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Analysis of Switching control model for Self Excited Induction Generator using MATLAB/Simulink

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***Abstract*—The focus of this paper is to develop and analyses switching control model for frequency and voltage of self-excited induction generator (SEIG). This model is designed to make the terminal voltage and frequency of SEIG even in variable load conditions. Voltage and frequency under variable load can be controlled by adjusting excitation capacitance and load. Involvement of synchronous machine is simulated in the model along with induction generator works as synchronous condenser to compensate excitation to control terminal voltage. Secondary load bank is designed to operate as per load situations to regulate frequency. The system model has been tested with load change in steps and results are analyzed to know the feasibility.**

Keywords—Induction Generator, control of reactive power,frequency control,voltage control.

I. INTRODUCTION

Induction generators were used from the beginning of the 20th century until they were abandoned and almost disappeared in the 1960s. With the dramatic increase in petroleum prices in the 1970s, the induction generator returned to the scene. With such high-energy costs, rational use and conservation implemented by many process of heat recovery and other similar forms became important goals. By the end of the 1980s, wider distribution of population over the planet, as improved transportation and communication enabled people to move away from large urban concentration, and growing concerns with the environment led to demand by many isolated communities for their own power plants. In the 1990s, ideas such as distributed generation began to be discussed in the media and in research centers [1].

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. For its simplicity, robustness, and small size per generated kW, the induction generator is favored for small hydro and wind power plants.

The need of external reactive power, to produce a rotating flux wave limits the application of an induction generator as a stand-alone generator. However, it is possible for an induction machine to operate as a self-excited induction generator (SEIG) if capacitors are connected to the stator terminals to supply sufficient reactive power.

The induction generator has the very same construction as induction motor with some possible improvements in efficiency. There is an important operating difference; the rotor speed is advanced with respect to stator magnetic field rotation. For prime mover speed above synchronous speed, the rotor is being driven at a speed more than synchronously rotating magnetic field. The rotor conductors are now being cut by the rotating flux in a direction opposite to that during motoring mode. This shows that rotor generated emf, rotor current and hence its stator components change their signs. As the speed during induction generator operation is not synchronous, it is also called an asynchronous generator.

II. ISOLATED CAPACITOR-EXCITED IG SYSTEM

Fig. 1 presents a system in which a capacitor-excited IG operates isolated from the utility grid. In this circumstance, the active power of the ac load affects considerably the amplitude and the frequency of the voltage at the IG terminals. In this case, the synchronous frequency is not constant, even if the rotor speed is kept constant by the action of a speed governor. Assuming that the mechanical, electrical, and magnetic losses are negligible, the electric power converted by the generator is given by the product between the rotor speed and the generator torque.

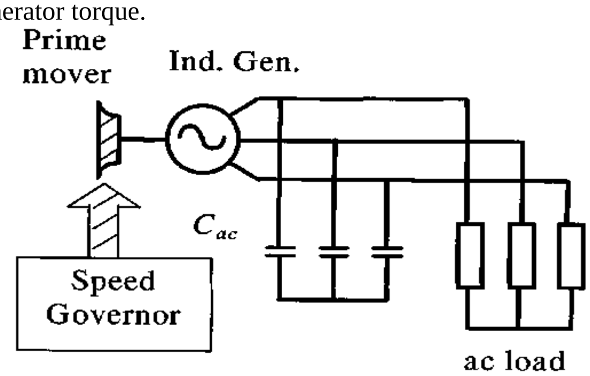

Fig. 1

Supposing the rotor speed is invariable, the increase of the active power required by the ac load yields a drop in the stator frequency, as it is the only possible way the IG can raise its rotor slip frequency and consequently elevate the torque, so that it is able to suit the load power demand.

Fig. 2 illustrates qualitatively a situation in which the induction generator was feeding a unity power-factor load so

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that the steady-state operation point is "A." The synchronous frequency (fs) of the stator magnetomotive force (MMF) is equal to fs1 in point "A." The point "A" of the IG torque characteristic (Fig. 2) corresponds to an equivalent steady-state point "A" in the generator magnetization characteristic, as shown in Fig. 3.

When the active power required by the ac load increases, the synchronous frequency decreases from fs1 to fs2, producing a torque increment to match the higher power demand. Thus, the new stable steady-state operation point is steered to point "B." Notice that the speed governor is supposed to maintain the rotor speed constant.

