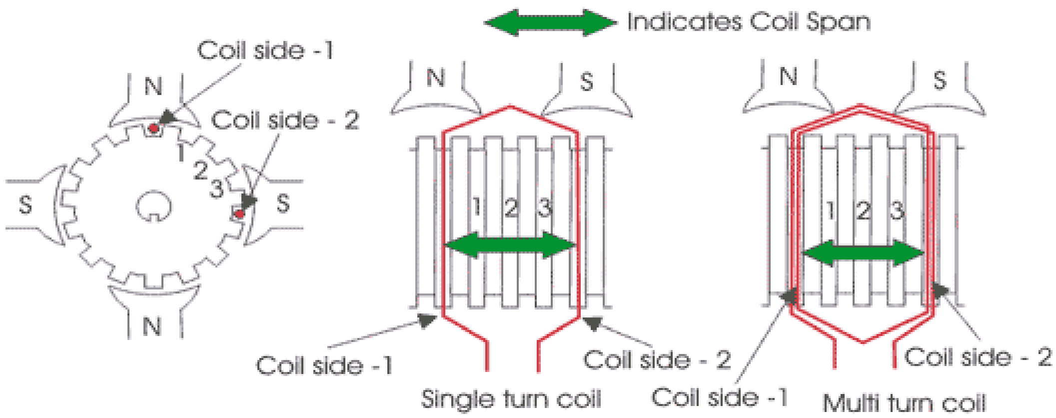



**Figure 0-8: A typical diagrammatic representation of coil span**

$Where\ n\ is\ 5\ slots$

To get the starting slot for each phase,

$$Phase\ difference = \frac{phase\ angle * coil\ span}{180°\ or\ (2\pi\ electrical\ degrees)}$$

$$Phase\ difference = \frac{120 * 9}{180}$$

$$Phase\ difference = 6$$

**Winding configuration for the 3 phases**

The winding configuration for the coil sets for each of the phases based on the slot per pole per phase is shown in the table below, it must be recalled that in lap winding, the coil sets are connected start to start and finish to finish.

| PHASE | POLE 1 | POLE 2 | POLE 3 | POLE 4 |
|---|---|---|---|---|
| R | 1,2,3 | 10,11,12 | 19,20,21 | 28,29,30 |
| Y | 7,8,9 | 16, 17, 18 | 25, 26, 27 | 34, 35, 36 |
| B | 13,14,15 | 22, 23, 24 | 31, 31, 33 | 4, 5, 6 |

**Calculation for the coupling**

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shafts during operation; torque is transmitted from the Petrol engine to the Alternator through the coupling. Slip can be defined as the difference between the flux speed (Ns) and the rotor speed (N). The speed of the rotor of an induction motor is always less than its synchronous speed. It is usually expressed as a percentage of synchronous speed (Ns) and represented by the symbol 'S. Since the synchronous speed of the alternator is 1500 rpm, for the alternator to produce, it has to be driven at a speed higher than 1500rpm to allow for the slip to be negative.

Therefore

$$speed\ of\ prime\ mover = synchronous\ speed + \%\ slip\ speed$$
$$Speed\ of\ prime\ mover = 1500 + \%\ slip\ speed$$

Minimum requirements for the prime mover (e.g. a 13HP petrol engine)

$$power(kW) = HP * 746$$
$$Power = 13\ * 746$$
$$Power = 9698\ Watts$$
$$Power = 9.698\ kW$$

The torque needed to for the induction generator to produce electricity is $35.014\ Nm$ ($3.57\ Kgm$). If the slip of the coupling is -3%, the speed of the petrol engine is:

$$\%\ slip = \frac{N_S - N}{N_S} * 100$$

Where, $N_S = Synchronous\ speed$

$N = Rotational\ speed$

$(Engineering\ ToolBox, 2009)$

$$N = N_S\left(1 - \frac{\%\ slip}{100}\right)$$

ISSN: 2582-6271
Vol. 5, Issue.2, March-April 2024, page no. 58-80

$$N = 1500 * \left(1 - \frac{(-3)}{100}\right)$$
$$N = 1500(1 + 0.03)$$
$$N = 1500 * 1.03$$
$$N = 1545\ rpm$$

