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# Voltage and frequency regulation for autonomous induction generators in small wind power plant

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ABSTRACT

This paper discusses the voltage regulation of a self-excited and self-regulated autonomous induction generator (AIG) with various operating modes and varying loads. The generator excitation is provided by a three-phase capacitor bank. The Excitation of the asynchronous generator with capacitor bank enables it to generate rated voltage with and without load. A detailed simulation analysis for different performances including loading and unloading characteristics of the self-excited induction generator is also presented in the paper.



## 1. Introduction

Induction machines with cage rotors in isolated regions are invariably used for generation of electricity from wind. Self-excited induction generators (SEIG) are reported to be suitable for small scale wind power plants (Slimene and Khlifi, 2017; García et al., 2018) because of their advantages such as low price, robustness, ease of maintenance, self-protection, easy maintainability, availability and capability to produce electrical power even at variable speed (Slimene et al., 2015a; Pathak et al., 2015; Joshi et al., 2006). These may be operated on/off grid-connected. In off grid mode or Autonomous Wind Power Conversion System (AWPCS), SEIG is useful for supplying remote areas such as islands, military equipment, ships and small villages far from conventional resources.

The need for gearbox arises from the fact that lower rotational speeds on the wind turbine side should be converted to high rotor speeds, on the electrical generator side, for electrical energy production (Chan, 1995; Tian et al., 2010; Yu et al., 2006; Djurović et al., 2015).

SEIG systems consist of a squirrel cage induction motor, prime mover, excitation capacitor and three phase load. The primary requirement for the induction machine to work as an induction generator is excitation current to produce rotating magnetic field. For grid connected machine it takes reactive current from grid whereas for a standalone machine reactive power is supplied locally by the help of shunt and series passive elements (Srivastava et al., 2012; Kalamen et al., 2012; Wei and Chen, 2013; Chatterjee, 2011).

Induction generators play an important role in renewable energy sources such as wind and hydraulic energy. Moreover, self-excited induction generators (SEIG) have been used to operate as wind-turbine generators in an autonomous mode (Slimene et al., 2015a; 2015b; Khlifi et al., 2016).

The existing control schemes of SEIG do not consider the variations in magnetizing inductances during the generator operation which simplifies the control but introduces errors in various estimated quantities during the control of the generating system. In this paper, a model based strategy of providing variable excitation from a battery and fixed excitation using capacitances are considered for voltage stabilization of the induction generator system over a widely varying wind speed range and varying operating loads. This paper exposes the voltage and frequency regulation for autonomous induction generators in small wind power plant.

## 2. Proposed scheme

The proposed scheme is illustrated in Fig. 1. It employs a squirrel cage induction machine excited by a fixed value capacitor connected across each of its terminals and driven by a wind turbine over a wide

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speed range. Because of the varying speed, the power generated would have variable voltage and variable frequency.

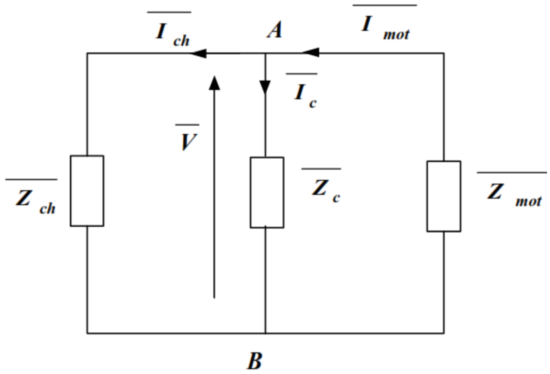


**Fig. 1:** Simplified SEIG scheme

To avoid the similarity rate, the mathematical model of SEIG is developed by Slimene and Khlifi (2017).

## 3. Optimum voltage and frequency operation of the autonomous induction generators (AIG)

The capacitance value is given and the rotor speed is considered variable. Once the polynomial (20) is solved, the pulse is deduced it calculates the magnetizing inductance from (19) and all quantities that characterize the machine will be determined such that the slip g, currents (Im, I1, I2, Ic, and IL) and voltage are obtained for a critical speed recorded and V=81.7 V. The rated voltage is reached for a rotor speed equal to 330rad/s, such as Fig. 2.

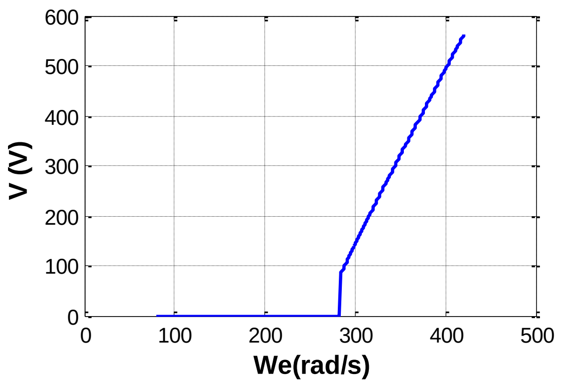


**Fig. 2:** Voltage build-up with constant capacity (C1=13μF)

We proceed in the same way as for V= f(We) constant capacity to trace the pace V= f(We) for different capacitance values. For each capacity value of the allure is drawn V= f(We) Finally, the network is obtained from the curves of Fig. 3.

