Design and Simulation of Current Sensor Based Electronic Load Controller for Small Scale Three Phase Self Excited Induction Generator System

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Received: 18.09.2020 Accepted:11.10.2020

Abstract- In standalone renewable energy systems, the power balance methods must exist to match the generated power and load demand; otherwise the excess power creates the disturbance in terms of voltage and frequency fluctuations. This paper presents a design and simulation of an electronic load controller (ELC) for the power balance in constant power prime mover-coupled three phase self-excited induction generator (SEIG) system. A current sensor based ELC is designed in such a way that to operate the generator unit always at its full capacity by coordinating between the two load systems termed as main and dump load. The controller unit has an uncontrolled 3-phase full-bridge rectifier circuit, a logically controlled insulted-gate bipolar transistor (IGBT) chopper switch, and a current sensor. The current sensor provides the feedback signal to the gate trigger circuit of IGBT and which inevitably controls the ON/OFF position of the switch. The ON condition of switch means a partial or full portion of generation power is diverted to the dump load, and the sum of both loads is equal to the rated capacity of SEIG. The proposed system is simulated in MATLAB, and the power balance is achieved with help of ELC. The voltage regulation of SEIG is addressed by adding extra reactive power (VAR) compensation. Further, in this study, the basic configuration of SEIG and the importance of self-excitation phenomena for voltage generation are also highlighted.

Keywords Constant power prime-mover, self-excited induction generator (SEIG), electronic load controller (ELC), current-sensor, power balance.

Nomenclature

Term	Abbreviation
RES	: Renewable energy
SHP	: Small hydro power
SEIG	: Self-excited induction generator
VAR	: Reactive power
ELC	: Electronic load controller
IGBT	: Insulted-gate bipolar transistor
PWM	: Pulse width modulation
PID	Proportional integral derivative
I_{rated}	Rated current
I_M	Main load current
R_s	Stator resistance
R_r	Rotor resistance
X_m	Magnetizing reactance
X_{ls}	Stator leakage reactance
X_{lr}	Rotor leakage reactance
C_{min}	Minimum excitation capacitance
P_{rated}	Rated power
R_D	Dump load resistor

1. Introduction

To reduce the enormous amount of greenhouse gas emissions from the large-scale conventional coal and oil-based power generation units, small/micro range distributed power generation systems are emerged in recent decades. In this context, the power generation using renewable energy sources (RES) such as wind, solar, biomass and small hydro either in grid or off-grid mode is drawing much attention from both load end-users and suppliers due to many advantages [1]-[19]. The locally available RES-based systems are not only useful in reduces the global warming problems, but also easy to install in the range of few Kilowatt (kW) to Megawatt (MW). It reported that the typical size of such micro-scale generation systems for standalone applications ranges from 1 to20 kW rating. Except for the solar, the remaining RE sources need the generator solution to convert the mechanical energy into electrical energy [14], [18], [25].

The selection of generator mainly depends on the type of the available source, mode of distribution, i.e., grid or off-grid, and rating of connected loads. In small scale isolated (off-grid) mode operation, where the loads in hilly areas and rural/remote locations, an induction generator (IG) is one of the best choices among the other generators. Some of the advantages of IG are easy in operation, low-cost, rugged construction of core and winding, also suitable for harsh environment, and brush-less arrangement [1]-[12], [15], [17], [22]-[50]. In grid-connected operation, the required reactive power is supplied by the grid itself to generate the rated voltage of IG, whereas in the case of off-grid mode, it should be provided from the external source. Generally, pre-charged capacitors are used for such a purpose. A suitable rating of the capacitor bank is needed to connect across the stator terminals and maintained the rotor speed above the synchronous speed to generate the voltage; this phenomenon is called self-excitation [1]. The capacitor-based self-excited featured IG is called a self-excitation induction generator (SEIG). A comprehensive review on prospects of applications, configurations and mode of operations, types of prime movers of induction generators for the deployment of renewable energy source based small scale power generation systems is discussed in [7]-[10].

The micro/pico-hydro source reservoirs provide constant power generation. The output power of the turbine depends on the height and discharge of the water reserved in the hydro electric systems [14]-[20].

In the off-grid mode of operation, the total power generation should always consumed by the loads, where the battery storage not a part of the system. The demand at the load end varies time to time from minimum to maximum. In common practice, the isolated systems are designed for a pre-defined rating of loads, and they are equal or less than to the rated capacity of the generation [22]-[29].

The total system load depends on consumer demand and generation relies on source. If the source input power is constantly available, then power balance operation should take place in the system. Under the loading condition, if the load value is less than the generation, then the excess power should be consumed by auxiliary or dump load to balance the power. A logical controller-based circuit called the electronic load controller (ELC) is used for power consumption purposes. The ELC mainly consists of i) an uncontrolled bridge rectifier for rectification of generated voltage, ii) a controllable DC-chopper switch, iii) a DC-link capacitor, and iv) a dump resistor. The dump resistor is designed in such a way that to withstand the rated power capacity of the system [25], [26].

