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Manage the Stator Winding Load in Self-Excited Induction Generators by Changing Their Elevation

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Abstract

An Electronic Demand Controller (EDC) can keep the electrical demand constant, which allows a fixed-speed low-head hydroturbine to power a Self-Excited Induction Generator (SEIG), which in turn can provide steady voltage and frequency. It is common practice to use a chopper with a dump load in conjunction with consumer loads in the Conventional-ELC (C-ELC) to control voltage and manage frequency. Due to the short connection and subsequent disconnection of the dump load from the winding during each chopping cycle, the stator windings and excitation capacitors in a C-ELC system are subject to significant strain during chopper activity. A new ELC structure could alleviate this strain. Unlike the C-ELC, which only had one component, the primary dump load now contains two. Reducing the strain on the stator windings and excitation capacitors and making the SEIG more resistant to overall load fluctuations is possible by connecting a portion of the dump load in parallel with the consumer loads. Applying the design per phase with bidirectional power switches might make it function with imbalanced consumer loads. The suggested design can control voltage from no-load to full-load, according to simulations conducted with imbalanced three-phase loads (using bidirectional switches per phase). The Total Harmonic Distortion (THD) study of the output current (stator current) also reveals an improvement of 9% over the most recent findings in the literature.

Keywords: Insulated-Gate Bipolar Transistors (IGBTs), choppers, and exit capacitors are all part of microhydro.

Introduction

A significant portion of the world's population relies on traditional biomass for their everyday energy requirements, such as cooking, heating, and lighting, and a quarter of that population does not have access to electricity [1]. Particularly in developing countries, a high reliance on traditional biomass sources like wood may shorten the average lifespan due to the effects of several health problems [1]. A paradigm shift toward the use of alternative and renewable energy was driven by this motivation, together with growing environmental awareness, increasing electrical energy demand, decreasing supplies of conventional fuels, and technical breakthroughs in power electronics. Renewable energy sources including wind, pico-hydro, and micro-hydro turbines are ideal for remote areas without easy access to large-scale electrical generating services on the grid since they are stable and easy to install. Separate from the main electrical grid, these power plants are known as stand-alone power generating units.Ideal candidates for the squirrel cage self-excited induction generator (SEIG) [2-4] are standalone generating units with a power rating of less than 20kW driven by a constant speed uncontrolled turbine. The first account of the self-excitation phenomenon was provided by Besant and Potter [5] in a local bank of capacitors across the output terminals of an induction generator.

Compared to DC generators or wound rotor induction generators, SEIGs have many benefits, such as a lower unit cost per generated kilowatt, greater durability, no brushes, easier maintenance, and self-protection under fault conditions [6,7]. On the other hand, SEIGs aren't very good at controlling voltage and frequency. This has led to a plethora of research aimed at overcoming these constraints in the last few decades [8]. Variations in consumer loads or mechanical power supplied by the primary mover will cause the SEIG's output voltage and frequency to vary. In remote mountain areas, where penstock fed hydro turbines mitigate the effects of fluctuations in mechanical power delivery, continuous load power allows for voltage and frequency regulation.

To keep the load power consistent, you may employ a variable or moveable dump load. A variable or adjustable dump load should be connected in parallel with consumer loads to maintain a constant overall load. The use of electronic load controllers (ELCs) allows the hydro turbine to maintain a consistent total power output. Although VAR sources for voltage regulation are theoretically feasible [7–13], their complexity and high cost make them impractical for use in pico or micro size producing units. Thus, several ELCs for SEIGs have been recorded by researchers over the last twenty years [4, 14–23], and we will go into each of them in further detail below. Earlier works on this subject were by Bonert and Hoops [14]. A method for controlling impedance was laid forth. Assembling an unregulated three-phase rectifier, a dump load, and a chopper switch in series enables voltage regulation. By aligning the helicopter with the sixty-degree conduction intervals of the bridge, the voltage distortion is reduced to a minimum. The feasibility of controlling asymmetrical loads and an automated generator start-up mechanism were later described by Bonert and Rajakaruna [15]. There was a brief investigation of this method by Singh [16]. Lastly, the method's unregulated rectifier, chopper, and dump load were designed in detail by Singh, Murthy, and Gupta [2]. With just one power switch, this system is simple, cheap, and reliable, but it can only handle the imbalanced three-phase loads

that generators in less densely populated regions, such as rural or suburban areas, can handle. Three methods were proposed by Smith [17] according on the induction generator's intrinsic characteristics. Several voltage control methods were created, such as those that use binary weighted switching resistors, a chopping scheme with a programmable mark-space ratio, and phase angle control.

