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Review On Electronic Load Controller

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***Abstract*— This paper presents an extensive review of the analysis, modeling, design, testing and other aspects of an electronic load controller (ELC) found in the literature .The assumptions made and a brief description of the solution methods is presented. This paper describes step by step development in the area of ELC which provides helpful information and resources for the future studies for those interested in the problem or intending to do additional research in area of small hydro power generation.**

***Keywords*- Electronic load controller, self-excited induction generators, dump loads, insulated gate bipolar transistors, voltage and frequency controller, transient analysis and single point operation.**

I. INTRODUCTION

Distributed power generation has received greater attention in recent years for use in remote and rural communities due to the cost and complexity of grid systems with related transmission losses and reduced reliability. Thus, suitable stand-alone systems using locally available energy sources have become a preferred option. With increased emphasis on ecofriendly technologies the use of renewable sources such as small hydro, wind and biomass is being explored. Subject to availability, small hydro systems with minimal civil works to energize local communities are considered attractive. As these systems are located in remote areas, they must be robust, reliable, economical and manageable by local communities: this applies to the prime mover, generator and associated controllers. Micro turbines or pumps as turbine are used as prime movers. The squirrel cage induction generator in self-excited mode is found to be the most suitable option as generator due to such advantages as low cost, simple construction, ruggedness, brushless rotor, absence of DC source, maintenance-free nature, self-protection against short circuits and off-the shelf availability. Due to low power ratings (less than100 kW) uncontrolled turbines are preferred, which maintain the input hydropower constant, thus requiring the generator output power to be held constant at varying consumer loads. This requires a controllable dump load connected in parallel with the consumer load so that the total power consumed is held constant. Traditionally, complex and costly hydraulic or mechanical speed governors similar to large hydro systems have been used to regulate the water flow into the turbine as the load demand varied. Over the last two decades, electronic load controllers (ELC) have been developed that have increased the simplicity and reliability of modern micro hydro power systems.

The basic concept any ELC uses is to let the turbine and generator run at their full power, or possibly a manually set partial power, and keeps the electric load just right to attain the correct speed. ELC will measure turbine speed, and control the power delivered to one or more dump loads, to keep the speed correct An ELC is a solid state electronic device designed to regulate output power of a micro hydropower system. Maintaining a near constant load on the turbine generates stable voltage and frequency. The controller compensates for variation in the main load by automatically varying the amount of power dissipated in a resistive load, generally known as the ballast or dump load, in order to keep the total load on the generator and turbine constant. Water heaters are generally used as ballast loads. An ELC constantly senses and regulates the generated frequency.

There are several advantages of electronic load controller:

- ELC enables the use of simpler, cheaper turbine with less moving part.
- No hammer effect from load changes.
- ELC allows lighter, less robust penstock and imposes less wears and tears on machinery.
- High reliability, low maintenance and simple to operate.
- ELC can be fitted at any point in electrical system.
- Ballast load can usefully deployed example water and/or space heaters implying 100% load factor of the power plant.
- ELC is less expensive than equivalent flow control governor.

II. Review Of Litrature

This paper gives general backgrounds of research and development in the field of deign, modeling, testing and performance analysis in of Electronic Load Controller (ELC) based on over 50 published articles. The following open literature presents the summary and application of each method for several aspects of ELC. The related assumptions made, strengths and weaknesses of each solution methods are highlighted.

In July 84, Kormilo and Robinson [1] described the role of electronic load controllers in reducing the cost of small hydro schemes with particular reference to the situation in Papua New Guinea. A prototype controller based on an AIM 65 microcomputer is described. Program algorithm and input/output circuitry are described. Conditions necessary for stable load controller operation are discussed and quantified.

In July 1999, Wekhande and Agarwal [2] proposed a variable speed, constant voltage controller for induction generator operating in self excited mode. A new PWM controller is proposed to regulate the induction generator terminal voltage. The proposed controller regulates three-phase AC output voltage of the self-excited induction generator with varying rotor speed, transient load conditions and reactive loads. The proposed scheme does not require any real time computations for calculating excitation current, thus minimizing the electronic hardware and the cost of the controller.

In August 2001, Jun and Bo [3] presented a new electronic load controller in which a microprocessor is used as a control kernel and the IGBT is used as a switch. With current and frequency dual feedback, simulation and experimental results show excellent performance. The application is to a small-scale hydropower system.