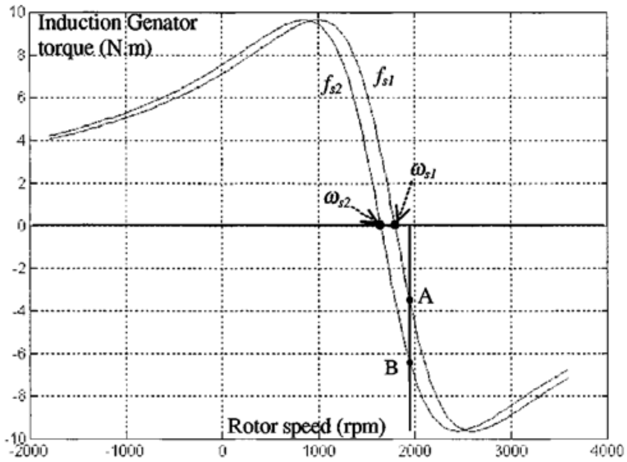

Fig. 2. Torque-speed characteristics of the induction generator, for different synchronous frequencies (f > f).

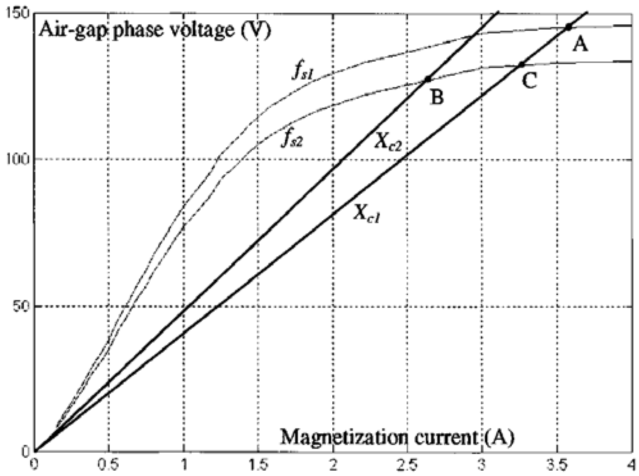

Fig. 3. Magnetization characteristics of the induction generator, for different synchronous frequencies (f > f).

The frequency drop to reduces the magnetization characteristic voltage (Vg) in the same proportion, assuming that the air-gap flux is kept constant, i.e.Vg/fs, is constant.

In addition to the change in the magnetization characteristic, the frequency reduction affects the capacitive reactance of the excitation bank (Xc), according to (1).Xc1 and Xc2 are the capacitive reactance correspondent to the frequencies fs1 and fs2 respectively.

Altogether, the resulting effect of increasing the ac load active power is the IG terminal-voltage reduction, due to changes in the magnetization characteristic and in the excitation bank capacitive reactance.

The capacitance Cac could be increased even more, in order to recover the capacitive reactance. In this case, the slope of the capacitor-bank voltage characteristic will return to its previous value, however, the steady-state operation point in the magnetization characteristic will now be "C " instead of "A," as the frequency remains fs2. The new operation point at the torque characteristic (Fig. 2) would depend on the behavior of the ac load under voltage variations.

It should be highlighted that the voltage drops at the stator and rotor resistance and leakage reactances are not the main cause of the poor voltage and frequency regulation in the isolated IG. The fundamental factor that affects the IG voltage regulation is the influence of the frequency on the generator magnetization characteristic.

Note that the voltage and frequency variations presented previously were caused by increments made exclusively in the ac load active power. In case the ac load inductive reactive power increases, the voltage reduction would be even higher, due to the demand of capacitive reactive power from the excitation bank to compensate for that.

Reductions at the rotor speed as a result of torque elevations, due to a nonregulated shaft speed, would degenerate voltage and frequency even more.

Substantial efforts have been made to overcome the poor voltage regulation of the isolated induction generator under load active and reactive power variations [5]. These efforts have been concentrated on different types of voltage regulators acting as volt–ampere-reactive controllers, based on series-shunt capacitor compounds [4], [5]–[8], switched discrete capacitor banks [9]–[11], thyristor-switched inductors [12], or saturated reactors [13], [14]. Such approaches rely on contactors, relays, or semiconductor switches. Although the methodologies mentioned attain valuable improvement in voltage regulation, they have solved the problem only partially, as the frequency is yet variable. Besides that, the generator still experiences variation in its magnetization characteristic with the frequency, which leads to the requirement of a wide range of capacitance values at the excitation bank. However, an excessive increase in the capacitance would deeply saturate the generator, leading to voltage waveform distortions. This analysis leads to the conception of a strategy which maintains constant frequency at the IG stator terminals and, simultaneously, guarantees reactive power both to magnetize the generator and to compensate for the ac load demand.

