# Operation of stand-alone self-excited induction generator supported by energy storage systems for small scale wind energy generation

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# Operation of Stand-Alone Self-Excited Induction Generator Supported by Energy Storage Systems for Small Scale Wind Energy Generation


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***Abstract*—Self-Excited Induction Generators (SEIGs) are increasingly used, in the distribution networks, as a key segment in the wind generation as Small Scale Embedded Generation (SSEG). The operation stability of stand-alone SEIG is constrained by the local load conditions, and that can be achieved by maintaining the load's active and reactive power at optimal values [1]. The changes in power are dependent on customers' demand and any deviation from the pre-calculated optimum setting may affect the machine's operating voltage and frequency. In this paper, the Electrochemical Battery is used as an Energy Storage System (ESS) to play the kernel role in regulating the voltage magnitude and frequency for stand-alone SEIG during load changes, where a Controlled Current Source is used to charge and discharge the battery.**



***Keywords*--Energy storage systems, islanded operation, renewable resources, self-excited induction generator.**


## I. INTRODUCTION

Among the different types of the generators used in the applications of the wind energy, the self-excited induction generator (SEIG) became the key segment in Small Scale Embedded Generation (SSEG). It could be the better option for low/medium speed applications in the future and specially in wind energy systems (WESs) [2]. This is due to its low cost, simple construction, low maintenance requirements. As the induction generator doesn't have a separate field winding, a capacitor bank is required to build up the terminal voltage. The main difficulty of SEIG is the lack of ability to control the machine terminal voltage and frequency under un-predicted load and speed conditions. Many research have dealt with the topics of the characteristics of the isolated self-excited operation of the induction generators [3] - [5], wind generation stability [6]- [8], and the islanded operation of the SEIG under random settings of local active and reactive load [9], [10]. Other studies focused on compensating the variations of the customer loads [11] - [13]. In other interesting literatures, different electronic converter topologies and control architectures have been studied to maintain the stable operation of the standalone SEIG [14], [15]. This work is an improvement of the study [1], which has illustrated that the voltage magnitude and frequency of stand-alone SEIG can be maintained within their statutory limits, if the locally connected load is kept constant as a percentage ratio of the IG rating. These optimal ratios are 84.73% for the active power, and 50.81% for the reactive power. The objective of this paper is to design a control circuit able to keep the power drawn from the induction generator at the pre-calculated optimal values, during the variation of the customer load demand. To achieve this goal, a Matlab/Simulik Model has been built, presenting both of the power circuit, including induction generator, main grid, local load, ESS that is fed by a bidirectional converter, and the control circuit, including the controlled current source and the control scheme required for the desired operation.

## II. SEIG UNDER OPTIMAL OPERATION

Figure 1 shows a Simulink model for (2.3 KVA) SEIG connected to a main grid via a circuit breaker (CB). A three phase capacitor bank is connected in parallel to the generator stator terminals, providing a reactive power of (1.1686 KVAr) to present the optimal reactive power required to balance the local grid. An active load of (1.9488 KW) is shunt connected to this grid to present the optimal active power consumed by the local customers.

The circuit breaker should be closed at first, insuring the machine magnetic field to be built up. Figure 2 shows that the voltage magnitude and frequency are within their permissible values [16], when the local grid is disconnected from the main grid during the time interval (1 – 9) Sec, keeping the optimal load to be fed only from the stand-alone SEIG.