The torque generated by the prime mover (e.g. a 13HP petrol engine) with output power,13HP ($9.698\ kW$) and speed, $1545\ rpm$ is:

$$T = \frac{60}{2\pi} * \frac{P * 1000}{N}$$

Where: $P = Power\ output\ in\ kW$

$N = Rotational\ speed\ of\ machine\ in\ RPM$

$(Engineering\ ToolBox, 2004)$

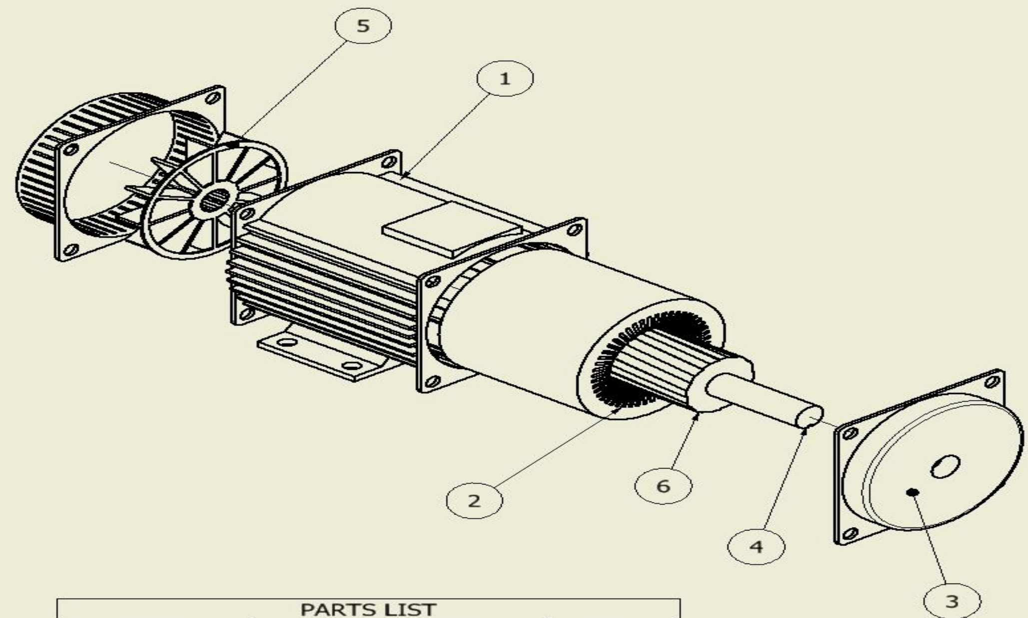
$$T = \frac{60 * 9.698 * 1000}{2 * \pi * 1545}$$
$$T = \frac{581880}{3090\pi}$$
$$T = 59.941\ Nm$$
$$T = 59.941\ Nm * 0.102$$
$$T = 6.11\ Kgm$$

**Conceptual design of the Induction Generator**

The design concept of the induction generator showing all the major parts is shown below:

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80




| PARTS LIST | | |
|---|---|---|
| ITEM | PART NUMBER | QTY |
| 1 | Generator casing | 1 |
| 2 | Stator | 1 |
| 3 | Fan end case | 1 |
| 4 | Rotor shaft Assembly | 1 |
| 5 | Fan | 1 |
| 6 | Rotor | 1 |

**Figure 0-9: An exploded view of the Induction generator.**

Other specifications and detailed measurements for all of the Induction generator parts are contained in the appendix.

