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# PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

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**Electronics**
**Electrical Power**
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# ELECTRICAL POWER ENGINEERING

# Design of 1-hp Three-phase Self-excited Induction Generator for Wind Power Generation

Thant Zin Soe[#1], Salai Tluang Za Thang[*2]

[#] *Department of Electrical Power Engineering, Mandalay Technological University*
*Patheingyi Township, Mandalay Division, Myanmar*

[*] *Government Technical Institute*
*Hakha, Chin State, Myanmar*

[1] pskntz@gmail.com
[2] tzthang@gmail.com

*Abstract*— **The increasing importance of fuel saving has been responsible for the revival of interest in so-called alternative source of energy. Thus, the drive towards the decentralization of power generation and increasing use of non-conventional energy sources such as wind energy, bio-gas, solar and hydro potential, etc. has become essential to adopt a low cost generating system, which is capable of operating in the remote areas, and in conjunction with the variety of prime movers. With the renewed interest in wind turbines and micro-hydro-generators as an alternative energy source, the induction generators are being considered as an alternative choice to the well-developed synchronous generators because of their lower unit cost, inherent ruggedness, operational and maintenance simplicity. The ability of induction generator to generate power at varying speed facilitates its application in various modes such as self-excited stand-alone (isolated) mode; in parallel with synchronous generator to supplement the local load, and in grid-connected mode. This paper covers the design of stand-alone 1-HP self-excited induction generator for wind energy. In this paper, the essential features of induction generator and the selection of the generator for low speed are explained. Moreover, the design and calculation of the three-phase 1-hp self-excited induction generator are included in detail.**

*Keywords*— **Self-excited, induction generator, wind power, renewable energy, low speed.**

## I. Introduction

The increasing concern for the environment and resources has motivated the world towards rationalizing the use of conventional energy resources and exploring the non-conventional energy sources to meet the ever-increasing energy demand. A number of renewable energy sources like mini/micro hydro, wind, solar, industrial waste, geothermal, etc. were studied. Since small hydro and wind energy sources are available in plenty, their utilization was felt quite promising to accomplish the future energy requirements. Harnessing mini-hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for quality and reliable power supply.

Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous features over conventional synchronous generators. These features are brush less and rugged construction, low cost, maintenance and operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. The later feature facilitates the induction generator operation in stand-alone/isolated mode to supply far flung and remote areas where extension of grid is not economically viable; in conjunction with the synchronous generator to fulfill the increased local power requirement, and in grid-connected mode to supplement the real power demand of the grid by integrating power from resources located at different sites.

The technology of induction generator is based on the relatively mature electric motor technology. Induction motors are perhaps the most common types of electric motors used throughout the industry. Early developments in induction generators were made using fixed capacitors for excitation, since suitable active power devices were not available.

## II. Types of Wind Turbines

A wind turbine is a turbine driven by wind. Modern wind turbines are technological advances of the traditional windmills which were used for centuries in the history of mankind in applications like water pumps, crushing seeds to extract oil, grinding grains, etc. In contrast to the windmills of the past, modern wind turbines used for generating electricity have relatively fast running rotors. In general wind turbines are divided by structure into horizontal axis and vertical axis.

## III. Self-Excited Induction Generator

For its operation, the induction generator needs a reasonable amount of reactive power which must be fed externally to establish the magnetic field necessary to convert the mechanical power from its shaft into electrical power. Therefore, the external reactive source must remain permanently connected to the stator windings responsible for the output voltage control. In interconnected applications, the synchronous grid supplies such reactive power.

In stand-alone applications, the reactive power must be supplied by the load itself, or by a bank of capacitors connected across its terminals, or by an electronic inverter. When capacitors are connected to induction generator, the system is usually called a SEIG (a self-excited induction generator), as shown in Fig. 1. When the shaft is rotated externally, such movement interacts with a residual magnetic field and induces a voltage across the external capacitor, resulting in a current in the parallel circuit which, in turn, reinforces the magnetic field and the system builds up an increasing excitation.

