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Self Excited Induction Generators Performance Evaluation

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Abstract

A self-excited (Stand-Alone) asynchronous machine (SEIG) to generate sustainable AC voltage was investigated experimentally in this work. Using evaluated three power capacitors connected in star with the output leads of the induction machine, enabled a maximum phase voltage of 245 volts at a speed of 1400 rpm.
The self-excited induction generator performance characteristics were investigated by carrying out no-load test and load test using resistive, capacitive, inductive and a combination of these loads as long as the machine was not overloaded. Apart from the capacitors acting as the exciter, it also plays the role of compensating for the reactive power in the system.
The use of the induction generator has its short comings in that it has poor voltage regulation when subjected to loading and its inability to start under load. However, this set-back can be overcome with a suitably designed Electronic Load Controllers.

Keywords: asynchronous, synchronous, induction, machine, self-excited, generator, capacitor, controllers.

1. Introduction

Until recently, Pico/micro hydro installations have always used synchronous generators to produce AC electricity if no grid supply is available. Often, for reasons of availability and low cost, machines designed for use with petrol or diesel sets are used. These machines are generally designed for intermittent use, under direct drive conditions. It is little wonder that they do not last long in continuous operation, especially when belt driven by a water turbine with a runaway speed considerably higher than its normal operating speed. Quality synchronous machines are built for such arduous duties, though they are less easy to obtain and expensive. Electrical machines used as generators are usually classified as (a) separately excited generators such as shunt, series, and compound wound, and (b) self-excited generators according to the way in which their fields are excited [1].

In recent years [2], induction machines have been installed as generators in micro power schemes. After thorough testing and evaluation, Induction motor as generator can be used to cater for the demand of a rural/isolated area. The scheme is meant to be a cheaper and efficient method of generating AC power (usually a few kilowatts). It is well known that a conventional induction machine can work as a generator if sufficient amount of capacitance is connected across the machine terminals to sustain the excitation requirements, while the rotor speed is maintained by some mechanical power [3, 4].

The advantages of using either single or three phase squirrel cage induction machine as a self-excited induction generator over synchronous alternators of the same rating are the lower cost due to their simple construction, ruggedness, availability, low cost maintenance. The performance characteristic of induction motors as presented in the works of [5–7], enables its application. In addition, Induction machines are manufactured in large range of sizes and their low speed operation make direct drive from turbine possibility. In addition to these inherent fixtures, one does not need a separate, expensive source of AC excitation current which is required for synchronous alternators. They generate AC voltage of the purest sine wave. They do not use brushes and do not produce any Radio frequency interference (RFI) [8]. Induction generators possess an inherent overload protection. Subsequently removing the load will usually cause the generator to start again [8]. At the occurrence of fault, the load current will be limited by the excitation, and the machine voltage will collapse immediately [3]. In practice the issue of overload, over speed and short-circuit cannot be predicted, hence the need for electronic load controller and protection circuitry cannot be over emphasized to shut off the induction generator. Also the built of this scheme is that induction generators can be paralleled without any difficulty, eliminating the need for costly synchronizing equipment [9].

2. Self-excited (Stand Alone) Induction Generation Operating Principles

The desired magnetizing current required magnetic flux in induction machine can be supplied in total or in part, by capacitors. In the case of a stand-alone induction generator, the total admittance of the asynchronous machine and rest of the connected load must be zero, therefore, in order to obtain the required operating voltage determined by the magnetic flux at the desired frequency, the right amount of capacitance must be carefully chosen [4]. Hence for three phase operation the three phase capacitor bank should be sufficient value, such that the induced electromotive force (emf) circulates leading current in the capacitors and the produced flux would assist the residual magnetism [4]. As saturation occurs, the flux becomes constant and final steady state value of the voltage is obtained [4]. The frequency, slip, airgap voltage and the operating range of the system are affected by the characteristics of the induction generators and the choice capacitors sizes. The operating slip in a self-excited mode is generally small and the variation of the frequency depends on the operating speed range [10].

