Modeling and Experimental Analysis of Variable Speed Three Phase Squirrel Cage Induction Generator

Rituparna Guchhayat[1]
[1]Department of Electrical Engineering
[1]Sigma College of Engineering, Bakrol, India

Abstract — Induction machines have wide applications in renewable power system and particularly in wind turbine power systems. In case of standalone wind power system applications, for generating single phase electricity single phase or three phase induction machines can be used. Three phase induction generator can be used to generate single phase electricity at constant or above synchronous speed by using the two-series-connected-and-one isolated (TSCAOI) winding connection without an intermediate stage. In contrast with single-phase cage induction machines, three phase induction machines are significantly less expensive, more efficient, and smaller in frame size in comparison with their single-phase counterpart of similar power ratings.

This paper introduces a novel cage induction generator and presents a mathematical model, through which its behavior can be accurately predicted. The proposed generator system employs a three-phase cage induction machine and generates single-phase, constant-frequency electricity at varying rotor speeds without an intermediate inverter stage.

The technique uses any one of the three stator phases of the machine as the excitation winding and the remaining two phases, which are connected in series, as the power winding. The two-series-connected-and-one isolated (TSCAOI) phase winding configuration magnetically decouples the two sets of windings, enabling independent control. Electricity is generated through the power winding at both sub and super-synchronous speeds with appropriate excitation to the isolated single winding at any frequency of generation.

I. INTRODUCTION

The use of renewable energy as an alternative to low cost fossil energy, which was in abundance, has never been considered as an economically viable option in the past. However, the excessive, unnecessary, and inefficient use of fossil energy has now become a global concern, owing to rapidly decreasing fossil resources, rising fuel prices, increasing demand for energy, and, more importantly, the awareness of global warming and environmental impact.

Consequently, it has now become a common practice of governing bodies to place more emphasis on energy saving, harnessing renewable energy, and particularly on energy management through efficient generation, conversion, transmission, and distribution. This initiative incited a new area of active research and development within both academia and industry under the context of "green or clean or renewable" energy.

Nuclear energy has several advantages over coal in that no carbon dioxide or sulfur dioxide are produced, mining operations are smaller scale, and it has no other major use besides supplying heat. The major difficulty is the problem of waste disposal, which, because of the fears of many, will probably never have a truly satisfying solution.

Because of these problems, along with the rising energy demand in the 21st century and the growing recognition of global warming and environmental pollution, energy supply has become an integral and cross cutting element of every countries economy. In recent years, more and more countries have polarized sustainable, renewable and clean energy sources such as wind power and other forms of solar power are being strongly encouraged.

Wind power may become a major source of energy in spite of slightly higher costs than coal or nuclear power because of the basically non-economic or political problems of coal and nuclear power. This is not to say that wind power will always be more expensive than coal or nuclear power, because considerable progress is being made in making wind power less expensive. But even without a clear cost advantage, wind power may become truly important in the world energy picture.

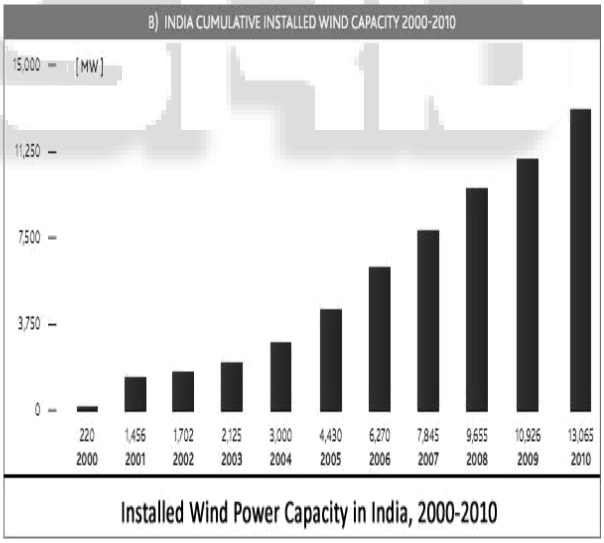

Fig. 1

Wind power has now established itself as a mainstream electricity generation source, and plays a central role in an increasing number of countries' immediate and longer term energy plans. After 15 years of average cumulative growth rates of about 28%, the commercial wind power installations in about 80 countries at the end of last year totaled about 240 GW, having increased by more than 40 times over that same period. Twenty two countries have more than 1,000 MW installed. The following figure shows the 1999 WIND FORCE 10 blueprint and actual development globally [1].

There are various techniques for conversion of mechanical energy into electrical energy. Typically, small renewable energy power plants rely mostly on induction machines, because they are widely and commercially available and very inexpensive. Induction generators are useful in applications such as mini hydro power plants, wind turbines, or in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls. It is also very easy to operate them in parallel with large power systems, because the utility grid controls voltage and frequency while static and reactive compensating capacitors can be used for correction of the power factor and harmonic reduction.