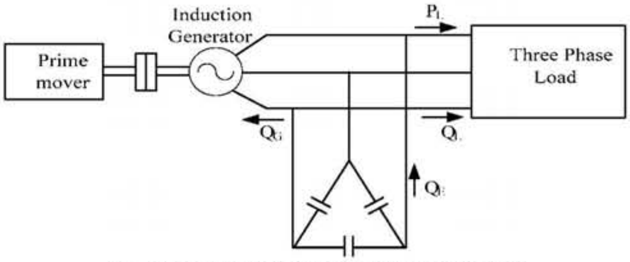


Fig. 1 Capacitor self-excited induction generator

## IV. Torque-speed Characteristics of Induction Generator

In Fig. 2 it can be observed that, for $0 < s < 1$ (or $0 < n_r$ <1800 rpm), the machine absorbs electric power in the rotor to convert it to a positive mechanical torque. If $s = 0$ (or $n_r = n_s$) there is no electromotive force induced in the rotor and, therefore, there is no power transfer from the stator to the rotor, and there is no mechanical torque: If $s < 0$ (or) $n_r > 1800$ rpm, the mechanical power is converted into electric power by the external application of torque in the shaft to turn the rotor, and the machine works as a generator.

If $s \geq 1$ (or) $n_r \leq 0$, the machine works as a brake, absorbing mechanical power, which acts negatively on its shaft ($P_{mec} < 0$).In the characteristics $T \times n_r$, the current $I_2$ assumes values that depend on the rotation assumed for the rotor. In the characteristic $P_{mec} \times I_2$, in contrast, when establishing the values of $I_2$, the slip factor s varies according to it.

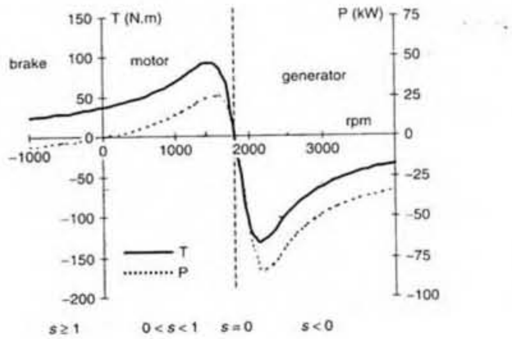


Fig. 2 Torque power speed characteristics of the induction machine working as a brake, motor or generator

## V. Design Theory of Three-phase Induction Generator

The main aim of three-phase induction generator design is to obtain the complete dimensions of various parts of the machine and to improve the torque. The main steps of designing the three-phase induction generator are considered as the following procedures.

- main dimensions of stator core,
- details of stator winding,
- complete details of rotor and its winding,
- performance characteristics: i.e. iron losses, no-load current, short circuit current, efficiency, slip, torque and capacitance

The factors that needed to determine the above design information are:

- detailed specification of induction generator,
- limiting values performance parameters like iron losses, copper losses, no-load current, power factor and efficiency,
- design equations, based on which design procedures are to be initiated,
- information for proper choice of various design parameters,

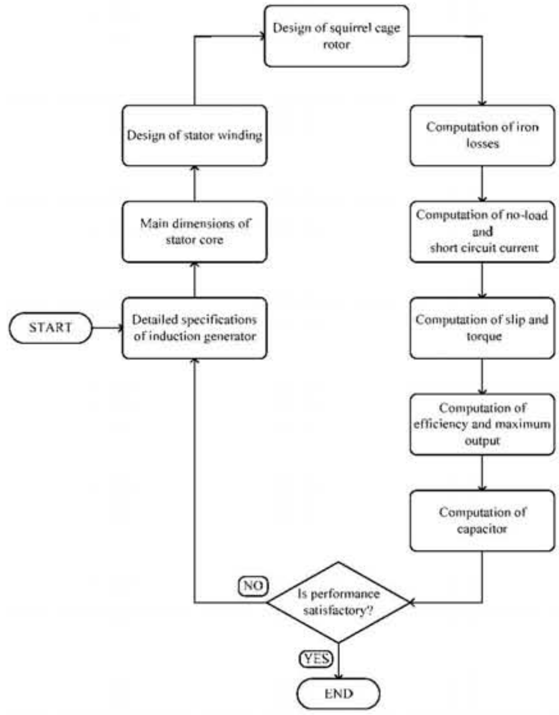


Fig. 3 Design algorithm of three-phase induction generator

Important specifications needed to initiate the design are rated output power, rated voltage, speed, numbers of phase, frequency, connection of stator winding (star/delta), type of rotor (squirrel cage/slip ring), numbers of pole and temperature rise. The design is worked out by resorting to various approximation methods based on accumulated experience realized in different formulae, equations, tables, charts, etc. The design algorithm of three-phase induction generator is described in Fig. 3.

