DESIGN AND DEVELOPMENT OF VOLTAGE AND FREQUENCY CONTROLLERS FOR ASYNCHRONOUS GENERATORS IN ISOLATED SMALL HYDRO POWER GENERATION

by

V. RAJAGOPAL
Department of Electrical Engineering

Submitted
In fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI
MAY 2011

CERTIFICATE

This is to certify that the thesis entitled, "Design and Development of Voltage and Frequency Controllers for Asynchronous Generators in Isolated Small Hydro Power Generation", being submitted by Mr. V. Rajagopal for the award of the degree of Doctor of Philosophy is a record of bonafide research work carried out by him in the Department of Electrical Engineering of the Indian Institute of Technology, Delhi.

Mr. V. Rajagopal has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results obtained here in have not been submitted to any other University or Institute for the award of any degree.

Dated:

(Prof. Bhim Singh)
Electrical Engineering Department
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi- 110 016, India
Email:-bhimsinghr@gmail.com
bhimsinghiitd@gmail.com

ACKNOWLEDGEMENTS

I do express my deepest gratitude and indebtedness to Prof. Bhim Singh for providing me a life-time opportunity to do the Ph.D work under his supervision. Working with him has opened a new horizon of state-of-the-art knowledge on voltage and frequency controllers for off-grid asynchronous generators. Deep insight of Prof. Singh about the subject, ample research ideas, vast resourcefulness in electrical engineering and versatile exposure in international forum and his strong perception has immensely helped me to do the research work. His continuous monitoring, valuable guidance and input, has been always a source of inspiration and courage which are the driving forces to complete my work. It is a life time experience which I am to cherish always.

My heartfelt thanks and deep gratitude to Prof. T. S. Bhatti, Prof. G. Bhuvaneswari and Dr. B. K. Panigrahi, all SRC members who have equally given me valuable guidance and advice to improve quality of my work. I am overwhelmed with their immeasurable valuable input received during my research work. I do convey my sincere gratitude and respect to Prof. B. P. Singh and Prof. M. Veerachary who have taught me all the relevant course works in IITD and helped a great deal to enrich my knowledge.

I am grateful to the staffs of PG section, Central library, Electrical Engineering Department Library for their valuable co-operation. I am extremely grateful particular to Shri Gurcharan Singh, Shri. Srichand, Shri. Puran Singh and other staffs of Electrical Engineering's Drive and Simulation Lab., IIT Delhi for providing me immense facilities and assistance to carry out my research work. I am also thankful to Mr. Mohit Mahajan of FITT for processing my patents in time with valuable suggestions.

I would like to earnestly extend my sincere thanks to Sh. D. Madhan Mohan, Dr. Gaurav Kasal, Dr. P. Jayaprakash, Dr. Sanjeev Singh, Sh. Ashish Srivastava and Sh. Sunil Kumar who have provided me initial start up in my area of research. I am really to appreciate the towering efforts, relentless supports and utmost sincerity provided by Sh. Shailendra Sharma, research scholar in the journey to complete my hardware implementation work. It is an exemplary and I am to always cherish his valuable contribution.

Sh. Ram Nivas, Sh. Sabharaj Arya, Sh. M. Rajesh, Sh. M. Sandeep, Sh. N. K. Swami Naidu, Sh. Arun Kumar Verma, Sh. Jeevanand for their valuable assistances and co-operation. I am also grateful to those who have directly or indirectly helped me to complete my thesis work.

My deepest love, appreciation and indebtedness goes to my wife Smt. Rama Devi, Srivarsha (daughter) and Rohan (son) for their wholehearted support, encouragement and valuable time sharing. If I get any success today for the research work, the entire credit and honour should go to my family. It will remain unacknowledged if I don't mention the blessings of my father Late. Sarangapani, my mother Rajeshwari, my in-laws who have always provided the moral supports and enthusiasm in conducting this research work.

I am beholden to almighty and to my SAI BABA, BALAJI and SHIV SHANKAR for their blessing to help me raise my academic level to this stage. I pray for their benediction in my future endeavors.