Due to its variable lagging power factor, the SEIG could encounter issues when using the phase angle control approach. Discrete control of output power and complexity in connecting the power electronic switches are the main drawbacks of the binary weighted switched resistor technique. A simplified version of the impedance controller approach [14] developed for a single-phase system is used by the variable mark-space ratio technique. Mathematical models of SEIGs with improved ELCs have been presented, as stated by Singh [18]. An improved ELC was created by integrating a high frequency DC chopper with a current controlled voltage source inverter that relies on three Insulated Gate Bipolar Transistors (IGBTs). In order to maintain balanced generator currents, the improved ELC produces compensating currents in the event of unbalanced loads. A voltage regulator for unbalanced three-phase loads might be made from the improved ELC, despite the complexity of the proposed control method. In contrast, a newly constructed phase locked loop circuit and a voltage source converter devoid of a chopper are used for a slightly different approach in [19]. A more exact localization of the rotor flux was achieved by means of the control method, which included the induction machine's magnetizing curve. Several control mechanisms, each with its own unique twist, have been reported in the literature based on the architecture outlined in [19]. In [20], one method is proposed for controlling the terminal voltage by modifying the converter's modulation index in response to changes in consumer loads-induced variations in DC capacitor voltage.

System and Induction Generator

Creating models A d-q frame induction generator's (IG) equivalent circuit is shown in Figure 1. Using MathWorks's MATLABSIMULINK and the modeling approach outlined in [25], we construct a modular Simulink model in the stationary reference frame. In order to simplify the simulation, a common matrix formulation has been used, which is based on the method given in [26]. The following matrix equations, expressed as state space equations, are used for transient analysis of the three-phase SEIG.

$$\dot{x} = Ax + By$$

where $x = [i_{ds}, i_{qs}, i_{dr}, i_{qr}, V_{dL}, V_{qL}, i_{dL}, i_{qL}]^T$, $y = [V_{ds}, V_{qs}, V_{dr}, V_{qr}]^T$, $\dot{x} = \dfrac{dx}{dt}$

$$A = K \begin{bmatrix} R_s L_r & -\omega_r L_m^2 & -R_r L_m & \omega_r L_r L_m & L_r & 0 & 0 & 0 \\ \omega_r L_m^2 & R_s L_r & \omega_r L_m L_s & -R_r L_m & 0 & L_r & 0 & 0 \\ -R_s L_m & \omega_r L_r L_m & R_r L_s & \omega_r L_s L_r & -L_m & 0 & 0 & 0 \\ -\omega_r L_m L_s & -R_s L_m & -\omega_r L_s L_r & R_r L_s & 0 & -L_m & 0 & 0 \\ 1/CK & 0 & 0 & 0 & 0 & 0 & -1/CK & 0 \\ 0 & 1/CK & 0 & 0 & 0 & 0 & 0 & -1/CK \\ 0 & 0 & 0 & 0 & 1/LK & 0 & -R/LK & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/LK & 0 & -R/LK \end{bmatrix} \quad B = K \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K = \frac{1}{(L_m^2 - L_r L_s)}$$

Proposed Electronic Load Controller

Proposed ELC topology

As shown in Figure 3a, a standard system consists of the following components: a prime mover, an induction generator, an excitation capacitor bank, three-phase unbalanced loads, electronic load controllers, and the control circuits that link them. These components collaborate to provide gate signals for the IGBT switches that are used. The anticipated ELC structure is shown in Figure 3b across all stages. You can see a comparison between the topology in [4] and the one in Fig. 3c. A chopper switch is the main element of the ELC in the proposed design. A better switch () has replaced the chopper switch in the schematics. It should be noted that in experimental and simulation research, bidirectional IGBT switches should be employed instead of this ideal switch [4, 23]. The ELC in the suggested design consists of a chopper switch, two series resistances, and a single-ended circuit. It is possible to connect a portion of the dump load in parallel with the consumer loads while the chopper switch is closed. For clarity's sake, Fig. 4 shows the analogous circuit of the

chopper switch in this configuration. Here, with the chopper switch off, the total dump load is, and with the chopper switch on and the ELC connected to the system, it grows to. Figure 4(a) and (b) depict these two possibilities. Figures 4c and d show the same circuit diagram of the method proposed in [4]. In the method proposed by Ramirez [4, 23] and in all ELC approaches that involve chopper and dump loads, the dump load is not connected to the induction generator when the chopper is off (Fig. 4c). However, in the proposed topology, a small non-zero dump load is connected to the system (Fig. 4a), leading to a more uniform generated power and reducing machine stress. Following is an explanation of the procedure used to develop the proposed ELC.

Experiment Outcomes

Results from a simulation study investigating the feasibility and efficiency of the proposed ELC are shown here. The proposed ELC design was used to model the voltage control of a 3 kW, 220V Donly IG in MATLABSIMULINK. A 316 rad/s driving speed was applied to the selected IG using a 60 three-phase star-connected excitation capacitor bank that was charged to 10V, 10V, and -20V as starting voltages. Both the voltage and frequency of the generator's outputs level out at. The two sudden changes in the three-phase unbalanced consumer loads used in this simulation are summarized in Table 1. The consumer load and the predicted ELC are both connected to the generator at. At and, there are two separate changes made to the loads that consumers are expected to pay. Figure 5 displays the recommended ELC's regulated output voltage, magnetizing current, root-mean-square (RMS) value, instantaneous generated power (both with and without ELC), and instantaneous output voltage. Sections (a) and (b) show the current and magnetic inductance, respectively, in this figure. The RMS output voltage is shown in Figure 5c both with and without the ELC. The proposed ELC brings the system's voltage fluctuations down to around 4 V RMS, or 1.8%. Fig. 5c displays the transient voltage's amplitude. Under steady-state conditions, the output voltage's root-mean-square (RMS) variance is less than 1%. The output voltage has a standard variation of 31 V RMS (248 minus