In October 2001, Wekhande and Agarwal [4] presented a new variable speed, constant voltage controller for self-excited induction generator (SEIG). The proposed PWM controller regulates the induction generator (IG) terminal voltage against varying rotor speed and changing load conditions. This scheme does not require any real time computations and information regarding rotor speed for calculating the excitation current, thereby minimizing the electronic hardware and the cost of the controller.

In November 2003, Singh, Gupta and Murthy [5] described the mathematical modeling of self-excited induction generators (SEIGs) with are improved electronic load controller (IELC) for microhydel applications supplying variety of loads. In small hydro plants, governor unit of turbine can be eliminated using IELC, which is simple and cost effective. The improved electronic load controller is a combination of a three-phase insulated gate bipolar transistor (IGBT) based current controlled voltage source inverter (CC-VSI) and a high frequency DC chopper which keeps the generated voltage and frequency constant in spite of change of balanced/unbalanced loads. A dynamic model of the SEIG-IELC supplying different types of loads using stationary d-q axes reference frame is developed for predicting the behavior of the system under transient conditions. The simulation is carried out for compensation of balanced/unbalanced loading conditions. The simulated results show that generated frequency and voltage remain constant with change in load. The proposed IELC acts as reactive power compensator, harmonic eliminator, load balancer and load controller.

In November 2003, Murthy, Singh, Kulkami, Sivarajan and Gupta [6] presented a unique filed experience of a standalone power generating scheme using self-excited induction generator and electronic load controller by exploiting locally available small hydro potential needing minimal civil works. Water is made to flow in a channel and stored in a fore bay tank whose discharge is regulated to have a near constant head. A Pelton wheel receiving water through a penstock pipe works as a turbine, which drives a self-excited induction generator (SEIG). Two types of electronic load controllers (ELC), back-to-back thyristor based ELC and uncontrolled rectifier chopper based ELC were developed and installed in the field to provide power balance at varying consumer loads.

In November 2003, Singh, Murthy and Gupta [7] presented a transient analysis of self-excited induction generator (SEIG) with electronic load controller (ELC) used in stand alone micro hydel power generation employing uncontrolled turbines. In view of the need to feed both 3-phase induction motor and static loads from such systems, the transient behavior due to switching in of such loads is of interest and is carried out here. Combining the modeling of prime mover, SEIG, ELC and load has developed a composite mathematical model of the total system. Simulated results are compared with the experimental ones, obtained on a developed laboratory prototype of a SEIG-ELC system by starting a motor and switching in a resistive load. For the induction motor, a star/delta starter is used to avoid inrush current. Harmonic analysis is carried out to assess total harmonic distortion (THD) in the voltage and current to assess the power quality.

In January 2004, Singh, Murthy and Gupta [8] described the modeling of an electronic load controller (ELC) for a self-excited induction generator (SEIG), used for power balancing at varying consumer load as required for standalone micro-hydel generators driven by uncontrolled turbines, is presented. The implemented ELC consists of a rectifier-chopper system feeding a resistive dump load whose power consumption is varied through the duty cycle of the chopper. While the dynamic modeling of the SEIG is carried out using d-q variables in a stationary reference frame including magnetic saturation, the ELC is modeled through circuit concepts incorporating a switching function. Both the modeling and control technique of the ELC-SEIG are validated through simulated and experimental results.

In August 2004, Bozec, Cullen, McCormack, Dawson [9] described the major sources causing deterioration of the electromagnetic environment. In many cases, when electromagnetic compatibility (EMC) tests are performed on such devices, the load conditions during the tests can be significantly different from the actual load conditions that the device operates under in the field. They presented the results of radio frequency (RF) emission measurements which have been performed on various SMPSs and SELCs to examine the effect of the loading conditions on the RF emissions observed from the devices. Results of this research have led to the drafting of a code of practice for the design of SMPSs and SELCs giving guidance on how to design such devices to ensure good EMC characteristics.

In November 2004, Sekhar and Muni [10] described an induction machine driven from external prime mover at a speed greater than synchronous speed, it acts as induction generator provided reactive power is supplied. This reactive current generates required magnetic field for self-excitation of induction generator (SEIG). The induction generator thus produced has poor voltage regulation. To get better voltage regulation the reactive current need to be changed suitably during load variation from no load to full load. In stand-alone induction generator the required reactive power is supplied by capacitor bank and reactive power supplied is controlled by various voltage regulating schemes. In this paper different voltage schemes like power electronic controller, electronic load controller and magnetic amplifier are presented.