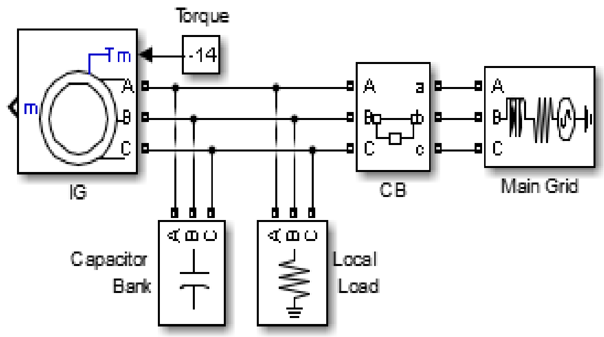


Fig. 1. SEIG in optimal load operation

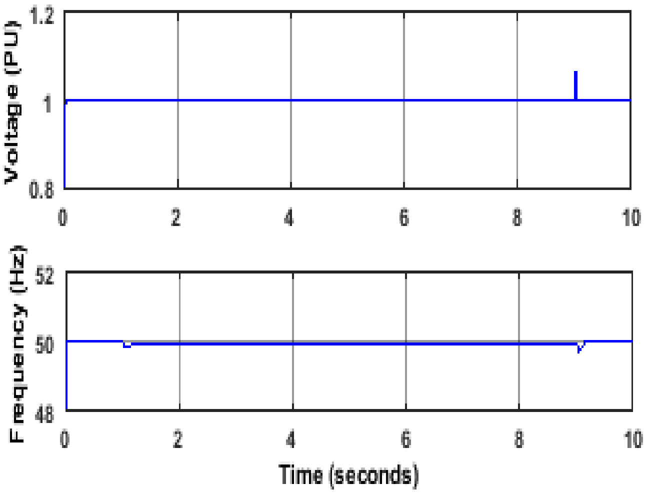

Fig. 2. Voltage and frequency in optimal load operation

## III. CONTROL AND WORKING PRINCIPLE

At the instant of disconnecting the main grid; the local active and reactive power should be maintained at their optimal values:

$$P_O = 0.8473 \times S_G \quad (1)$$
$$Q_O = 0.5081 \times S_G \quad (2)$$

Where: $S_G$ is the Induction Generator rating (VA).

The difference between the optimal and the load active power is measured and sent to drive the Controlled Current Source, which is in turn, will absorb/inject the same amount of power from/into the grid in order to charge/discharge the battery. Meanwhile, the battery SoC is sensed and the logic controller for the control principle is shown in Figure 3.A, where:

- If the difference in power $(dP = P_{Optimal} - P_{Load})$ is positive, $(P_{Load} < P_{Optimal})$, and if the battery (SoC) is less than its maximum level, a switch (S1) only will close charging the battery until the (SoC) reaches its maximum value, then (S1) will open and a switch (S2) only will be closed to dissipate the power into the dummy load.
- If the difference in power $(dP = P_{Optimal} - P_{Load})$ is negative, $(P_{Load} > P_{Optimal})$, and if the battery (SoC) is greater than its minimum limit of depth of discharge, the switch (S1) only will close discharging the battery until the (SoC) reaches its minimum limit, then (S1) will open and a switch (S3) only will be closed to supply the load from an ancillary source.

Three DC current paths are required to achieve the above described principle, for charging/discharging the battery, dissipating the power in a dummy load and supplying the power from an ancillary source. Figure 3.B shows the DC side requirement for this operation principle, where the three circuits in addition to the Controlled Current Source are presented. The reactive power is also regulated during this operation because of using voltage magnitude regulator to drive the gates of the voltage controlled voltage source converter based on PWM scheme [17] [18].

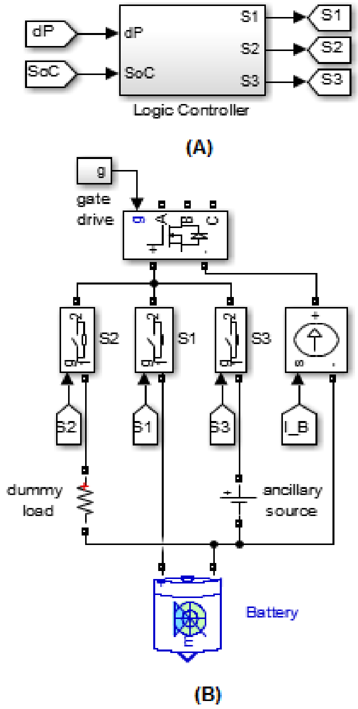

Fig. 3. A) The logic controller, B) The DC side circuits to ensure stable operation