### Working Principle of Induction Generators

In normal motor operation, the stator flux rotation is faster than the rotor rotation. This causes the stator flux to induce rotor currents, which create a rotor flux with a magnetic polarity opposite to stator. In this way, the rotor is dragged along behind stator flux, with the currents in the rotor induced at the slip frequency. The motor normally turns slightly slower than the synchronous speed; the difference between synchronous and operating speed is called "slip" and is usually expressed as per cent of the synchronous speed.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

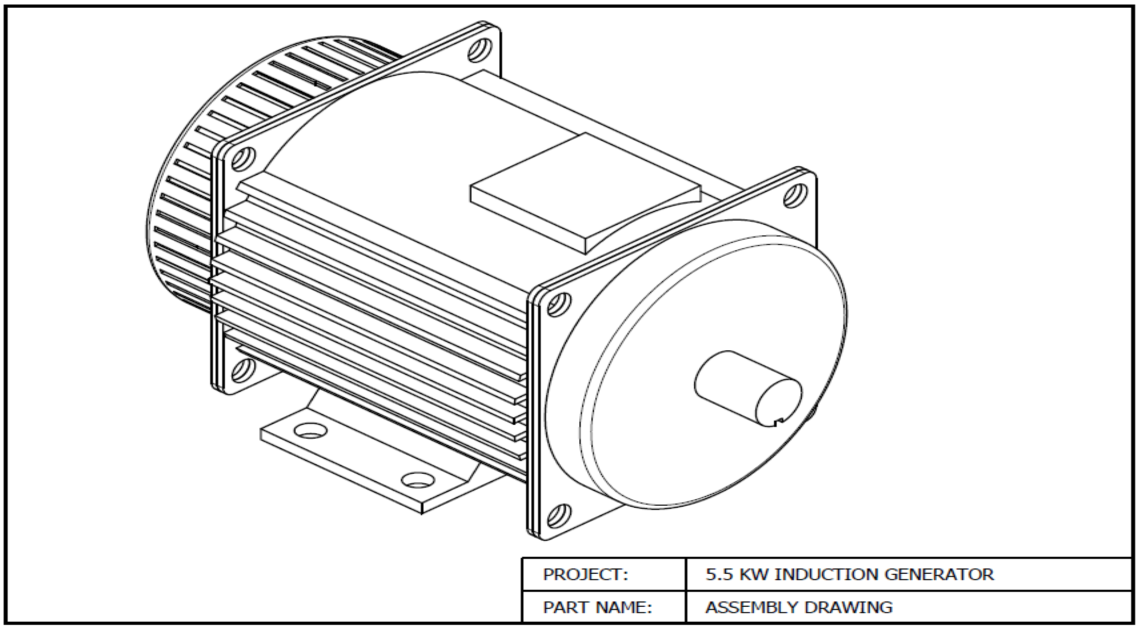



**Figure 0-10: Assembly of the Induction Generator**

However, for induction generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed (negative slip). The stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid. An induction machine requires an externally-supplied armature current. Because the rotor field always lags behind the stator field, the induction machine always "consumes" reactive power, regardless of whether it is operating as a generator or a motor. A source of excitation current for magnetizing flux (reactive power) for the stator is still required, to induce rotor current. This can be supplied from the electrical grid or, once it starts producing power, from the generator itself. An induction machine can be started by charging the capacitors, with a DC source, while the generator is turning typically at or above generating speeds. Once the DC source is removed the capacitors will provide the magnetization current required to begin producing voltage. An induction machine that has recently been operating may also spontaneously produce voltage and current due to residual magnetism left in the core.

International Journal of Applied Science and Engineering Review
IJASER
ISSN: 2582-6271
Vol. 5, Issue.2, March-April 2024, page no. 58-80