In October 2005, Singh, Murthy and Gupta [11] presented transient analysis of a self-excited induction generator (SEIG) with electronic load controller (ELC) used in stand-alone micro-hydro power generation employing uncontrolled turbines. In view of the need to feed both dynamic [three-phase induction motor (IM)] and static loads from such systems, the transient behavior due to switching in of such loads is of interest and is carried out here. A composite mathematical model of the total system has been developed by combining the modeling of prime mover, SEIG, ELC, and load. Simulated results are compared with the experimental ones, obtained on a developed prototype of an SEIG-ELC system for the starting of an IM and switching in a resistive load. For the starting of an IM, a star/delta starter is used to avoid inrush current. Harmonic analysis is carried out to find total harmonic distortion of the terminal voltage and current to assess its power quality.

In March 2006, Singh, Murthy and Gupta [12] presented an analysis and design of an electronic load controller (ELC) for three-phase self-excited induction generators (SEIGs) suitable for stand-alone pico-hydro power generation with constant input power. Here, the SEIG can be used to generate constant voltage and frequency if the electrical load is maintained constant at its terminals. Moreover, under such operation, SEIG requires constant capacitance for excitation resulting in a fixed-point operation. For this purpose, a suitable control scheme has to be developed such that the load on the SEIG remains constant despite change in the consumer load. In such applications, water is freely available and, hence, a simple and cheap controller has to be developed, which can operate almost unattended in remote and hilly regions. The proposed ELC consists of an uncontrolled rectifier and chopper with a series "dump" load. Proper design of rectifier, chopper, and dump load is very important for trouble free operation of ELC. An analysis along with a design procedure for computing the rating of various components of ELC is presented for a range of SEIGs.

In April 2006, Singh, Murthy and Gupta [13] presented the design, implementation and control of an electronic load controller (ELC) to regulate voltage and frequency of single-phase self-excited induction generator (SEIG) for constant power applications such as uncontrolled turbine in pico hydro power generation. An electronic load controller is developed for maintaining constant voltage and frequency of SEIG with variable consumer loads driven by uncontrolled water turbine. The transient behaviour of SEIG-ELC system at different operating conditions such as application and removal of resistive and reactive (0.8 pf) loads and starting of a single-phase induction motor as dynamic load is investigated to demonstrate the capability of proposed ELC. Extensive tests are conducted on the developed prototype of SEIG.

In August 2006, Li, Cao, Zhang and Zhao [14] described the application of μ theory in the electro hydraulic load simulator is studied. Robust control strategy of the electro-hydraulic load simulator is put forward. The electro-hydraulic load simulator is a complicated mechanical-hydraulic compound system, moreover it is a strong coupling and time varying controlled object. Synthetically considering uncertainties such as parameter perturbation, model perturbation and external disturbances etc., robust force controller of electro hydraulic load simulator is designed using μ synthesis theory.

In September 2006, Jaraman and Bryce [15] described the extensive field experience in micro-hydroelectric systems in remote rural communities demonstrates that the use of a typical automatic voltage regulator (AVR), as supplied with a brushless self-exciting synchronous alternator, can be the cause of unsatisfactory system performance. Results are presented from experiments undertaken on a full-scale micro-hydroelectric test rig as well as system modeling with PSCAD. The source of the instability is considered to stem from the similar time constants of the ballast load frequency controller and the AVR as two competing feedback control systems. System modeling is used to verify steady state operating points, and confirms that the under-frequency roll-off characteristic of the AVR also contributes to unsatisfactory performance.

In November 2006, Serban, Ion, Marinescu, and Cirstea [16] described the analysis of an electronic load controller - also known as dump load - in order to improve the regulating behavior in stand-alone generating systems. The considered dump load can be implemented in two alternatives. Each solution is analyzed from the current harmonics injection point of view, through simulations and experimental trials.

In December 2006, Murthy, Ramrathnam, Gayathri, and Naidu [17] presented the dynamic and steady state performance of a stand alone self excited induction generator (SEIG) with digitally controlled electronic load controller feeding single phase and three phase loads. The values of the capacitances are chosen to ensure self-excitation of the machine and to minimize the unbalance between the stator voltages. The excitation capacitors, ELC and load combined with the d-q model of the machine, together with the saturation are used to predict the dynamic behavior of the SEIG.

In December 2006 Singh, Murthy, Madhusudan, Goel, and Tandon [18] described steady state analysis of self-excited induction generator (SEIG) operating with an electronic load controller (ELC) for regulating its voltage and frequency under varying load condition. The ELC consists of a rectifier and a chopper circuit whose operation generates harmonics on AC side of the SEIG system. To achieve an adequate performance characteristics of the SEIG with ELC information of harmonic contents and real power is necessary.