Induction generators have outstanding operation as either motor or generator; they have very robust construction features, providing natural protection against short-circuits, and have the lowest cost with respect to other generators. Abrupt speed changes due to load or primary source changes, as usually expected in small power plants, are easily absorbed by its solid rotor, and any current surge is damped by the magnetization path of its iron core without fear of demagnetization, as opposed to permanent magnet based generators. The induction generator has the very same construction as the induction motors with some possible improvements in efficiency.

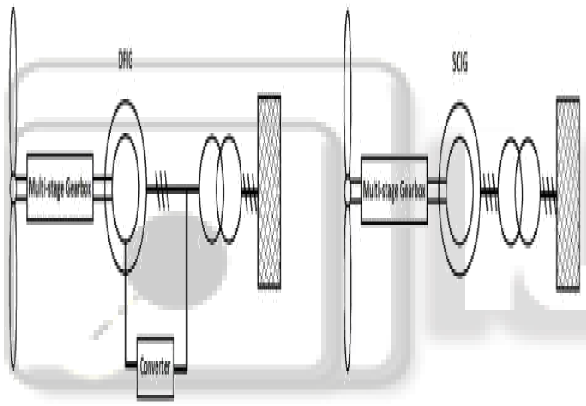

Fig. 2

Induction generators have been also employed to generate single-phase electricity, particularly for standalone or residential use [5]. In [6] and [7], a self-excited and self-regulated single-phase induction generator has been reported for the generation of single-phase electricity. In contrast, the analysis of the self-excitation of a dual-winding induction generator has been presented in [8]. This paper, which uses a single-phase cage induction machine with an auxiliary winding, has been extended by connecting an inverter to the auxiliary winding to achieve more flexibility in power control.

II. INDUCTION GENERATOR IN TSCAOI CONFIGURATION

Induction generators have been also employed to generate single-phase electricity, particularly for standalone or residential use .A self-excited and self-regulated single-phase induction generator has been reported for the generation of single-phase electricity. In [9], a novel method for self-regulated single phase induction generator by using an ac adjustable capacitor is introduced. All these reported schemes employed a single-phase induction generator and an auxiliary winding in some cases or a three phase induction generator to generate single-phase electricity at constant or above synchronous speed. In contrast with single-phase cage induction machines, three phase cage induction machines are less expensive and small in size for a similar power rating.

As, explained in [10] three-phase cage induction machine can be used as a single-phase generator under both sub- and super-synchronous variable-speed conditions without an intermediate inverter stage. The technique uses one of the three windings in isolation for excitation and the remaining two, which are connected in series, as the power winding for the single-phase electricity generation.

The three-phase cage induction machine is mathematically modeled in the proposed two-series connected- and-one-isolated (TSCAOI) phase winding configuration. The proposed technique allows for both energy storage and retrieval through the excitation winding and is expected to gain popularity, particularly in small-scale applications, being relatively simple and low in cost. The following figure shows the proposed induction generator in the TSCAOI configuration.

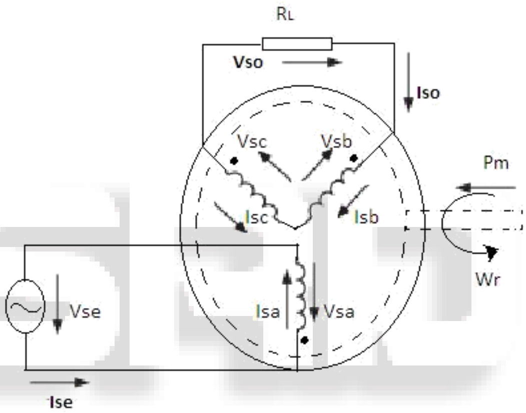

Fig. 3

Cage induction machines are undoubtedly the workhorse of the industry and can be still regarded as the main competitor to permanent-magnet machines. This is because they are self-starting, rugged, reliable, and efficient and offer a long trouble free working life. Of these cage induction machines, three phase machines are significantly less expensive, more efficient, and smaller in frame size in comparison with their single-phase counterpart of similar power ratings. Consequently, three-phase cage induction motors are economically more appealing and have thus become the preferred choice for numerous applications, even at derated power levels.

The proposed novel technique uses a three phase cage induction machine, exploiting its economic advantage, to generate single-phase electricity at variable rotor speeds without an intermediate inverter stage. The technique configures the three stator windings of the three-phase cage induction machine in a novel way to create separate or rather decoupled excitation and power windings. In this configuration, any one of the three phase windings is solely used in isolation for excitation, whereas the remaining two are connected in series to generate power at a desired frequency while the rotor is driven at any given speed. Alternatively, the machine can be also configured in such a way that the two series-connected windings provide the excitation while the single winding generates.

As mathematically shown, the TSCAOI winding configuration magnetically decouples both excitation and power windings from each other and thus allows for independent control as in the case of a single-phase induction motor with an auxiliary winding. In the proposed technique, excitation for the generator is provided through the single winding to study the voltage build up process at no load and at load.

III. REFERENCES

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