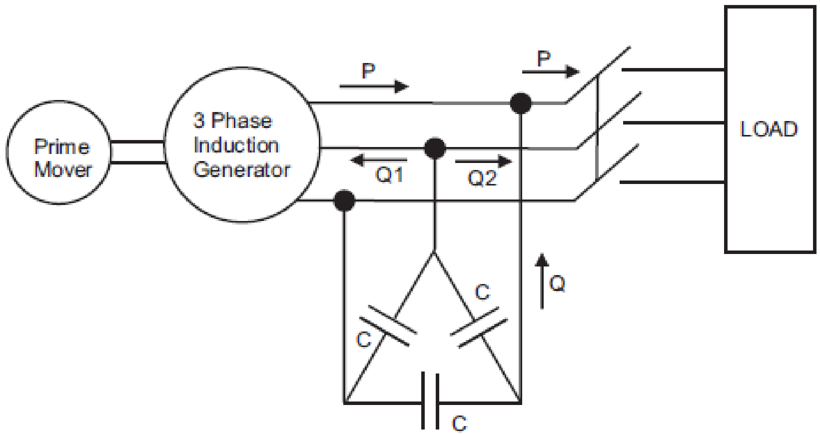



**Figure 0-11: A capacitor excited 3-phase Induction Generator (Electrical4u, 2012).**

**Method of Fabricating**

Induction generators are basically induction motors driven by a prime mover at speed above synchronous speed; the method adopted in this study is to rewind a 6.8 kW scrap induction motor to the desired 5.5 kW output, therefore the designs and calculations will be based on the specifications of the scrap induction motor and decided the desired output of the study; after which the coils on the old materials will be removed and replaced with the new rewound coil wound based on the calculations and the specifications of the design.

The process of rewinding involves the following:

**Study and record of data from the scrap induction motor**

The coils from the scrap Induction generator were removed while the data like the no of slots and the number of poles were recorded for use in calculations for the 5.5kW induction generator.

**Burning and cleaning of slots using a blow touch**

Due to the impossibility of totally removing the insulations from the slots, a blow torch was used to burn the sticky leftovers, Industrially the stator is put in a sandblast where all areas of the slot is reached by smooth sand moving at high velocity and it cleans the stator and slots when friction happens on contact; however due to the absence of a sandblaster, the blowtorch and a hard toothbrush was used to clean the slots.

**Wounding of stator and rotor coils based on the calculations and application of Varnish**

After the insulation papers were fixed in the slots, the stator was wound based on the slot configuration and the number of turns as calculated above. Also, the ends are soldered start to start and finish to finish.

## MATERIALS

The materials used for the project can be classified into consumable and non-consumables, consumable materials being the materials that are used in the process of the design and production of the machine, while non-consumables are testing devices, soft wares etc. that were not directly involve in the production process as they can still be used for other projects outside of the scope of this study.

### Consumables

**Insulation paper:** Insulating papers are the primary layers of insulation in motor coils and they are inserted in motor winding just to separate each of the winding coils from another. Thus, the windings of the motor will not get shorted to each other because lots of parameters like voltage rating current carrying capacity depends upon the number of windings. Paper insulation is used because of the voltage and its durability at high voltages.

**Diodes:** these allow for the flow of current in one direction

**Varnish:** Motor varnish refers to the second layer of insulation that is applied to the coils on the rotor and stator windings in a motor, but can be used for anything from insulating the coils in a machine to the coils of a generator in a power plant. Motor varnish immobilizes windings so the coils do not move.

**Winding wire:** In the design of a motor, the wire size is an engineering trade-off decision between the coil resistance (cross-sectional area × wire length × material resistivity) and the number of turns that can fit into the physical space available. This choice is based on the performance requirements for the design (speed, acceleration, power consumption, cost, etc.), and also subject to constraints on the maximum amperage a particular wire size and electrical insulation can survive, and other factors, based on these factors, SWG 22 (0.711mm) was chosen for the project.

**Sandpaper:** rough surfaced paper used to remove the coatings from the copper wire windings.

**Insulation sleeve:** These fiber sleeves are acquired from the best. Heat-shrink tubing is a shrinkable plastic tube used to insulate wires, providing abrasion resistance and environmental protection for stranded and solid wire.

**Cotton thread:** these are used to hold the windings in place to allow for order and neatness non-consumables

**Nose plier:** they're commonly used to cut and bend small wires and electrical wiring, needle-nose pliers have other uses, as well. They can bend, cut and grip where fingers and other tools are too big or clumsy.

**Spanner:** A wrench or spanner is a tool used to provide grip and mechanical advantage in applying torque

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

to turn objects—usually rotary fasteners, such as nuts and bolts—or keep them from turning

**Oil can:** is a can that holds oil (usually motor oil) for lubricating machines. An oil-can can also be used to fill oil-based lanterns. Sometimes referred to as an Oiler, it is used (among other tools) to lubricate machinery.

**Mallet:** a mallet is used to softly and safely hit the rotor and other parts in place, a mallet is used more over hammers because of the delicate nature of the windings or coils.