Many researchers have reported the design and implementation of ELC with various controllers, such as analog, digital, microprocessor, micro controller, proportional (P), proportional and integral (PI), proportional and derivative (PD), proportional integral derivative (PID) and fuzzy logic controllers are reported in the literature to enhance the efficiency [23]-[50].

The electricity demand in isolated/rural areas is low compared to urban users. In the context of offgrid small-scale energy systems, a load power balancing unit is needed to match with the total generating power. In this work, a current sensor- based ELC is designed for a SEIG isolated load system. The input of SEIG is a micro/pico-hydro turbine and which is emulated by a constant power prime mover; hence the generated power is always persistent and maintained at rated value by connecting the suitable rating of minimum excitation capacitor (C_{min}) bank and reactive power (VAR) compensation. In the proposed system , the voltage exception is not allowed from no-load to full-load condition, and only the variation of load current is taken as a feedback signal to logically turn-on the IGBT based DC chopper switch of current sensor based ELC. The voltage drop is compensated by adding the extra VAR to the SEIG. The role of the proposed ELC is to balance the power of the micro/pico hydro isolated system through power electronic based switch without any effect on the generating unit.

The schematic of the proposed SEIG system is discussed in section II. Operating principle and design aspects of current sensor based ELC is described in section III. Results and discussions are given in section IV. Conclusion is given in section V.

2. Schematics of Proposed SEIG System

This section covers the schematics of the proposed SEIG system and self-excitation phenomena in SEIG.

2.1. Schematics of the proposed SEIG System with ELC:

The schematic diagram of the proposed 3-phase SEIG system with ELC is given in Fig 1. Here, the current sensor based ELC balances the system power between the generation unit, i.e., SEIG and power consumer units, i.e., load and dump load. The self-excitation phenomena of SEIG is given in the next sub-section, and the detailed working principle and design procedure of ELC is discussed in section III.

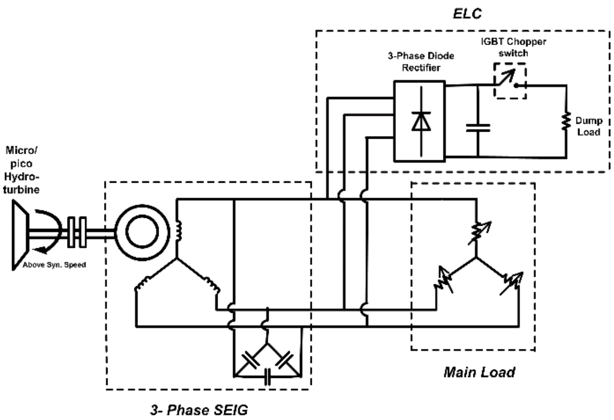

Fig. 1. Schematic diagram of proposed 3-phase SEIG System with ELC.

2.2. Self-excitation Phenomena of SEIG:

In SEIG, the phenomena of self-excitation play a vital role in voltage build-up across the generator terminals under the no-load condition. This is exploited due to continuous energy exchange between the electrical field of the capacitor and the magnetic field of the generator. For generating the rated voltage and frequency of SEIG in the isolated load applications, the following two conditions should meet a) the rotor of the shaft of the machine rotate above the synchronous speed b) suitable rating of reactive power must be supplied to the generator through the external source for core magnetization; This phenomena is called capacitor excitation [1].

The value of stator resistance (R_s) is calculated from the DC test. The blocked rotor test is performed to calculate the leakage impedance. Air-gap voltage ratio (V_g/F) depends on magnetizing reactance (X_m) and the relation obtains from the synchronous impedance test [1]-[10]. The specification of the selected SEIG, equivalent circuit parametersts and value of minimum excitation capacitance (C_{min}) are given in the Appendix 1. Under the no-load condition, the process of self-excitation to generate the required voltage waveform is given in Fig 2.

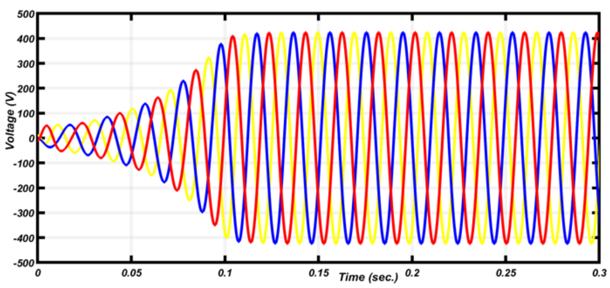

Fig. 2. Self-excitation process of SEIG.

