

**ANALYSIS AND DEVELOPMENT OF LOAD CONTROLLER  
AND STATIC COMPENSATOR FOR SELF-EXCITED  
INDUCTION GENERATOR BASED AUTONOMOUS  
GENERATING SYSTEM**

by

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**Submitted**

**in fulfilment of the requirements of the degree of Doctor of Philosophy**

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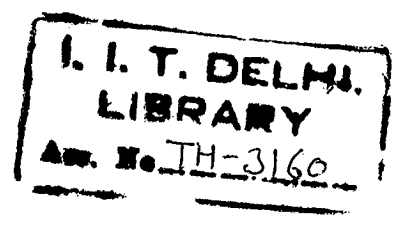
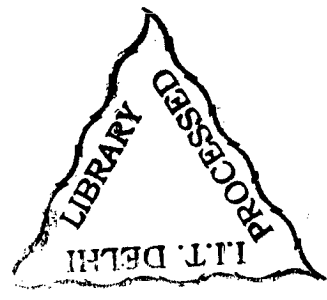


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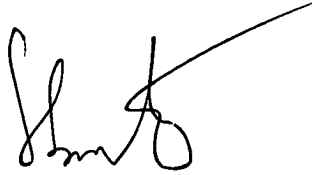
*Dedicated*  
*to my daughter*  
*Charu*



## CERTIFICATE

This is to certify that the thesis entitled, “**Analysis and Development of Load Controller and Static Compensator for Self-Excited Induction Generator Based Autonomous Generating System,**” being submitted by **Mrs. Sushma Gupta** for the award of the degree of **Doctor of Philosophy** is a record of bona fide research work carried out by her in the Electrical Engineering Department of Indian Institute of Technology, Delhi.

Mrs. Sushma Gupta worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results obtained here in have not been submitted in part or in full to any other University or Institute for the award of any degree.



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## ABSTRACT

The fast depletion of conventional energy resources is motivating researchers to search for every other source of alternative energy. A higher emphasis is given to non-conventional and renewable energy resources such as solar, wind, micro-hydro, biomass, tidal, geo-thermal and wave energies. Harnessing of energy from such non-conventional resources requires development of viable energy generating systems. In last two decades, self-excited induction generator (SEIG) has attracted considerable attention due to its applicability as a stand-alone generator using some of conventional and non-conventional energy resources.

Supplying electrical energy to far-flung rural and hilly areas is another area of concern as it involves high cost and hard maintenance requirements. Application of SEIG in stand-alone mode has emerged as a viable option due to its numerous advantages over conventional synchronous generator such as simpler construction, robustness, small in size, reduced unit cost, easy to maintain, absence of DC supply, brushless feature and better transient performance.

Considerable literature is available on the steady-state analysis of the SEIG, which illustrates the correlation among the reactive power requirements, speed of prime mover and balanced/unbalanced, static/dynamic loads. The reported literature is found to have complicated algorithm to find the behavior of SEIG with load or to know the excitation requirement of SEIG with load. In this thesis an attempt has been made to simplify the algorithm for finding the behavior of SEIG under balanced/unbalanced conditions. Transient behavior of a self-excited induction generator at sudden application and removal of load, opening of one phase of load or capacitor from the system is of interest from the suitability of machine winding, level of insulation, rating of capacitor and protection point of view. In a distribution system the consumer

loads on the all three phases may and may not be balanced and in extreme case single phasing also takes place. An algorithm has been developed so that one can predict the behavior of SEIG under balanced and unbalanced load or excitation system.

In small micro-hydro turbine system with no governor control, a self-excited induction generator has been found the most suitable candidate due to simple in construction, economically feasible, maintenance free, capable to operate at all environmental conditions, good quality of generated power. For such applications, the simplest control strategy is that the SEIG should operate at a single point operation by ensuring a constant input power to and constant output power from the machine. Seasonally input power to a micro hydro turbine is almost constant and the output power is maintained constant by having an electronic load controller (ELC), which ensures a constant load at the generator terminals in spite of variation in the connected consumer load. As consumer load reduces, the electronic load controller diverts the excess power to a resistive load called dump load.

In this thesis, analysis and design of electronic load controller for SEIGs of different ratings have been carried out. Based on the design, a prototype of electronic load controller has been developed and tested under different types of load. The electronic load controller basically consists of an uncontrolled rectifier feeding a chopper-controlled load. An uncontrolled rectifier rectifies the SEIG output AC voltage and the resulting DC voltage is supplied to a resistive load connected in series with the chopper switch. Power consumed in the resistive load is controlled by varying the duty cycle of the chopper. The chopper control signal is derived from the SEIG terminal voltage that in turn keeps the total output power of SEIG constant, since the speed and frequency of the generator are maintained constant.

Other prominent case of stand-alone power generation relates to engine driven generators. Fuel for such engines may be oil, gas or biomass. Governor control of engine ensures automatic power balance unlike as small hydro turbine with no governor control. Here the speed is nearly constant with marginal drop from no load to full load. SEIG can be an attractive option here too. But suitable controller needs to be developed for desired power quality of voltage and frequency at varying loads and nature of loads. Here capacitor VAR control is required as load power varies.

This thesis presents analysis and design of STATic COMPensator (STATCOM) based voltage regulator for SEIG. The STATCOM provides reactive power to the SEIG and acts as variable capacitor when generated voltage is less than rated voltage or absorbs reactive power and acts as variable inductor when generated voltage is more than the rated voltage. The STATCOM has been designed for its full rating and reduced rating conditions. In case of full rating STATCOM, excitation capacitors are selected such that SEIG generates rated voltage at no-load. Then STATCOM provides reactive power to the SEIG as well as load with increase in load. In case of reduced rating STATCOM, the value of excitation capacitors are selected such that SEIG generates rated voltage at half of rated load corresponding to the power rating of SEIG. In this case, if consumer load is less than half of the rated power of SEIG then STATCOM acts as an inductor and sinks the reactive power. If consumer load is greater than half of the rated power of SEIG then STATCOM acts as source of reactive power (capacitor) and supplies the reactive power to the SEIG and load (lagging PF).

Based on the design criteria, a prototype STATCOM has been developed and tested in the laboratory. The proposed STATCOM has the advantages such as: (1) it saves the SEIG from de-excitation during severe load perturbation, (2) it has fast

dynamic response for regulating the voltage when the SEIG faces the under/over excitation conditions, (3) it generates capacitive and inductive currents and (4) it has capability of load balancing and harmonic elimination. Therefore large AC capacitor, reactor banks and their associated switchgear and protection are not required as used in conventional SVCs.

The electronic load controller and STATCOM have certain merits and demerits. The electronic load controller is the most suitable candidate for the micro-hydro applications because it keeps the voltage and frequency constant in spite of change in consumer load. However it has the demerits of poor power quality in terms of injected current harmonics and caused voltage distortion at SEIG terminals. The STATCOM eliminates harmonics, maintains voltage of SEIG, corrects power factor and balances the system under unbalanced conditions but frequency decreases with application of load.

In this thesis an improved electronic load controller has been proposed which has merits of both electronic load controller and STATCOM. The novel electronic load controller keeps the voltage and frequency constant similar to electronic load controller and eliminates the harmonics, improves the power factor and balances the unbalanced system like STATCOM. Analysis and design of novel electronic load controller have been carried out for different ratings of SEIGs. A comprehensive mathematical model has been developed for the SEIG-novel electronic load controller system and tested with static/dynamic, balanced/unbalanced and linear/nonlinear loads under transient conditions.

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