For a build-up of voltage to occur, sufficient residual magnetism must be present in the rotor [6, 9]. Residual magnetism is the initial magnetism present in the rotor steel. These maybe insufficient magnetism, if, since it was last used, the machine received a large impact or generation collapsed with a resistive load connected. However, this can be corrected by connecting 120VAC or a 12VDC supply for a few seconds across any two of the machine terminals, before running the machine up to speed. Ordinary dry cells connected in series, can also be used [7].

A simplistic but usable way of understanding the basic operation of a stand-alone induction generator is to represent the machine simply by its magnetizing reactance as shown in fig 1.

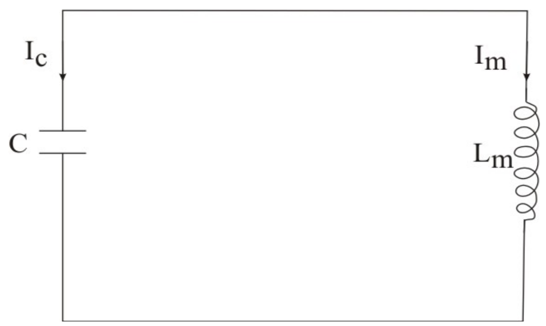


Fig. 1: Highly simplified induction generatorequivalent circuit.

This is a fairly accurate representation for the purpose of determining capacitor requirements. With shaft rotating, current will begin to flow due to the residual magnetism present in the rotor. The capacitor current I, will equal the magnetizing current and the machine reactance and capacitors will act as a resonant circuit at an angular frequency, ω, fixed by the shaft speed of the machine. Resonance circuits can cause very erratic excitation for generators and then its output will become erratic. Thus high voltage can be fed right back into the network [9]. Stable operation occurs when the impedance of the capacitors equals the machine magnetizing impedance as given by the equation below:

$$1/\omega_c = \omega Lm \quad (1)$$

Provided that sufficient capacitance is connected, the voltage against current characteristics for the capacitor meets the voltage against current characteristics for the magnetizing inductance. Self-excitation is possible only if the capacitor susceptance is at least as great as the minimum (unsaturated) magnetizing susceptance ($1/X_c$).

3. Capacitor Connection Effect

For a three phase system, the capacitors can either be star or delta connected, and the usual star-delta-star relationship holds. In the case of the star connected system, the star point of the capacitors should not be connected to the generator and system neutral as waveform distortion and increased losses will occur [11].

Base on star and delta mathematical relationship if the capacitors are connected in star, then three times as much capacitance is required for delta connection. For both cases more capacitance equals more voltage output [8, 12]. Both the stator and the rotor circuits are inductive with constant inductance of L_m, henries and thus consume reactive power. Magnetic circuits excited by alternating current consume reactive power, which produces magnetic flux. But for capacitor excitation, the current in capacitive circuit leads the voltage, causing $\emptyset$ to be negative, from which it follows that capacitive circuit generate reactive power. Thus capacitors are frequently used in industrial power systems to furnish reactive power, an arrangement known as power correction [13].

4. Calculation of Excitation Capacitance

For the approximate calculation of the excitation capacitance required for induction generators electrical test method and a technique requiring only induction motor performance data were used.

No Load Test

The electrical test method involved a no load test as a generator. No load test worthwhile for old machines results can be used to calculate excitation capacitance because “the apparent power drawn by the induction machine at no load is approximately equal to the reactive power required when running as a generator at close full load.

Calculation of Excitation Capacitance based on the following machine parameters.

Power rating =1.1–0.74kw; Cos ϕ=0.79; Efficiency,η=66.6(%); Voltage=380V; Current =2.6-2.2 Amp

Speed= 1400-70 Rpm; Operating frequency =50Hz

Using the system power relationship:

$$S^2 \text{ (VA)} = P^2 \text{ (W)} + Q^2 \text{ (VAR)} \qquad (2)$$

Where, S=Apparent power; P=Real power ; Q=Reactive power

$$P = \frac{1}{\pi}\int_0^{\pi} ied(\omega t) = EICos\emptyset = 0 \quad (3)$$

$$e = L\frac{di}{dt} = \sqrt{2\omega LICos\omega t} = \sqrt{2}XICos\omega t \quad (4)$$

$$= \sqrt{2}ECos\omega t \quad (5)$$

$$Q = EISin\emptyset. \quad (6)$$

Where, E=rms value of the induced voltage, (=XI), Volts,; I=root mean square value of the current, Amp,

$X=\omega L_m$, is the inductive reactance, ohms.; e=induced electromotive form in the circuit, Volts.