The constant-frequency approach ensures that the steady-state operation of the IG will take place following only one torque and magnetizing characteristic curves, both regarding the constant stator synchronous frequency. A generation system based on this modus operandi has to comprise three indispensable parts, namely, the induction generator itself, a voltage regulator, and a device which fixes the frequency, magnetizes the generator, and compensates for the ac load reactive power requisites.

It is important to mention that a constant-frequency system like this is suitable to work driven by energy sources which cause relatively narrow ranges of speed variations, such as microhydroelectric plants and fuel engine plants. Therefore, this approach is not adequate for systems where the speed variation is the basis to achieve profitable energy conversion, such as wind systems.

III. DESCRIPTION OF THE PROPOSED MODEL

The system design for this dissertation consists of building of a model consists of wind operated induction generator with three phase delta connected excitation capacitor bank. A synchronous generator with excitation controller is modeled to compensate positive and negative reactive power to control the terminal voltage of induction generator. Resistive variable dump load is modeled with a frequency controller to control frequency of induction generator.

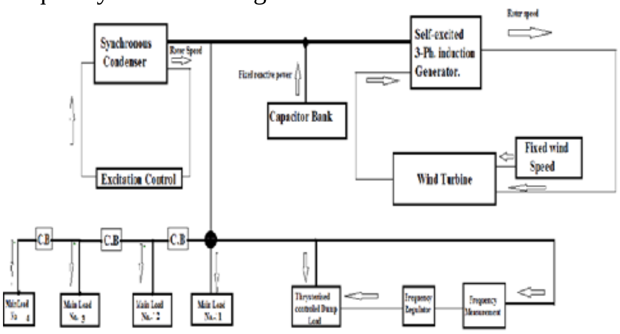

Fig. 4. Block diagram

Source blocks and scope blocks are provided to show frequency and voltage. Power computation block is designed to compute power of wind generator, power delivered to main load, secondary load and reactive power of synchronous generator.

In this model a 480 V, 220 kVA synchronous machine, a wind turbine driving a 480 V, 200 kVA induction generator, four customer loads 50 kW resistive, 25 KW resistive,50 KVA inductive and 10 KVAR capacitive customer loads and a variable secondary load (0 to 446.25 kW) are modeled. Above said resistive load of 25 KW is modeled with three phase circuit breaker having switching simulation time 2 seconds.

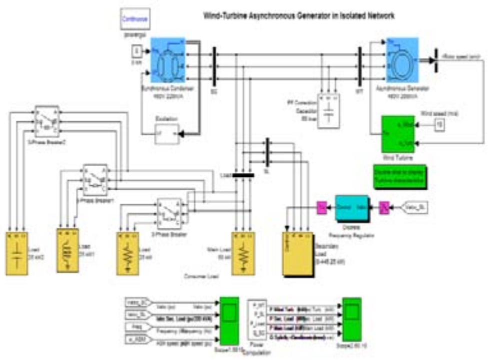

Fig. 5. Simulation Model

Inductive and capacitive loads are also modeled with three phase circuit breakers having switching simulation time of 4 seconds, 13 seconds respectively. The Secondary Load block consists of eight sets of three-phase resistors connected in series with GTO thyristor switches. The nominal power of each set follows a binary progression so that the load can be varied from 0 to 446.25 kW by steps of 1.75kW. GTOs are simulated by ideal switches. The frequency controller is the Discrete Frequency Regulator block. This controller uses a standard three-phase Phase Locked Loop (PLL) system to measure the system frequency. The measured frequency is compared to the reference frequency (50 Hz) to obtain the frequency error. This error is integrated to obtain the phase error. The phase error is then used by a Proportional-Differential (PD) controller to produce an output signal representing the required secondary load power. This signal is converted to an 8-bit digital signal controlling switching of the eight three-phase secondary loads. In order to minimize voltage disturbances, switching is performed at zero crossing of voltage.

The wind speed (10m/s) is such that the wind turbine produces enough power to supply the load. The synchronous machine operates as a synchronous condenser with its mechanical power input (Pm) set at zero. The model presents dynamic performance of the frequency regulation system when an additional customer load is switched on and the synchronous machine is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand.

IV. SIMULATION RESULTS AND ANALYSIS

The results of output of simulated model show amplitude vs. time graphs. In these graphical representations voltages, currents, powers, frequency & reactive power are simulated at various stages. For simulation the model developed is simulated for wind speed 10 m/s & 12 m/s. These models are developed to simulation for estimation of capacitance requirement for the model at different values of speeds with variable load.