The instant of capacitor "switch on" can be observed by a transient increase in generated voltage at the beginning of measured result of Figs. 4 and 5. The terminal voltage increases rapidly eventually achieving steady state in the saturation region.

The boot time will be held for a critical value of the capacitor rated voltage corresponding to (the breakdown voltage). When the capacity believes the stator voltage and also has the rated (V=220v) voltage of the machine is reached for an excitation capacity C1= 14.55μF.

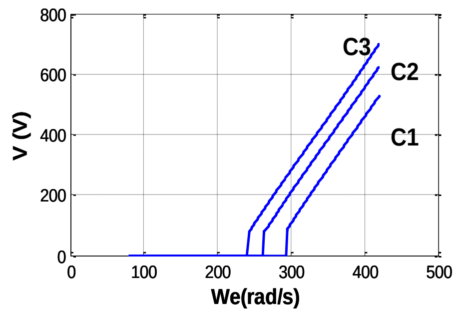


**Fig. 3:** Voltage build-up with the speed for different values of the excitation capacity (C1= 12 μF; C2= 15 μF C3= 18 μF)

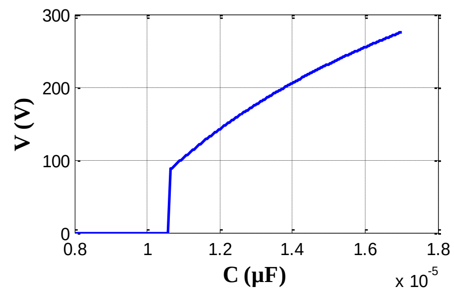


**Fig. 4:** Voltage build-up with capacity for constant rotor speed (We= 314 rad/s)

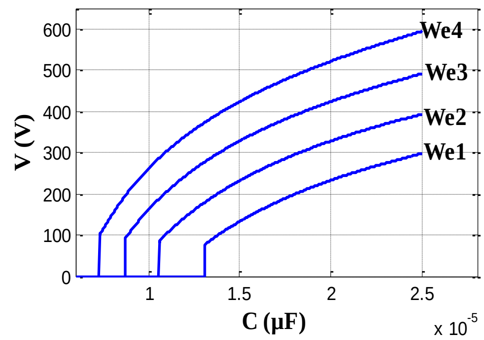


**Fig. 5:** the voltage variation with the ability for different values of the rotor speed with (We1= 0.9*314 rad/s; We2= 314 rad/s; We3= 1.1*314 rad/s; We4= 1.2*314 rad/s)

To test this case, simulation results are shown in Fig. 6 and Fig. 7. We observe that the variation of the current is also proportional to load changes. For the load, we note that the variation of is related to the regulation of the frequency and the variation of is for the voltage regulation.

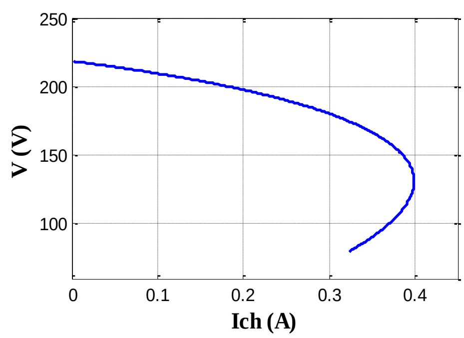


**Fig. 6:** load voltage versus capacity to load excitation current and constant speed (We= 314 rad/s C1=14.5 μF)

The variable voltage drops in the stator with significantly increasing the load current if the capacitor is kept constant, despite the choice of the adequate rotor resistance. To ensure the stability of the voltage, the capacitor has to be varied which requires an infinite number of capacitor values (Figs. 8 and 9).