$i=\sqrt{2}I\sin\omega t$, is the alternating current of constant frequency.

The total apparent power at full load, $S = \sqrt{3} \times V_{line} \times I_{line} = \sqrt{3} \times 380 \times 2.6$ =1711.3VA

The real power, $P = SCos\emptyset = 1711.30 \text{ X } 0.76 = 1300.60W$

The reactive power, $Q=\sqrt{(S^2 - P^2)} = \sqrt{1711.30^2} - 1300.60^2$=1112.20VAR

Thus, reactive power per phase, $Q_{phase} = \frac{1112.20}{3} = 370.70VAR$

For a star connected system, $I_{phase} = \frac{Q_{phase}}{V_{phase}} = \frac{370.70}{219.30} = 1.69A$

Therefore, Capacitance, $C = \frac{I}{2\pi fV} = \frac{1.69}{2 \text{ X } \pi \text{ X } 50 \text{ X } 219.30}$

$=2.45\mu F$

The property of the capacitor to store an electric charge q in coulombs when its plates are at different potentials is referred to as its capacitance [14].

$$\text{Thus, } C = \frac{q}{V} = \frac{\varepsilon_0\varepsilon_r A}{d} \quad (7)$$

Where, ε_0, ε_r represent permittivity of free space and relative permittivity of the material respectively.

d is the distance between the plates, while V, is potential difference between the plates, in volts.

The theory that presents the characteristics of this element makes its useful in induction generator application [14]. The use of single phase systems requires more capacitance, the induction generator operates at lower efficiency, and not easily excited. But small (minimum) capacitors excitation to the auxiliary winding is required to produce output voltage as voltage rises [7].

5. Result Analysis/ Interpretation

From the results presented graphically, the speed (rpm) at which the generator builds up its voltage is [15]:

$$\text{Engine drive speed} = N_S + \text{slip } (N_S - N_r), \text{ rpm} \quad (8)$$

Where,

N_S=the motor synchronous speed, rpm

Slip=a speed difference between the rotor and changing field in the stationary coils [7].

N_r= the rotor angular speed, rpm

Thus operating with positive slip the induction generator produced the same amount of power as it would have used as motor operating with negative slip [9, 16]. The generator rotor speed against the effect of capacitance is presented in Fig. 1.

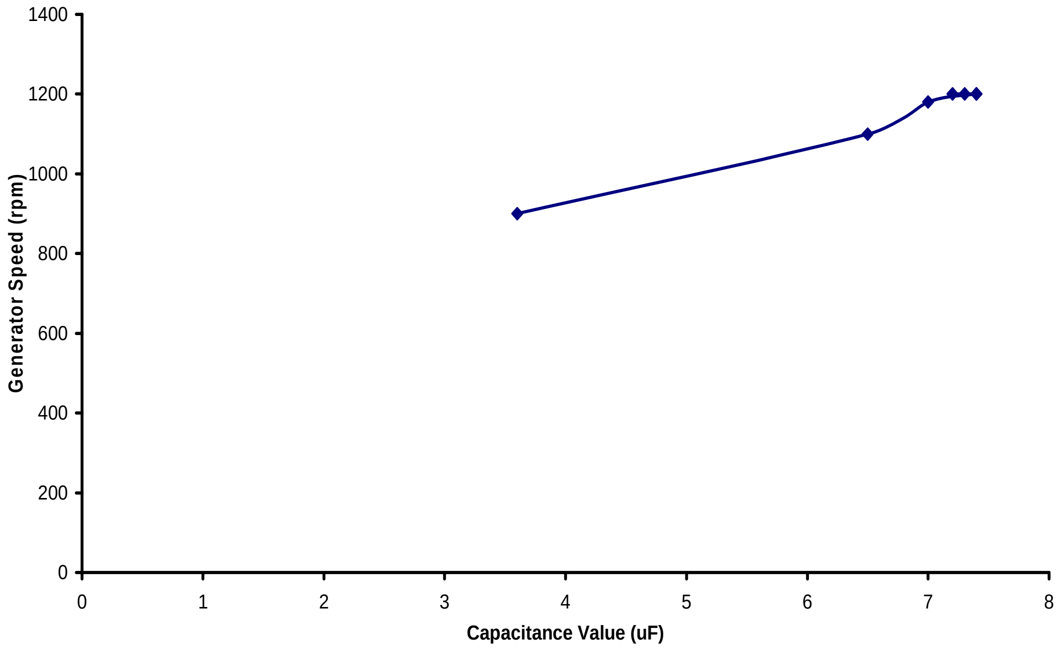


Fig. 1: Generator Speed Against Capacitance Value.