## VI. Design Calculation of Three-phase Induction Generator

The design calculation steps and equations are taken from the design theory in chapter four. To calculate the machine design, first step is based on the main data and the properly assumption values. The second step is to select the design data for the various parts of the machine and then used to calculate the performance. Important specifications needed to initiate in design calculation are given in Table I.

### A. Main Dimensions of Stator Frame Calculation

Based on the rating of the generator and giving due consideration to all the factors, that is, size of the generator, economic, performance, etc, the following values are assumed:

Specific magnetic loading ($B_{av}$) = 0.35 Tesla
Specific electric loading (q) = 13000 Amp cond / meter
Full load operating power factor (cos φ) = 0.8
Full load efficiency (η) = 0.8
For full pitch coil, winding factor, $K_w$ = 0.88

Output Power,

$$P = (11 B_{av} q K_{ws} \eta \cos\varphi \times 10^{-3}) D_s^{2} L n_s \quad (1)$$

Internal diameter of stator,

$$D_s = 1.5\ L \quad (2)$$

Turns per phase,

$$T_{ph} = \frac{E_{ph}}{4.44\, f\, \varphi K_{ws}} \quad (3)$$

Sectional area of stator conductor,

$$a_s = \frac{I_s}{\delta_s} \quad (4)$$

Mean flux density in stator teeth,

$$B_{mts} = \frac{\varphi}{a_s} \quad (5)$$

Total copper losses in the stator winding = $3\ (I_s)^{2}\ r_s$ (6)

Length of air gap,

$$l_g = 0.2 + 2\sqrt{D_s L} \quad (7)$$

TABLE I
SPECIFICATIONS OF 1-HP THREE-PHASE INDUCTION GENERATOR

| Specifications | Design Value |
|---|---|
| Rated output power (P) | 1-hp |
| Rated voltage (V) | 230 V/400 V |
| Speed | 1500 rpm |
| Numbers of phase | 3 |
| Frequency (f) | 50 Hz |
| Connection of stator winding | Star |
| Type of rotor | squirrel cage |
| Number of pole (p) | 4 |

### B. Main Dimensions in Squirrel Cage Rotor Calculation

The main dimensions of squirrel cage rotor are calculated as follow:

Outer diameter of rotor,

$$D_r = D_s - 2\ l_g \quad (8)$$

Rotor bar current,

$$I_b = \frac{K_{ws} \times S_s \times Z_s}{K_{wr} \times S_r \times Z_r} I_r \quad (9)$$

Cross sectional area of rotor bar,

$$a_b = \frac{I_b}{\delta_b} \quad (10)$$

Total copper losses in rotor bars = $I_b^{2} \times r_b \times S_r$ (11)

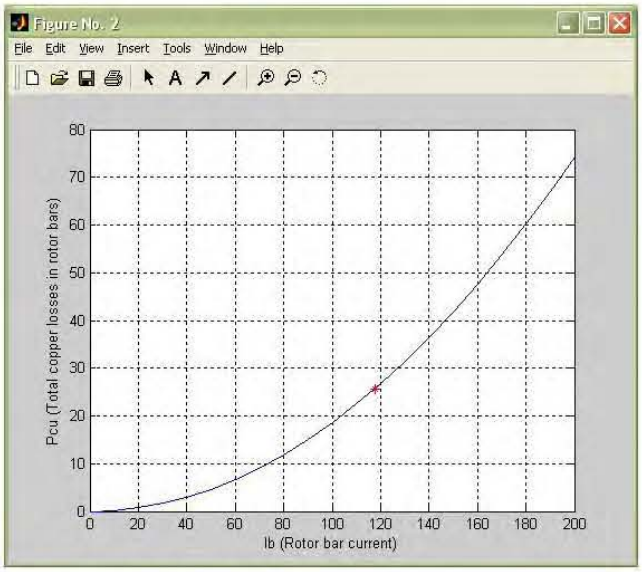


Fig. 4 Rotor Copper Losses Varying as $I_b$

### C. Performance Relating to Design

The losses in three phase induction motor under loaded conditions are stator losses, rotor losses and friction and wind age losses.