217) in the absence of active load regulation (ELC). The three-phase output power with the proposed ELC is shown by the black lines in Fig. 5d, while the power without it is represented by the gray lines. Table 1 shows a three-phase unbalanced load pattern, which means that even at steady state, the IG without ELC may produce power ranging from 0.2 to 3.05 kW. These results demonstrate that the proposed ELC design can control frequency, regulate voltage, and draw the rated power from the IG, even in an unbalanced system. Two separate ELCs and the consumer current make up the three-phase instantaneous currents seen in Figures 6 and 7. Figure 7 shows the ELC current for one full cycle under three different load conditions. After dumping power, total power, and imbalanced consumer loads are taken into consideration, Figure 8 displays the average power for each phase. In all, each process consumes around 1 kilowatt of power.

Table 1. The considered consumer load pattern with two step changes at 5.5 seconds and 8.5 seconds.

Consumer loads				
Connection Time (S)	0-1.5	1.5-5.5	5.5-8.5	8.5-12
Phase "a" load (Ω)	NL	1000	230	75
Phase "b" load (Ω)	NL	1200	300	63
Phase "c" load (Ω)	NL	800	160	61.5

Figure 9 shows typical dump load currents for the two topologies, along with other information, so that we may compare the proposed ELC to the one in [4]. Figures shown in the second column (right hand side) are simulation results based on [4], whereas the first column displays the dump load current based on the suggested architecture. The consumer loads used for this study are three phase star-connected loads with values of 55, 95, 150, and 300 Ω. The present dump load may only be between two sinusoidal waveforms in the suggested manner. Figures 9e–9h show the top sinusoidal waveform and zero, which are the equivalent bounds for the approach described in [4]. With a comparable setup to Figure 9, Figure 10 shows the harmonic content of the stator current based on the suggested technique and that in Figure 4. Every instance's Total Harmonic Distortion (THD) is shown. Compared to the topology in [4], the suggested topology has a lower THD. When compared to various topologies that

have been suggested, the one in [4] has the lowest total harmonic distortion (THD) level. Our suggested solution primarily aims to decrease the THD level by reducing the dump load current variations. Figure 11 shows the difference in THD level between the suggested ELC topology and the one in [4]. We can see the THD as a function of the load current utilized each phase. Shown in (a) is the stator current THD, and in (b) is the output voltage THD. In contrast to the THD of 45.5% in [4], the maximum THD for the output current of the suggested topology is around 36%. There is a close relationship between the two topologies in terms of the computed THD for the output voltage.
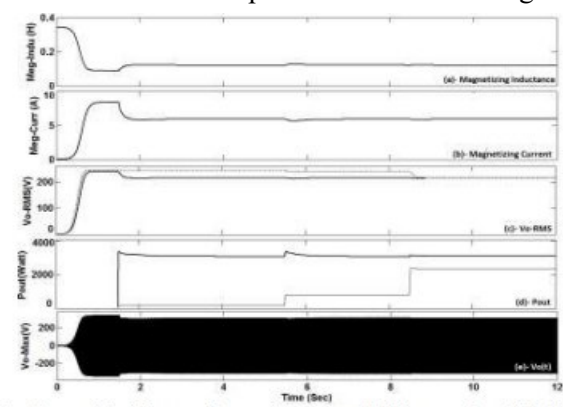

Fig. 1. Typical system characteristics, (a) magnetizing inductance, (b) magnetizing current, (c) RMS output voltage (dashed line: no ELC; black line: with proposed ELC) , (d) output power with (gray) and without ELC (black), and (e) instantaneous output voltage with proposed ELC.
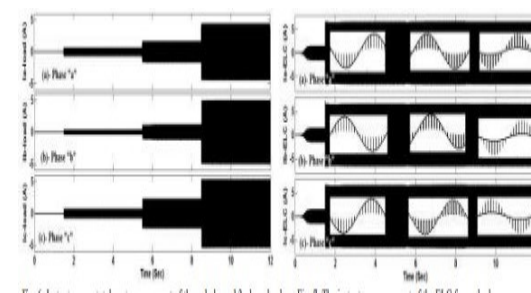

Fig. 2. Instantaneous total customer current of the unbalanced 3-phase load Fig. 7. The instantaneous current of the ELC for each phase.

Conclusion

For smaller hydroelectric dams, our study introduces a new and simple Electronic

Load Control technology. Their tool of choice is the induction generator. The suggested approach primarily aims to reduce strain on the stator windings of the generator. This was accomplished by use of a novel chopper circuit architecture. The proposed ELC works admirably for all types of consumer loads, even those with unbalanced three-phase loads, according to the simulation findings. It is more dependable and cost-effective than ELC solutions based on rectifier or converter architectures because to the reduced number of power switches required (3 bi-directional switches compared to 7 uni-directional switches). Extending the life of the induction generator is another possible benefit of lowering stator stress.

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