Fig. 2 presents, the outcome when the generator was subjected to resistive, capacitive, inductive and a combination of these loads. At a load of approximately 600 Watts, the generator voltage collapsed to zero and resulted in loss of residual magnetism meaning real power is equal to the apparent power. Also, as more inductive loads were added, the operating frequency also increased and this must be checked to avoid over-frequency. An attempt to load this set up with a 500W automatic voltage regulator, the excitation of the generator almost collapsed that the load was disconnected immediately. This is an indication that too large inductive load, connected the generator output voltage may collapse indicating real power less than apparent power.

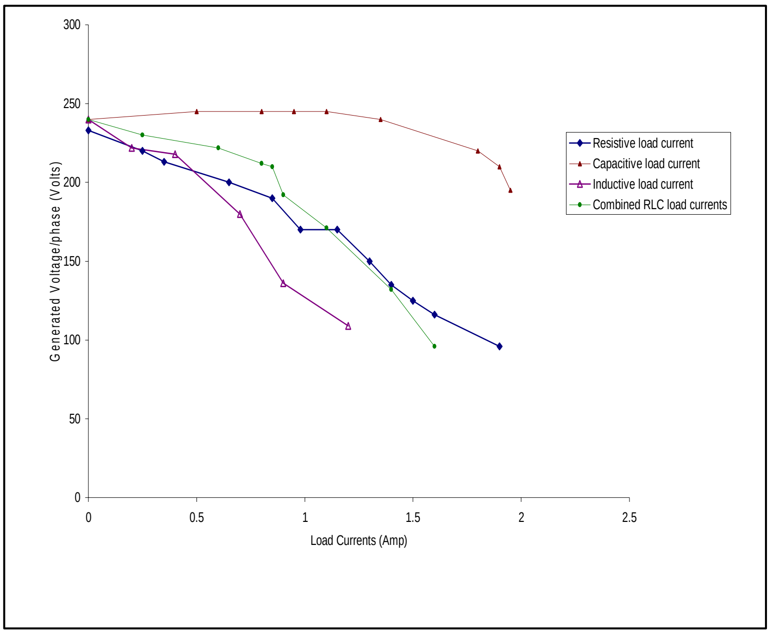


Fig. 2: Plot of generated voltage against load current for star-connected SEIG

The plot of efficiency against load at varied power factor presented in Fig. 3 depicts one of the drawbacks of the induction generator. Though it's almost unity on resistive loads, it is poorer in inductive and a combination of resistive and inductive loads.