**Wire gauge:** for certifying and ascertaining the wire diameter of the copper windings before use

Adjustable cutter: for cutting the copper wire.

**Micrometre:** this is for ascertaining the copper wire gauge, size or diameter.

**Material Selection**

The main objective of material selection is to minimize cost as well as selecting the appropriate material to be used for each component considering engineering factors as well as the environmental factors or service conditions of the components so that they will perform properly with a high degree of reliability. The selection of materials based on the calculations done and the working conditions of the machine is summarized in the Table below as well as the reasons for their selection.

**Table 0-2: Material choice and reasons**

| S/N | MACHINE COMPONENT | CRITERIA FOR SELECTION | MATERIAL USED FOR THE DESIGN | MATERIAL SUITABLE | REASONS FOR MATERIAL SELECTION |
|---|---|---|---|---|---|
| 1 | Stator | Strength, machinability, cost, availability, stability | Silicon steel | Silicon steel, mild steel, cast iron | Strength, low cost, machinability |
| 2 | Rotor | Strength, machinability, cost, availability, stability | Silicon steel | Silicon steel, mild steel, cast iron | Strength, low cost, machinability |

| | | | | | |
|---|---|---|---|---|---|
| 3 | Machine Frame | Weldability, machinability, surface finish, cost, strength | Mild steel | Mild steel, aluminium, stainless steel | Welding ability, cost strength |
| 4 | shaft | High torsional rigidity, high fatigue resistance | high strength steel | high strength steel, aluminium alloy, titanium and magnesium alloy | Strength, type of load and resistance |
| 5 | Bearing | Strength, type of load, cost | ball bearing | Ball bearing Roller bearing thrust bearing | Cost, type of load |
| 6 | Outer case | Corrosion resistance, lightness, surface finish, cost | Galvanized steel | Galvanized steel, stainless steel, mild steel | Lightness, corrosion resistance |

## RESULT AND DISCUSSION

Based on the calculations done for the design of the 5.5kW induction generator, the following are the detailed specifications of the induction generator, specifications of the required engine size for driving or testing the generator, the tests carried out on the generator and their respective processes, faults that happened in the process of testing, possible faults that can happen in the process of using an induction generator, symptoms or signs of those faults, how to detect and repair them.

### Detailed specifications of the Induction generator

The table below contains the specifications of the fabricated Induction generator and the minimum requirements for the prospective prime mover.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

**Table 0-1: specifications of the fabricated Induction generator**

| | |
|---|---|
| **Type of Generator** | Asynchronous or Induction generator |
| **Method of excitation** | Capacitor banks |
| **Power Output** | 5.5 kW, 6.4kVA |
| **Minimum starting Torque** | 35.014 Nm (3.57 Kgm) |
| **Number of phases** | 3-phase |
| **No of poles** | 4 poles |
| **No of slots** | 38 slots |
| **Power factor** | 0.86 |
| **Synchronous speed** | 1500 RPM |
| **Efficiency** | 85% |

**Table 0-2: Minimum requirements for the prospective prime mover.**

| | |
|---|---|
| **Type of Prime mover** | Turbine or Engine |
| **Minimum Power required (in Horsepower)** | 13 HP |
| **Minimum Power required (in kW)** | 9.698 kW |
| **The minimum Rotational speed required** | 1545 RPM |
| **Minimum Torque required** | 59.941 Nm (6.11 Kgm) |

**Testing and evaluation**

The process of testing the Induction generator was to ascertain if the output at the main upon connection to a prime mover is the same, higher or at least close to those calculated.

**Testing Equipment**

Some of the parameters tested include the generator speed on and without load, the output voltage across the lines and phases, the output current across the lines and phases, the torque and the continuity of the machine. Some of the machines used are listed below:

**Tachometer**

A tachometer is a sensor device used to measure the rotation speed of an object such as the engine shaft in a car and is usually restricted to mechanical or electrical instruments. This device indicates the revolutions per minute (RPM) performed by the object. It can also be used to measure Torque when used in tandem with other devices.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 58-80

**Multi-meter**

A digital multimeter is a test tool used to measure two or more electrical values—mainly voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

**Wattmeter**

The wattmeter is an instrument for measuring the electric power (or the supply rate of electrical energy) in watts of any given circuit. Electromagnetic variations can be used for measurement of utility frequency.