## IV. SYSTEM SIMULATION

A Matlab/Simulink model is built to simulate the above described circuit and to carry out the required study. The induction generator ratings and parameters are chosen to be:

$$S_G = 2.3\ KVA, V_{L_L} = 230\ V, f = 50\ Hz,$$
$$R_s = 1.115\ \Omega, \quad R_r = 1.083\ \Omega,$$
$$L_s = L_r = 0.00597\ \text{H}, \quad L_m = 0.2037\ \text{H},$$
$$J = 2 \times 10^{-4}\ \text{kg.m}^2$$

The load active power is set to be equal to the optimal value:

$$P_O = 0.8473 \times S_G = 0.8473 \times 2300 = 1948.8\ W$$

And the optimal reactive power is:

$$Q_O = 0.5081 \times S_G = 0.5081 \times 2300 = 1168.6\ VAr$$

The maximum permissible limit for the battery state of charge (SoC) is chosen to be (95%), and its limit of depth of discharge is set at (20%).

Three scenarios have been studied, assuming an increase of load active power, decrease of load active power and finally an increase in both load active and reactive power.

### A. *Increase of load active power*

The first scenario is to increase the load active power by three steps; each is by 10% of the optimal value, assuming no reactive power changes, as shown in figure 4. The main grid will disconnect at the time (t=1 sec) to reconnect again at (t=21 Sec). The first step of the additional load will take place at (t=3 Sec), and will be followed by the two other increases with time intervals of three seconds, to start to decrease later by the same time rate at (t=12 Sec). At (t=18 Sec), the load will reach again its optimal value. The battery (SoC) is set to be slightly higher than (20%) which is the minimum limit of depth of discharge. Figure 5 shows that the voltage and the frequency are within their permissible values during these changes, and figure 6 shows that both active and reactive of the self-excited induction generator load remains constant during this load changes at the optimal values of equations (1) and (2). Figure 7 shows that the battery stopped discharging when the SoC reached its minimum rate of depth of discharge (20%), and the control circuit will feed the load from the ancillary energy source. The currents from the battery and from the ancillary source are shown in figure 8.