Iron loss component current,

$$I_{\mu} = \frac{\text{total no load losses}}{3 \times V_{ph}} \quad (12)$$

Magnetizing current,

$$I_m = \frac{p_1 AT_{30}}{1.17 \times k_{ws} T_{ph}} \quad (13)$$

The magnetic circuit of an induction motor consists of the following five parts in series (i) stator core (ii) stator tooth (iii) air gap (iv) rotor tooth and (v) rotor core. The total ampere turns required by the magnetic circuit is the sum of the ampere turns needed by these parts.

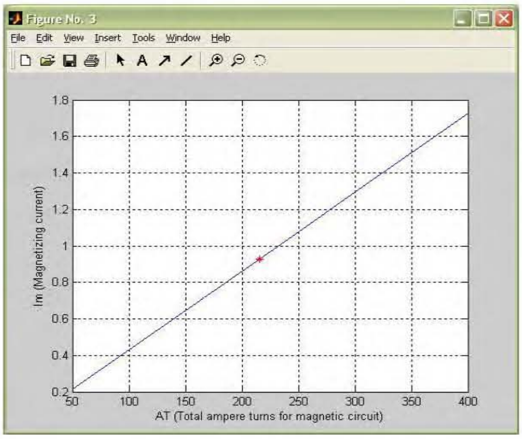


Fig. 5 Magnetizing Current Varying as AT

The total leakage reactance per phase,

$$X = (\text{slot} + \text{overhang} + \text{zigzag} + \text{differential})\ \text{reactance} \quad (14)$$

Total equivalent resistance,

$$R = r_s + r_r \quad (15)$$

Total equivalent impedance,

$$Z = \sqrt{R^2 + X^2} \quad (16)$$

Full load slip,

$$s = \frac{\text{full load rotor copper losses}}{\text{rotor input}} \quad (17)$$

Torque Equation,

$$T_{airgap} = \frac{3E_{ph}^2 r_r / s}{n_s \left[ (r_s + r_r/s)^2 + (Z^2) \right]} \quad (18)$$

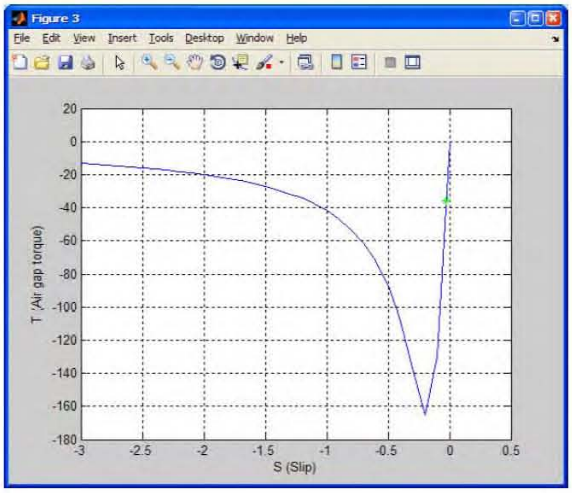


Fig. 6 Torque-Slip Curve of Designed Induction Generator

$$T_{airgap} = \frac{3E_{ph}^2 r_r / (1 - N_r/N_s)}{n_s \left[ (r_s + r_r/(1 - N_r/N_s))^2 + (Z^2) \right]} \quad (19)$$

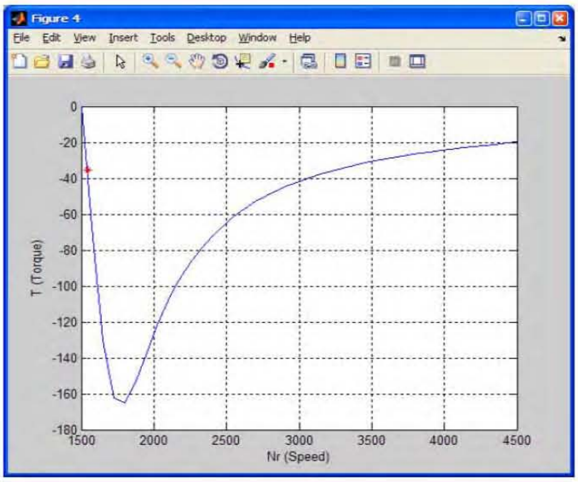


Fig. 7 Torque-Speed Curve of Designed Induction Generator

Efficiency at full load,

$$\eta = \frac{\text{output}}{\text{output} + \text{total losses}} \quad (20)$$

Full load efficiency for small size motor should be between 0.81 and 0.85.