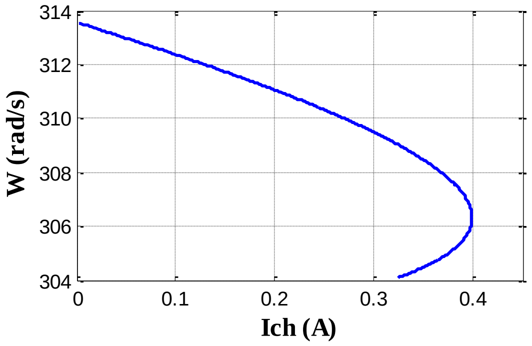


**Fig. 7:** Variation of pulsation based on speed and load current capacity constant excitation (We= 314 rad/s C1=13μF)

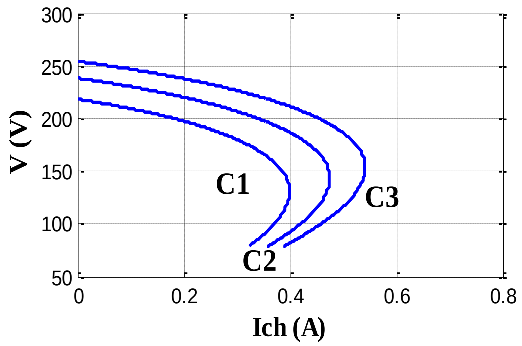


**Fig. 8:** load voltage versus load current at constant rotor speed and variable capacity (C1= 14.5 μF; C2= 15.5 μF C3=16 μF)

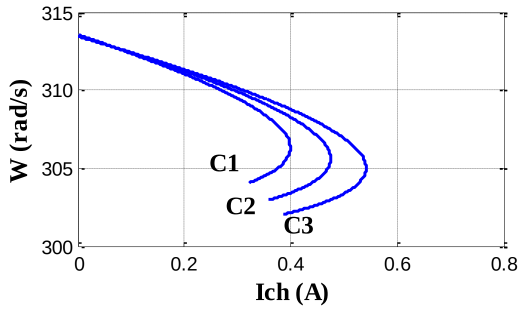


**Fig. 9:** Variation of the pulse based on the rate at constant rotor load current for different values of capacity (C1= 14.5 μF; C2= 15.5 μF C3=16 μF)

The voltage and frequency are controlled efficiently (Figs. 10 and 11). After transient periods, both the voltage magnitude and frequency return to their rated values as a result of the variation of the reactive power or active power dealt by the compensator. We conclude that results show that the proposed control system is effective for the regulation of the voltage and frequency when the wind speed varies. For a given speed of rotation, if one increases the excitation power characteristic of the voltage as a function of the load current flows and the maximum load impedance decreases. Follows the load variation range decreases and thus the stable operation region of the generator load to large values of the capacity reduces.

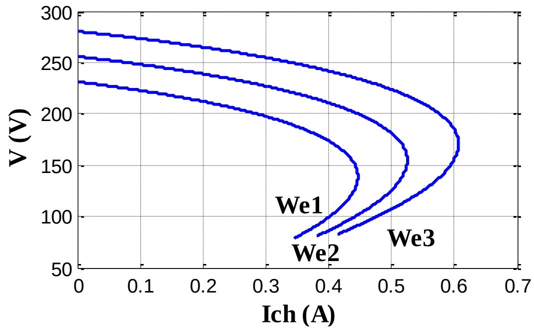


**Fig. 10:** Variable load voltage for different speed (We1= 314rad/s; We2= 322 rad/s; We3= 330rad/s)

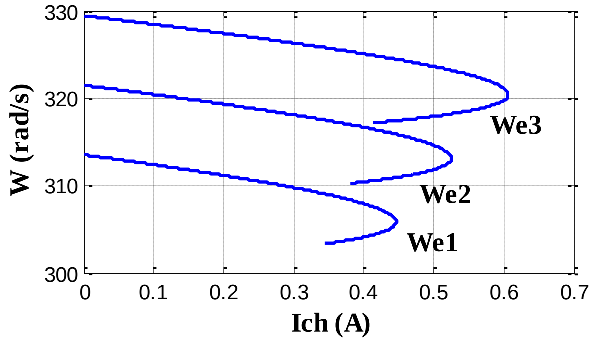


**Fig. 11:** Variation of pulsation based on the load at a constant capacity C2= 15μF for different speed (We1= 314rad/s; We2= 322 rad/s; We3= 330rad/s)

A detailed performance of SEIG along with an extensive simulation testing on an open stator winding ASG is developed. The developed mathematical models are implemented through Matlab using symbolic programming modeling utilities. The static results reveal ASG characteristics during transient conditions such as self-excitation and voltage buildup as well as effect of step loading of different resistive loads. Voltage buildup with regards to two different pre conditions of remnant charge being derived from rotor and excitation capacitance is analyzed.

## 4. Conclusion

The paper presents a near accurate method for the performance analysis of the AIG. The paper generates also a sequence with simple procedures for the voltage and frequency regulation in the squirrel cage induction generator. The transient analysis of the AIG in normal operations is studied deeply by the use of a series of simulation cases. It has been concluded that the proposed method is very suitable for current use. The paper also shows that the SEIG can work safely according to the distribution network and the active and reactive loads are set to their optimum values.

## Compliance with ethical standards

### Conflict of interest

The authors declare that they have no conflict of interest.

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