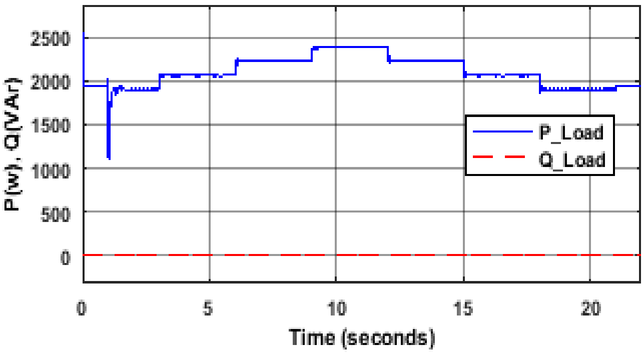

Fig. 4. Increase of load active power

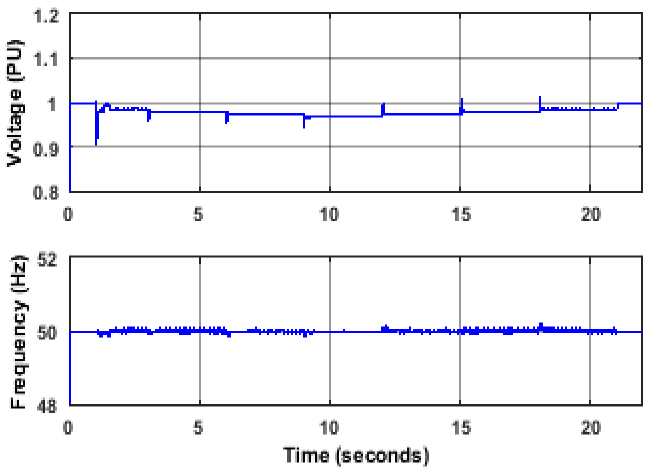

Fig. 5. Voltage and frequency during the increase of the load active power

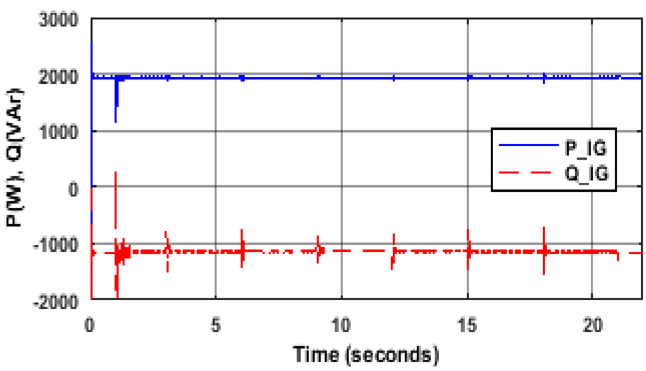

Fig. 6. The active and reactive power from the SEIG

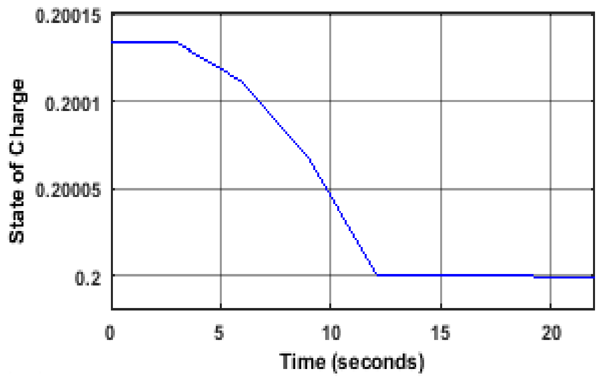

Fig. 7. Battery State of Charge during the increase of load active power

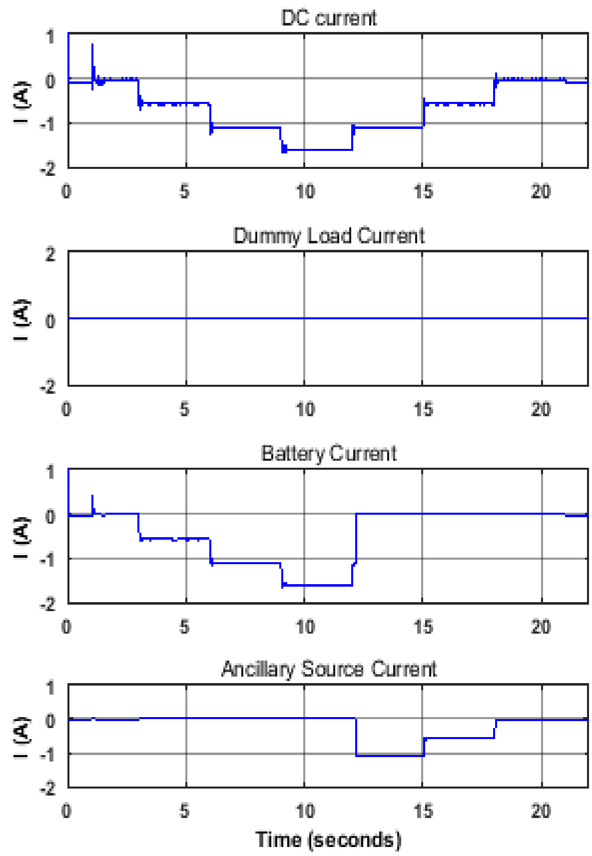

Fig. 8. DC Side Currents during the increase of load active power

*B. Decrease of load active power*

In this scenario, the load active power decreases by three steps, each is by 10%, with no change in load reactive power, as shown in figure 9. The battery (SoC) is set to be slightly lower than 95% which is assumed to be the maximum charging rate. The voltage magnitude and frequency for this case is shown in figure 10. Figure 11 shows that the active and reactive power drawn from the IG remain at their optimal values.The battery charging process will stop when the battery (SoC) reaches its maximum desired value (95%), as shown in figure 12, and the control circuit will dissipate the difference in power into the dummy load, as shown in the figure 13.