3. Operating Principle and Design Procedure of Proposed Current-based ELC

The proposed current sensor- based ELC operation of SEIG system is easy and economical as it requires one uncontrolled bridge rectifier and a DC chopper switch, and easy to practical implementation. switch. The circuit diagram of the proposed ELC is shown in Fig 3.

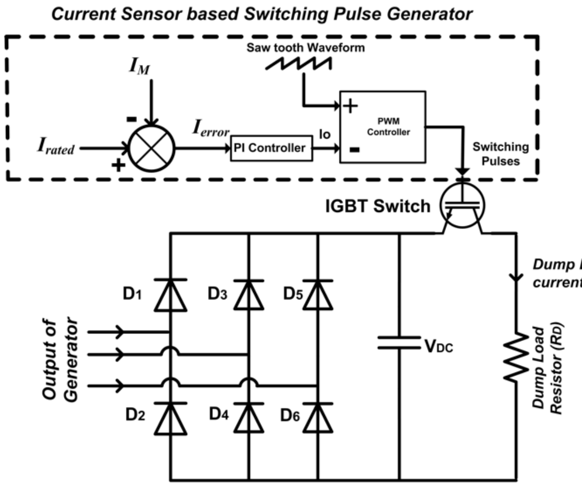

Fig. 3. Circuit diagram of the proposed current sensor-based ELC.

3.1. Operating Principle:

The logical ON or OFF of the IGBT switch depends on a simple logical function. If the actual main load current (I_M) is less than the reference current (I_{rated}) i.e., rated load current of SEIG, then the IGBT turn ON to divert the surplus generated power into the dump load. On the other hand, if the load current equal to the reference current, then the IGBT is in the OFF position, which does not allow the power into the dump load. The logic involved in the proposed current based- ELC is represented by the following steps (1)-(11).

Step 1: Initialize I_{rated}, I_M, I_D.
Step 2: Turn on: SEIG.
Step 3: Turn on: SEIG Main load.
Step 4: **while** (1) /* infinite loop*/
Step 5: Read I_{rated}, I_M
Step 6: **if** ($I_M < I_{rated}$)
Step 7: Turn ON Dump load
Step 8: **else-if** ($I_M = I_{rated}$)
Step 9: Turn OFF Dump load
Step 10: **end-if**
Step 11: **end-while**

3.2. Design Procedure:

It is noted that the main load current should be less or equal to the rated current of the SEIG. Rated current (I_{rated}) of the SEIG is given by (1).

$$I_{rated} = P_{rated}/1.73*V = 1100/1.73*415 = 1.53 \text{ Amps} \quad (1)$$

As shown in Fig 3, the functioning of the current sensor based switching pulse generator of the proposed

ELC is uses the PI controller to generatate the triggering pulses to the IGBT switch. The rated current is compared witht the sensed current, i.e., main load current (I_M) and the error current signal (I_{error}) is given to the PI controller as a input and which can be written as (2). The output siganal (I_o) is writen as (3) and which is compared with a saw tooth wave form and proceded through pulse width modular (PWM) controller to generate the switching pulses to the IGBT [25]-[39]. In (3), k_p and k_i are the constants of proportional and integral, respectively.

$$I_{error} = I_{rated} - I_M \quad (2)$$

$$I_o = k_p.\ I_{error} + k_i \int I_{error}\, dt \quad (3)$$

The selection of the output voltage of 3-phase full diode bridge rectifier (V_{rect}) and dump load resistor (R_D) is given by following equations (4) and (5), respectively.

$$V_{rect} = 1.35*V_{LL} = 1.35*415 = 560 \text{ Volts} \quad (4)$$

$$R_D = (V_{rect})^2 / P_{rated} = (560)^2/1100 = 285 \text{ Ohms} \quad (5)$$

4. Simulation Results of the SEIG System with Proposed Current- Sensor based ELC

In this section, MATLAB/Simulink based SEIG with the proposed ELC system is discussed. The performance of the system is verified by loading the SEIG up to rated current and maintained the power balance through the proposed current sensor- based ELC.

4.1 Voltage and Current profile of SEIG System under rated load

The simulation run time is 8 seconds. The voltage regulation of SEIG is compensated by adding the extra VAR. As shown in Fig. 4, to compensate the drop in the voltage, a total of 326 VAR compensation is added at the rated-load condition of simulation time of 6 - 8 secs to increase the RMS voltage from its 235 V to 305 V. The power quality improved voltage and the corresponding RMS current of SEIG is given in Fig 4 and 5, respectively.

In Fig 5, the simulation time 0-2 sec is the no-load, 2-3 and 3-5 are the with and without VAR compensation at 50% of load, and 5-6- and 6-8-seconds are the with and without VAR compensation at full load.