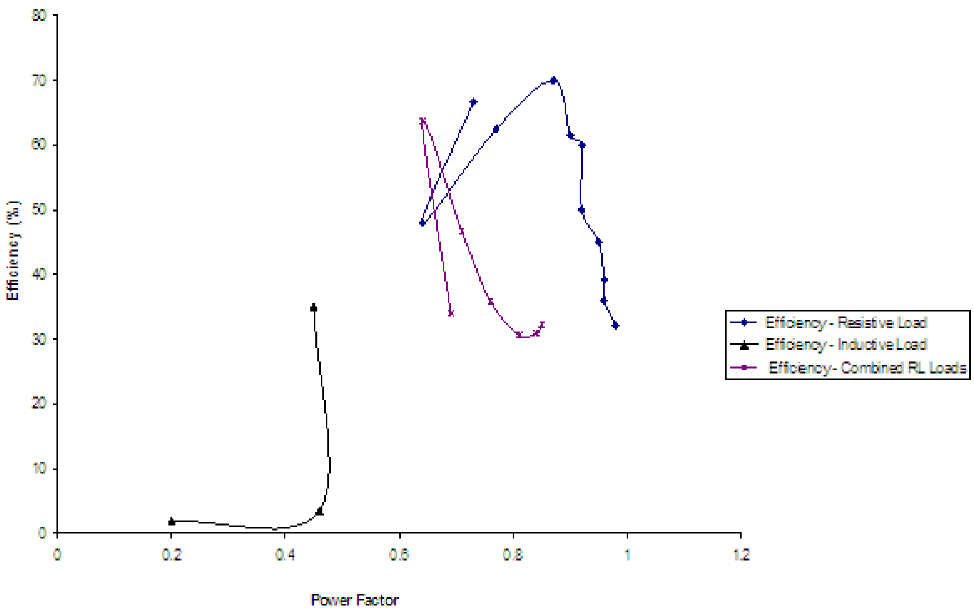


Fig. 3:

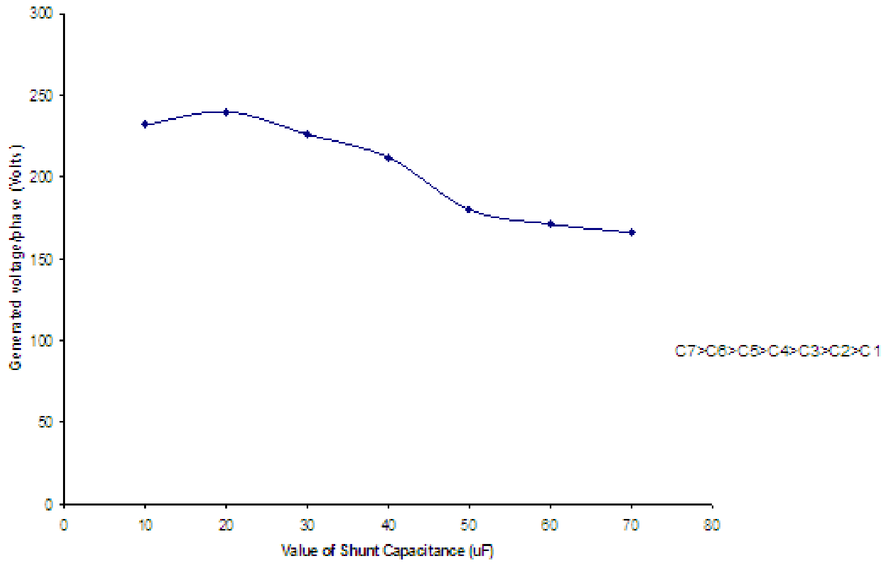


Fig. 4

Fig. 4 shows the maximum voltage that can be generated for different values of excitation capacitors, resulting from the magnetizing current trend. 10% efficiency is typical of this type of system [11].

