

2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies
2017 AEDCEE, 25-26 May 2017, Bangkok, Thailand

Efficiency Evaluation of Three Phase and Single Phase C2C Self-Excited Induction Generator for Micro Hydro Power Application

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Abstract

Squirrel-cage induction motor (SCIM) is used as generator to a great extent for micro hydropower applications due to their robustness, brushless construction, low cost, reliability, rare maintenance, and availability in a wide power range. Squirrel-cage induction generator (SCIG) normally requires excitation capacitors to build up the terminal voltage from residual magnetism. However, for rated and stable voltage and frequency operation, selection of an appropriate size of excitation capacitor is crucial. This paper presents the efficiency evaluation of an SCIG with different excitation capacitors to supply three-phase and single-phase resistive loads. A 1.5-kW three-phase SCIM was selected as the SCIG driven by a 3-kW three-phase SCIM as a prime mover. The shaft speed was controlled by a variable speed drive (Yaskawa A1000) with an incremental encoder for the speed feedback. Shaft torque was obtained from a torque sensor (TRB-2K) installed in between the two machines. Parameters of the SCIG were determined by DC, no-load, and locked rotor tests, then the required excitation capacitance was calculated. For three-phase operation star connected SCIG was excited by the capacitors in star connection to supply a three-phase resistive load. For the single-phase operation, the delta connected SCIG was excited with so-called C2C configuration.

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Peer-review under responsibility of the scientific committee of the 2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies.

Keywords: : Excitation capacitor, self-excited induction generator, Single-Phase C2C condition, Squirrel-cage induction motors

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Nomenclature

ω	speed
τ	torque
P_{load}	load power
P_{shaft}	rotor shaft power
P_{gen}	generator power
V_g	generator terminal voltage

1. Introduction

In most of the developing countries, one of the popular methods of rural electrification is from micro-hydro power generation systems (MHPGS). Such kind of MHPGS's operate in a stand-alone mode for isolated communities, for which construction of high voltage transmission line is not financially and geographically practical and are independent of utility grid systems. Small hydro systems are divided between a mini (less than 1000kW) and micro (less the 100kW) systems with respect to the power generation capacity [1]. In MHPGS, the kinetic energy from the water stream directed by penstock rotates the turbine connected to the generator to convert the shaft power into useful electrical energy.

Consequently, Squirrel-cage Induction Motor (SCIM) is the subject of this research. The primary reasons for supporting induction generator for wind and hydropower generation are its robustness and brushless construction. Other main reasons are its low cost, reliability, rare maintenance, no separate DC excitation and availability in a wide range, from a few kilowatts to a few megawatts [2]. Another unique property of the induction machine is that unlike synchronous machine, induction machine operates at variable speed. However, poor voltage and frequency regulations and low power factors are the drawbacks of induction generator. The major reasons of variable voltage and frequency are the variable rotor speed, value of the electrical load and the size of excitation capacitors. The selection of an appropriate size of excitation capacitance is an important part of the design for stable and constant output voltage and frequency. However, research studies are still in progress in order to resolve the lack of regulations of dynamic voltage and frequency of the self-excited induction generator (SEIG) system.

In this paper, three-phase induction generator (IG) supplies power for both three-phase and single-phase loads. However, single-phase IG can be used under SEIG system but arrangement and selection of excitation capacitors tends to make the system complex. Furthermore, three-phase induction motor (IM) is cheaper as compared to a single-phase IM [3]. In addition, to achieve a balanced system for higher efficiency in single-phase C2C SEIG, it is vital to assure the correct direction of the rotation of the machine associating to the phases to which C and 2C capacitors are connected. It is feasible to find out the right direction of rotor rotation from the machine windings. However, it is possible to have an incorrect rotation, if the windings are labelled wrongly. Therefore, it is possible to make sure that the phase is balanced by measuring the balanced power output or balanced phase current for each phase [4, 2, 3, 5]. Hence, the main objective of this study is to evaluate the efficiency of the three-phase and single-phase C2C SEIG system under balanced condition.

2. Experimental Setup and Methodology

A 1.5/2 kW/HP, three-phase, 230/380 V, 6.4/3.7 A, 50/60 Hz and 1430 RPM squirrel-cage induction generator (SCIG) driven by a 3/4 kW/HP, three-phase, 230/380 V, 11.6/6.7 A, 50/60 Hz IM as prime mover. A Yaskawa AC drive is used to vary the speed of prime mover to emulate the turbine of the hydropower system. The shaft speed from incremental encoder type speed sensor is given to the AC drive for closed loop speed control. The speed of the motor is adjusted around the rated speed to study the effect of the turbine speed variations. The input mechanical power is calculated from the torque measured by the torque sensor installed in between the two machines. The performance of the three phase and single phase C2C system is studied for various excitation capacitors under various load conditions. Equation 1 is used to calculate the efficiency of the system.

$$\text{Efficiency (\%)} = \frac{P_{load}}{P_{shaft}} = \frac{P_{load}}{\omega \tau} \quad (1)$$

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