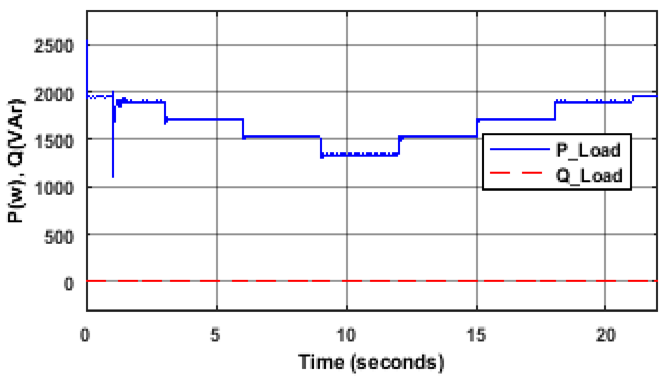


Fig. 9. Decrease of load active power

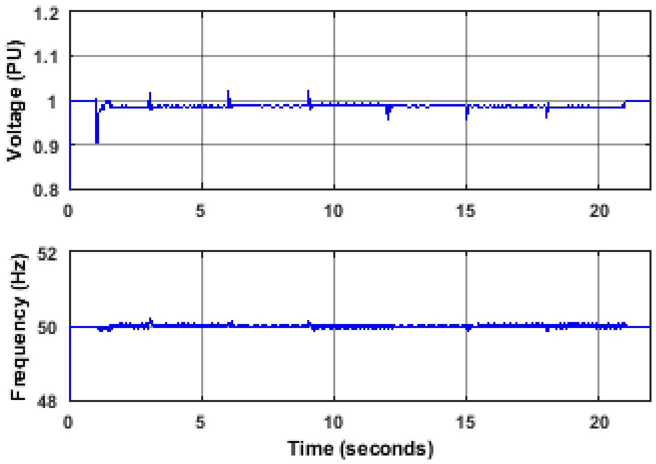


Fig. 10. Voltage and frequency during the decrease of load active power

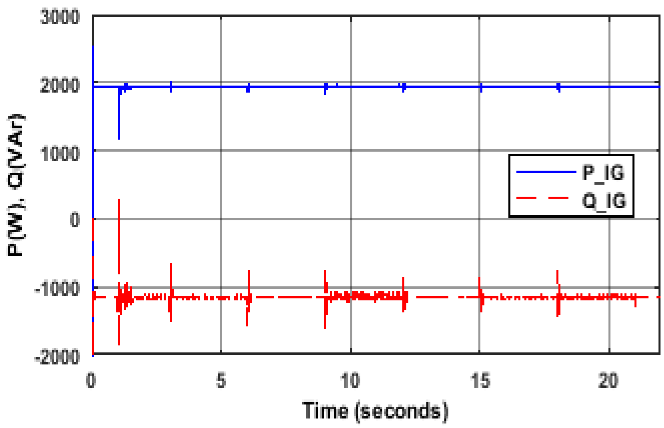


Fig. 11. Active and reactive power from the SEIG

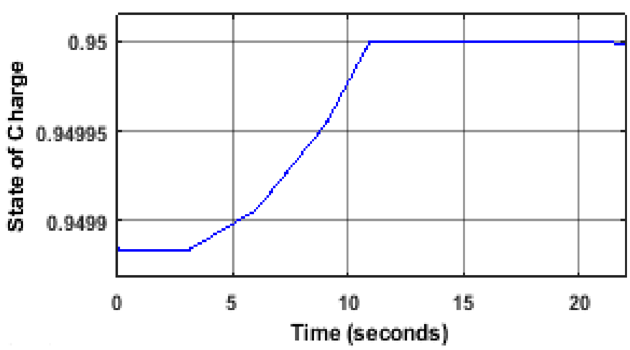


Fig. 12. Battery State of Charge during the decrease of load active power

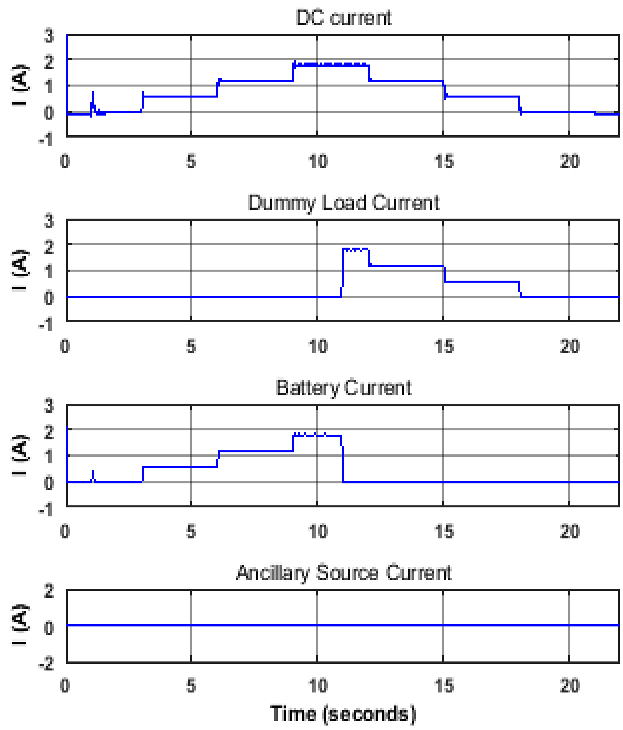


Fig. 13. DC Side Currents during the decrease of load active power

*C. Increase of load active and reactive power*

In this scenario, both active and reactive power increase by three steps of 10%. The time intervals and rates in this case are the same as the previous two cases. Figure 14 shows the change in load active and reactive power, where the voltage and the frequency are shown in the figure 15.

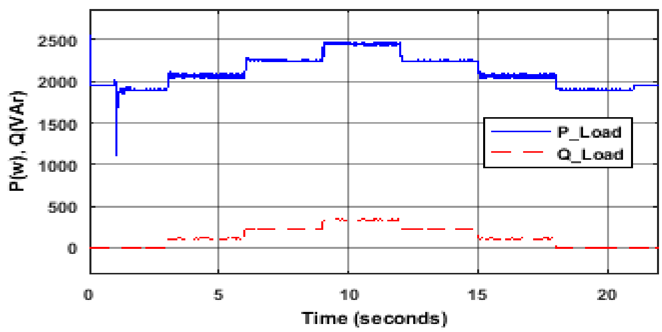


Fig. 14. Increasing of load active and reactive power

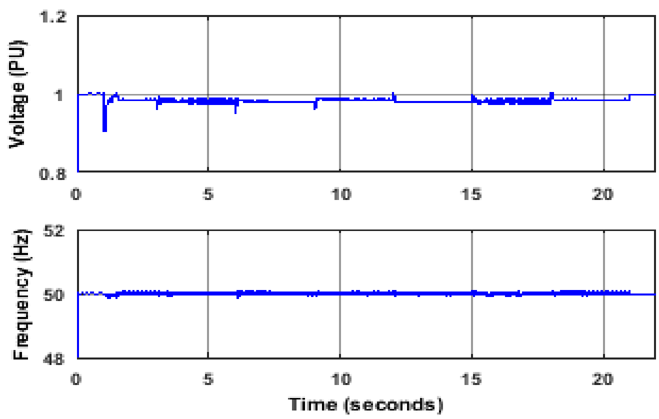


Fig. 15. Voltage and frequency in case of increasing P and Q

## V. CONCLUSION

The study presented in this paper illustrates the possibility for islanding operation of SSEG base on SEIG supported by ESS. The study showed a control principle to keep the drawn active and reactive power at their optimal values. The difference between the load power and the optimal values is calculated and a Controlled Current Source is used to absorb/inject this difference with the DC side of bidirectional power converter to ensure the stability of operation, charging and discharging a battery system. The battery state of charge is always sensed, and the charging/discharging process will stop when it reaches the predetermined maximum and minimum levels, respectively. A local dummy load and ancillary stand-by emergency generator are used to dissipate and inject the required power in either of these cases, respectively. a Matlab/Simulink model is built to achieve the described principle, and the results show that the voltage magnitude and frequency are within their permissible values for all the simulated scenarios.

## ACKNOWLEDGMENT

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