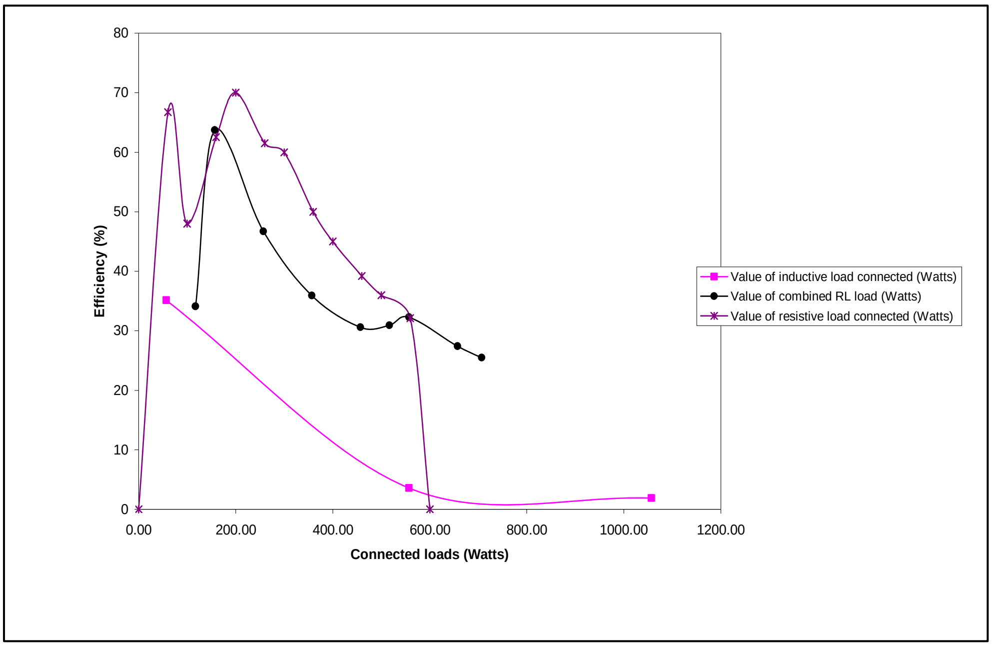


Fig. 5 a & b: Efficiency against Connected Load of Star-connected SEIG

While Figs. 5 (a) and (b) presents the generator efficiency at different loading condition and temperature difference.