**Testing**

The tests carried out on the alternator involved a no-load and a load test where the behaviour of the alternator under load was observed and recorded, the chosen load were altogether 2.3kW (2,300 Watt), the load was connected to phase 3 of the alternator; the parameters noted were the load and no-load speed, the load and no-load voltage.

**Test 1**

**Table 0-3: Test 1**

| Time | No-load Speed (RPM) | Load speed (RPM) | No-load voltage | | | Load voltage | | |
|---|---|---|---|---|---|---|---|---|
| | | | Phase 1 | Phase 2 | Phase 3 | Phase 1 | Phase 2 | Phase 3 |
| **1:00 pm** | 2644 | 2423 | 78 | 178 | 180 | 68 | 151 | 151 |
| **1:20 pm** | 2623 | 2439 | 81 | 176 | 180 | 68 | 156 | 158 |
| **1:40 pm** | 2572 | 2401 | 78 | 179 | 181 | 70 | 153 | 151 |
| **2:00 pm** | 2714 | 2426 | 88 | 188 | 189 | 72 | 151 | 156 |

**Test 2**

International Journal of Applied Science and Engineering Review
IJASER
ISSN: 2582-6271
Vol. 5, Issue.2, March-April 2024, page no. 58-80

**Table 0-4: Test 2**

| Time | No-load Speed (RPM) | Load speed (RPM) | No-load voltage | | | Load voltage | | |
|---|---|---|---|---|---|---|---|---|
| | | | Phase 1 | Phase 2 | Phase 3 | Phase 1 | Phase 2 | Phase 3 |
| **7:00 pm** | 2667 | 2400 | 88 | 179 | 184 | 79 | 156 | 158 |
| **7:20 pm** | 2696 | 2383 | 81 | 178 | 181 | 72 | 159 | 158 |
| **7:40 pm** | 2633 | 2390 | 85 | 180 | 180 | 78 | 157 | 158 |
| **8:00 pm** | 2609 | 2385 | 81 | 173 | 181 | 78 | 156 | 156 |

**Current and Power**

The current produced in any AC system is based on the load connected across the mains, the current generated based on the following parameters: 2.3 kW load, 0.8 power factor, and the corresponding line to neutral voltages for phase 3 are shown below:

**Table 0-5: Current based on the connected load**

| S/N | The line to neutral Voltage (V) | Current (Amps) |
|---|---|---|
| **Test 1** | | |
| **1** | 151 | 6.35 |
| **2** | 158 | 6.07 |
| **3** | 151 | 6.35 |
| **4** | 156 | 6.14 |
| **Test 2** | | |
| **1** | 158 | 6.07 |
| **2** | 158 | 6.07 |
| **3** | 158 | 6.07 |
| **4** | 158 | 6.07 |

**Problems encountered during testing and solutions**

In the process of trying to test the alternator, some problems were encountered, the alternator even though was been driven at over 2000 RPM wasn't giving producing any power. Based on the study regards what must have gone wrong for the alternator not to start, it was discovered that the stator windings needed to be changed as it had gotten burnt at start due to the short-circuiting of the coils, some of the laminations had removed due to the friction between the armature and the stator; also, upon rewinding the connection of the alternator was changed from Delta to star where the line voltage is the same as the phase voltage. After the corrections, the alternator produced voltage and the tests listed above were carried out.

## CONCLUSION

As a generator is a vital part to the electricity generating ability of a power plant, it is important to choose the type of generator to be used based on its maintainability, efficiency and price while considering the load requirements alongside; Induction generators are best for micro installations because they can produce useful power at varying rotor speeds. Also, they are mechanically and electrically simpler than other generator types. They are also more rugged since they require no brushes or commentators. Generally, the generator can be bought brand new or a scrap one rewound to the required specifications. While it may be economical to rewind, there are more advantages as it gives flexibility regards loading, power rating and a wide range of parameters, and ease of repair.

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