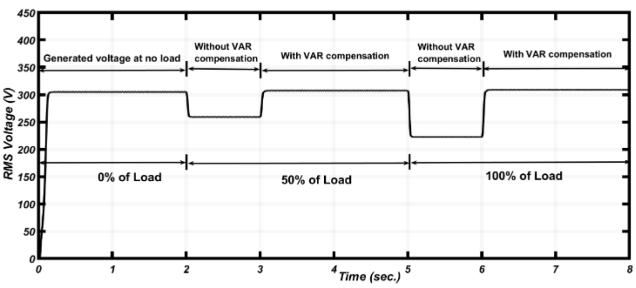

Fig. 4. Variation of RMS voltage according to the load and VAR compensation.

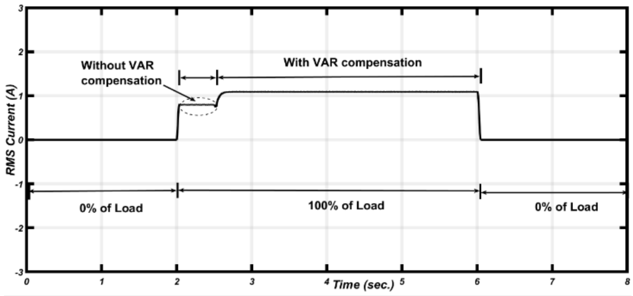

Fig. 5. RMS current of SEIG with and without VAR compensation.

4.2 Load Balancing through proposed Current Sensor-based ELC:

The load current balance in main and dump load of the SEIG system through the proposed current sensor based ELC is shown in Fig 6 and 7. The SEIG operation started with the 100% load up to 3 seconds of simulation. Under this condition, the main load draws the total current and hence the no current in the dump load. From 3-6 seconds, the rating of the main load has decreased to below the rated value, so the excess amount of current is diverted to the dump load. The proposed load current sensor- based ELC proved the concept of load power balance in the SEIG based micro isolated hydro system by employing the logical turn ON and turn OFF control of the IGBT DC chopper switch.

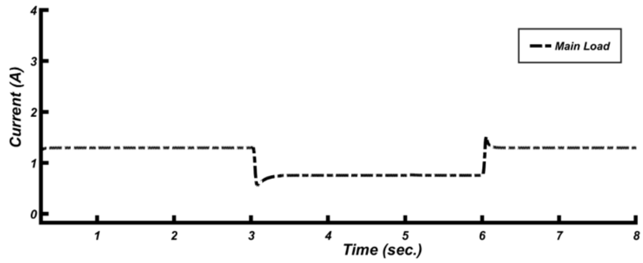

Fig. 6. Load balance of SEIG with proposed ELC: Main load current.

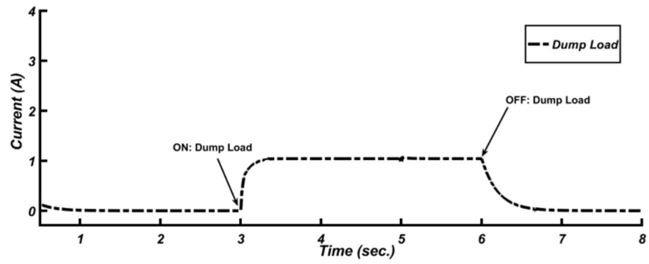

Fig. 7. Load balance of SEIG with proposed ELC: Dump load current.

5. Conclusion

In this paper, the design and working procedure of the current sensor-based electronic load controller for power balance in a small scale SEIG system are discussed and simulated in MATLAB. The power quality of the SEIG is improved by adding the VAR compensation under the load condition. By continuous sensing of load value, the surplus power can be utilized for the special purpose of heating applications. This solution is cost-effective as it requires only one logically operated IGBT switch and accurate one for power balance in the deployment of constant power driven small-scale isolated energy generating systems. For more realibility, some other renewable enerygy sources, like solar and wind sources can be considered in the system with the interface of power converters.

Appendix. 1. Specification of SEIG

S. No	Name of the Specification	Value
1	Rated power (P_{rated})	1100 W
2	Synchrnous speed (Syn. speed)	1000 r.p.m
3	Number of poles (p)	6
4	Frequency (F)	50 Hz
5	Stator resistance (R_s)	7.04 Ω/ph
6	Rotor resistance (R_r)	11.5 Ω/ph
7	Stator leakage reactance (X_{ls}) = Rotor leakage reactance (X_{lr})	11.08 Ω/ph
8	Stator leakage inductance (L_{ls}) = Rotor leakage inductance (L_{lr})	35.26 mH
9	Minimum excitation capacitance in delta manner	10.5 μF/ph

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