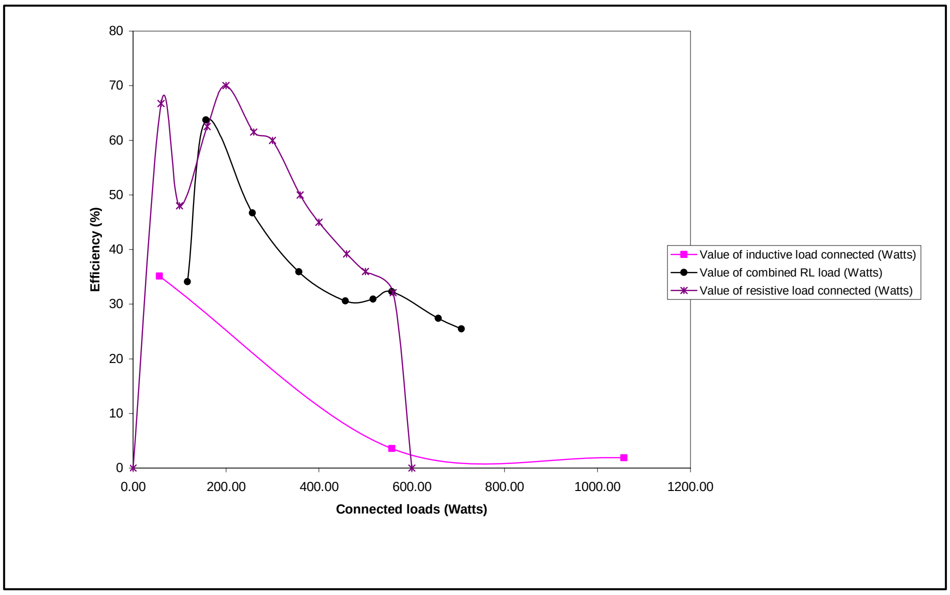


Fig. 5 a & b: Efficiency against Connected Load of Star-connected SEIG

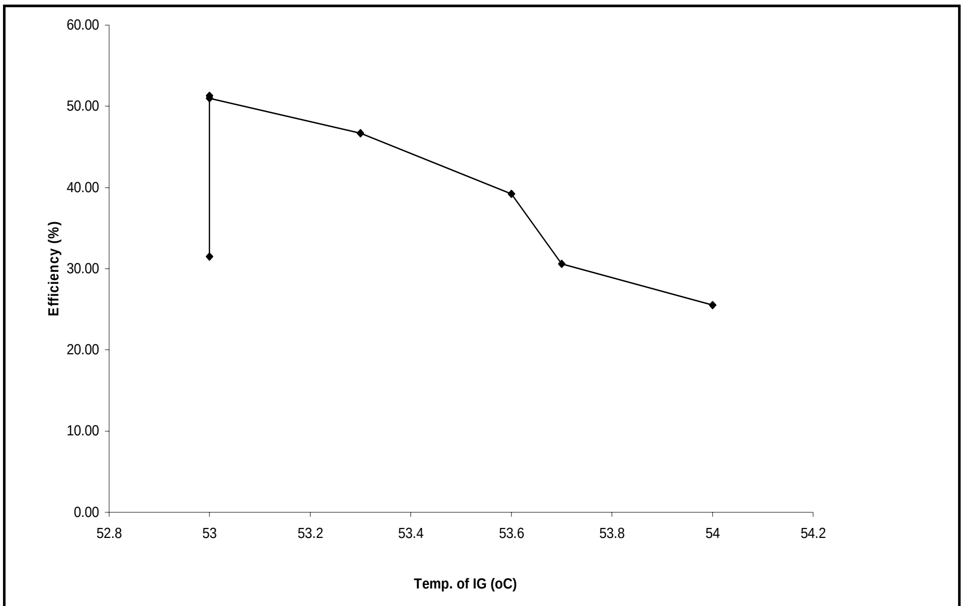


Fig Plot of Efficiency against Temperature for Star-connected SEIG

The perfect sine waveform without harmonics from the generator output as viewed from an oscilloscope is as shown in Fig 6. However, it was noticed that the amplitude of the waveform reduced when the generator was loaded.

Wave form of SEIG on no load
When loaded (resistive load) amplitude reduced

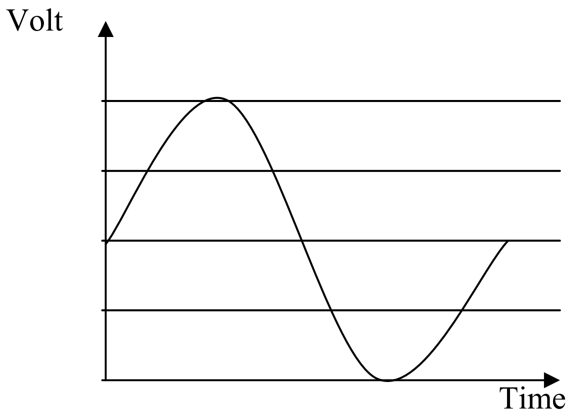
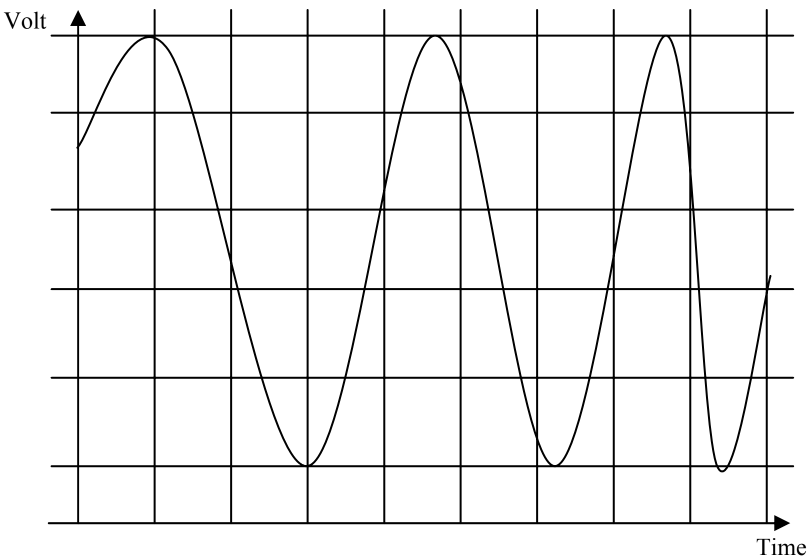


Fig. 6: A & b waveform of the SEIG on load and no load.



Furthermore the behavior of induction motor as induction generators at various loading conditions at remote location has been presented in the work of [15, 16][Igbinovia, et al;….], the findings shows that induction generators can be operated successfully as a stand-alone scheme or connected to the nations grid, but the non-sinusoidal output current generated at the grid [17], must be contented with.

6. Conclusion

The possibility of generating power from an induction generator using charge capacitors has been shown to be possible but with some setbacks. To minimize overheating in both the driving and driven motors arising from operating frequency fluctuation [16], that reduces the system output efficiency centrifugal fans wereincorporated in the generator housing. Also with the installation of appropriate induction generator electronic load controllers that requires very advance technology, research and fund, asynchronous machines for electric power generation are recommended for Pico/mini/micro Hydro schemes in Nigeria to boost rural/isolated area development and as well the standard of living of people, as this will provide a means of constantly monitoring the system loading conditions.

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