Date V. Rajagopal

Place (2008EEZ8030)

ABSTRACT

The depletion of conventional energy sources has given rise to an increased emphasis on renewable energy sources such as wind, mini/micro hydro, biogas, biodiesel, biomass etc. Therefore for rural electrification as well as electrifying remotely located community such energy sources employing an asynchronous generator becomes a prominent option. In renewable energy applications of low and medium power (up to 100 kW) the induction generator offers several advantages. In low power rating applications, uncontrolled turbines are preferred, as the generator output power to be held constant while varying consumer loads. An auxiliary load in shunt with the consumer loads is necessary to keep the electrical load constant at the generator terminals thus, the Isolated Asynchronous Generators (IAGs) can operate with constant input power.

Due to an increase in greenhouse gas emissions, reasonable attention is given to renewable energy sources. The hydro is one of the prominent renewable energy sources to supply electric power in remote and isolated areas, where grid supply is not accessible. An asynchronous generator for supplying electricity in such areas by harnessing available renewable energy sources such as hydro, wind and biomass becomes the most appropriate option compared to other electric generators like the reluctance generator, a permanent magnet (PM) generator, and a synchronous generator.

In hilly and isolated areas plenty of hydro potential is available. These hydro potentials can be used to drive hydro turbine to generate the electricity. However, asynchronous machine can be used as a generator provided its reactive power requirement is fulfilled by capacitor banks, is called Isolated Asynchronous Generators (IAGs).

The main problem of mini hydro/micro hydro is the prime mover input is constant to the isolated asynchronous generator but the loads are changing. Due to this the frequency and voltage of the generator is changing and wind driven generators the prime mover input as well as the loads connected are changing, the challenge lies in keeping the frequency and voltage constant under the varying input from the prime mover as well as varying loads and keeping the power quality into view. These harmonics in voltage and current increase the power losses, create unequal heating and cause pulsations on the shaft of the IAG and distort voltage to the consumer loads. If such harmonics are present in three-phase four-wire systems the neutral conductor dissipates more power losses and heating. In view of above, an effective and efficient controller is investigated for three-phase three-wire and three-phase four-wire IAG system to control the voltage and frequency, suppress the harmonics and neutral current compensation.

This research work is mainly focused on three-phase three-wire and three-phase four-wire applications for IAG driven by constant power hydro prime movers with no governor control. The advantages of using an asynchronous generator instead of a synchronous generator are well known. Some of them are reduced unit cost and size, ruggedness, brushless (in squirrel cage construction), absence of separate dc source, ease of maintenance, self-protection against severe overloads and short circuits, etc. For such isolated applications the simple control strategy is hold a single point operation by ensuring the input power and output power constant. The output power is maintained constant by having a voltage and frequency controller (VFC) in case of integrated controller and electronic load controller in case of decoupled controller, which ensures the sum of powers consumed by consumer load and controller auxiliary load constant. As consumer load reduces, the VFC diverts the excess active power into the auxiliary load.

The investigation covers design, simulation and development of various topologies of VFCs, which can make the system adaptable to feed various types of three-phase three-wire and three-phase four-wire consumer loads. In view of such requirement, various topologies of VFC may be explored especially for three-phase four-wire systems with various transformer configurations such as star/delta, zigzag/star, T-T connected, star/hexagon and star/polygon connections for neutral current compensation.

The various topologies of VFCs include the three-phase three-wire/four-wire integrated and decoupled voltage and frequency controllers. These controllers to control the voltage and frequency and improve power quality require generation of reference currents. The reference currents are extracted using some existing algorithms like IRPT (instantaneous reactive power theory), SRF (synchronous reference frame), ISCT (instantaneous symmetrical component theory), PI (proportional integral) , Adaline (**ADA**ptive **LIN**ear **E**lement), PBT (power balance theory), CSD (current synchronous detection), IcosΦ single-phase p-q theory and a new conductance based control algorithm with indirect current control. The VFCs with the generating system is modeled and simulated in MATLAB environment using Simulink and simpower system (SPS) toolboxes. The simulated results are validated with test results on a developed prototype to demonstrate the effectiveness of the VFC for the control of IAG feeding three-phase three-wire/four-wire consumer loads with the neutral current compensation.

TABLE OF CONTENTS