A. Simulation results at wind speed 10 m/s.

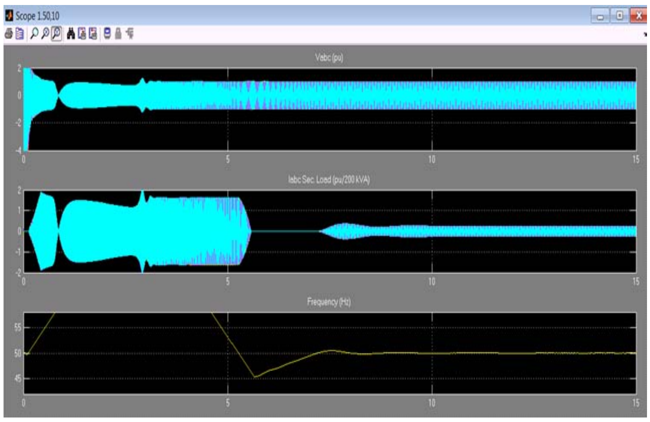

Fig. 6 results terminal voltage, current and frequency.

- Analysis of voltage output:- this model is simulated for simulation time of 15 seconds. at starting large variation in voltage is recorded up to 3 seconds and very small variations are recorded from 3 seconds to 6 seconds. From 6 seconds to 15 seconds voltage is almost equal to per unit voltage.

- Analysis of secondary load current: - current in secondary load increases 0 to 2 per unit from 0 to 1 second. For duration of 1 to 3 seconds it becomes 1.5 per unit. Further 3 to 5.5 seconds it becomes 1.75 pu. For a period of 5.5 to 7.5 seconds it becomes equal to 0 pu. Finally from 7.5 to 15 seconds it remains equal to 0.25 pu.

- Analysis of frequency: - at initial from 0 to 4 seconds rise in frequency up to 56 Hz is recorded. After 4 second it starts decreasing and becomes 45 Hz at 6 seconds. For duration of 6 to 7 seconds frequency rises up to pu level and remains almost constant for remaining time.

Figure 7 shows output of scope 2 it gives graphical output of Power Generated, power secondary load, power main load and reactive power of synchronous generator. It displays magnitude versus time graph of respective quantity. Time is displayed in seconds and duration of time is equal to simulation time.

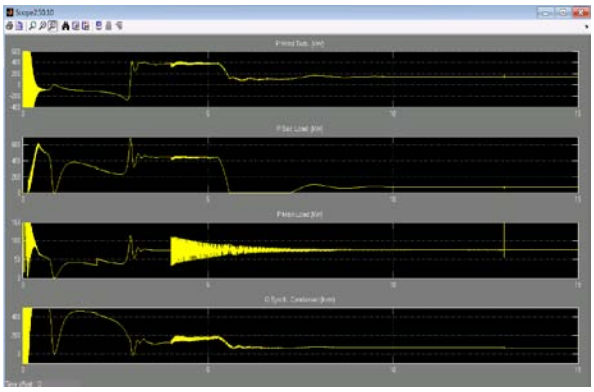

Fig. 7 Results Power input, Power main load, Power Secondary load.

- Analysis of power generated by the wind turbine:- power generated by wind turbine is 600 kw from 0 to 0.5 seconds. From 0.5 to 2.5 it drops up to -200. Further from 2.5 to 5.5 it increases to 400 kw.from 5.5 to 8.5 varies between 100 to 180 kw. Remains equal to 180 kw from 8.5 to 15.

- Analysis of power received by secondary load:- it fluctuates between 0 to 650 kw for 0 to 2.5 seconds. Small fluctuation between 300 to 425 kw from 2.5 to 5.5 seconds. Power remains zero from 5.5 to 7.5. for 7.5 to 15 it is 75 KW.

- Analysis of power consumed by primary load:- power consumed by primary load for 0 to 1 second fluctuates 0 to 160 KW. From 1 to 3 it fluctuates 0 to 110 kw. From 3 to 4 seconds 75 kw. a large fluctuation is observed from 4 to 6.5 seconds. Small fluctuation is observed 5.5 to 10 seconds. it remains almost constant from 10 to 15 seconds.

- Synchronous generator reactive power analysis:- very large reactive power fluctuation at starting from 0 to 3 seconds is observed. Small fluctuation is observed from 3 to 5 seconds. It became nearly constant equal to 30 KVAR from 5 to 15 seconds.

V. CONCLUSION

Self-excited Induction Generators are very suitable energy conversion device for small hydroelectric and wind operated power plant when designed for isolated mode. While feeding the consumer load it is very important to solve the power quality issues related to generation using Self-excited induction generator. SIMULINK model presented in this papper is mainly linked with these issues. Main problem of wind operated self-excited induction generator is fluctuation of voltage and frequency. With inserting secondary load and synchronous generator in conversion system increases the stability of voltage and frequency of generation.

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