The capacitance per phase,

$$C = 1/2\pi f X_c \quad (21)$$

TABLE II

DESIGN SUMMARY OF 1-HP 3-PHASE INDUCTION GENERATOR FOR STATOR

| Specifications | Design Value |
|---|---|
| Internal diameter of stator ($D_s$) | 0.12 m |
| Gross core length (L) | 0.08 m |
| Flux per pole (φ) | 2.62 mWb |
| Turns per phase ($T_{ph}$) | 450 |
| Number of slots | 36 |
| Full load current ($I_s$) | 1.35 A |
| Cross sectional area of conductor ($a_s$) | 0.51887 $mm^2$ |
| Size of the slot ($b_s \times h_s$) | 6 mm×20 mm |
| Max flux density in stator tooth ($B_{ts}$) | 1.53 Tesla |
| Resistance of stator winding ($r_s$) | 11.2 ohm |
| Copper losses in stator winding | 61.24 W |
| Outer diameter of stator stamping($D_o$) | 0.214 mm |
| Length of air gap ($l_g$) | 0.4 mm |

TABLE III

DESIGN SUMMARY OF 1-HP 3-PHASE INDUCTION GENERATOR FOR ROTOR

| Specifications | Design Value |
|---|---|
| Diameter of rotor ($D_r$) | 0.119 m |
| Number of rotor slots | 29 |
| Rotor bar current ($I_b$) | 94.22 A |
| Size of the slot ($b_r \times h_r$) | 15.4 mm×2.4 mm |
| Resistance of rotor bar ($r_b$) | $0.064\times10^{-3}$ ohm |
| Copper losses in bars | 16.48 W |
| Current in end ring ($I_e$) | 217.44 A |
| Area of end ring ($a_e$) | 72.48 $mm^2$ |
| Resistance of end ring ($r_e$) | $0.0536\times10^{-3}$ Ohm |
| Copper losses in end ring | 5.068 W |
| Rotor copper losses | 21.55 W |
| Equivalent resistance of rotor ($r_r$) | 5.43 Ohm |
| Inner diameter of rotor stamping($D_i$) | 0.04784 m |

TABLE IV

PERFORMANCE DESIGN OF 1-HP THREE-PHASE INDUCTION GENERATOR

| SPECIFICATIONS | DESIGN VALUE |
|---|---|
| TOTAL IRON LOSSES | 73.35 W |
| FRICTION AND WINDAGE LOSSES | 7.46 W |
| NO-LOAD CURRENT ($I_o$) | 0.9363 A |
| TOTAL REACTANCE PER PHASE (X) | 22.69 OHM |
| TOTAL RESISTANCE PER PHASE (R) | 16.63 OHM |
| SHORT CIRCUIT CURRENT ($I_{SC}$) | 8.176 A |
| SHORT CIRCUIT POWER FACTOR ($\cos\Phi_{SC}$) | 0.59 |
| TOTAL LOSSES AT FULL LOAD | 163.6 W |
| EFFICIENCY AT FULL LOAD (H) | 82.01% |
| SLIP AT FULL LOAD (S) | 2.7806% |
| GENERATOR SPEED | 1541.709 RPM |
| SPECIFICATIONS | DESIGN VALUE |
| SLIP SPEED | 41.709 RPM |
| AIRGAP TORQUE ($T_{AIRGAP}$) | -35.748 NM |
| CAPACITOR | 15MF, 250V |

## VII. DISCUSSION AND CONCLUSION

In this paper, a 746 W, 4 poles induction generator is designed for wind power plant. The generator has 4 poles and therefore its synchronous speed is 1500 rpm with frequency of 50 Hz. The aim of design is to obtain completely the dimensions of all the parts of the machine to furnish these data to the manufacturer. The design should be carried out based on the given specification, using available materials economically and to achieve lower cost, lower weight, reduced size and better operating performance.

To obtain high efficiency, it is important to get lower stator copper losses, rotor copper losses and no load losses. So we are very careful stator internal diameter and gross length calculations at the beginning of designed calculation because the later calculations depend on these results. If the results are exact, the target efficiency will be good. In self excited induction generator, if slip percentage is low, air gap torque and generator speed are low. If not, they are large. In a self-excited induction generator, capacitors bank for self excitation between rotor cage and stator winding is needed to generate necessary power. At starting condition of SEIG, rotor cage must have a little residual voltage. If not, the SEIG does not generate electric power because the induction generator can improve necessary voltage only from residual voltage. The disadvantages of SEIG do not directly connect load to generator at starting condition.


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