In December 2006 Singh, and Kasal [19] described the analysis and design of voltage and frequency controllers for asynchronous generators to be used in isolated constant power applications such as pico and micro hydro sites. These controllers are basically load controllers which maintain the load power constant at generator terminals which in turns maintain the system frequency constant. A set of load controllers are designed, modeled and simulated in Matlab using Simulink and PSB (Power System Block-set) toolboxes to demonstrate their performance.

In June 2007, Ramirez, and Torres [20] proposed the design of an electronic load controller (ELC) for a self-excited induction generator (SEIG) on stand alone applications. With constant input power and fixed value of capacitance, the induced voltage varies with the applied load. This paper proposes an ELC scheme whose control strategy is simple and reliable. Anti-parallel IGBT switches are used to control the connection and disconnection of dump load. The proposed ELC is tested under several critical situations, providing an excellent voltage and frequency regulation. Harmonic analysis is carried out to determine the total harmonic distortion (THD).

In June 2007, Ramirez, and Torres [21] proposed the design of an electronic load controller (ELC) for a self-excited induction generator (SEIG) on stand alone applications. With constant input power and fixed value of capacitance, the induced voltage varies with the applied load. This paper proposes an ELC scheme whose control strategy is simple and reliable. Anti-parallel IGBT switches are used to control the connection and disconnection of dump load. The proposed ELC is tested under several critical situations, providing an excellent voltage and frequency regulation. Harmonic analysis is carried out to determine the total harmonic distortion (THD).

In October 2007, Singh, and Kasal [22] proposed a voltage and frequency controller for an isolated power generation system based on asynchronous generator (AG) driven by pico hydro turbine and supplying 3-phase dynamic (asynchronous motor) loads. The proposed controller is a combination of a static compensator (STATCOM) and an electronic load controller (ELC) for independent control of the reactive and active powers of the system to control the voltage and frequency respectively. The proposed generating system along with its controller is modeled in MATLAB using SIMULINK and PSB (Power System Block Sets) toolboxes.

In November 2007, Singh, and Kasal [23] proposed a voltage and frequency controller for parallel operated isolated asynchronous generators used in constant power applications such as driven by uncontrolled pico hydro turbines. The proposed controller is having capability of controlling the voltage and frequency in decoupled manner. For controlling the voltage, a static compensator (STATCOM) is used as a reactive power compensator along with harmonic eliminator and a load balancer while for controlling the frequency; an electronic load controller (ELC) is used to regulate the total active power at the generators terminals. The STATCOM is realized using IGBTs (Insulated gate bipolar junction transistors) based voltage source converter (VSC), and a capacitor as an energy storage element at its DC link, while an ELC consists of a diode bridge rectifier, a chopper switch and an auxiliary load. The proposed generating system along with its controller is modeled in MATLAB using SIMULINK and PSB (Power System Block Sets) toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system with the proposed controller.

In February 2008, Wang, Zou, Jia, Li, Zhang, and Xu [24] proposed a new test equipment for single-phase ac power source tests named PEL(power electronic load), the proposed architecture consists of two power stages such as input AC-DC imitation converter to imitate various loads and the output grid-connection converter to send back the recycling energy to the utility grid. In PEL, the controllable imitation converter enlarges the load bound that can be imitated, make the system more flexible, it even can simulate the nonlinear load to verify the stability of the tested ac power; and the grid-connection transformer ensures the system operate in security. A simple control scheme based on P(proportion) and PI(proportion and integral) control is proposed to ensure the system operate normally. But the phase delays in the digital control system and the controlled plant, the change of the parameter in the PEL, the unpredictable disturbances in the system will degrade the effectiveness of the simple control scheme. The repetitive control is proposed to solve the problem, it can ensure the system with excellent steady characteristics, to remedy the shortage of the repetitive controller in dynamic characteristics, the traditional P controller is connected with it in parallel connection, the compound controller acts well both in steady state and dynamic state, it even can hold a perfect effect in simulating the nonlinear load.

In February 2008, Sisworahardjo, El-Sharkh, and Alam [25] proposed Microturbines (MTs) as alternative energy sources demonstrate high potential to meet user's needs for distributed generation application. Efficient model and controller are essential to understand and investigate the MT operation characteristics. They introduced a controller based on artificial neural network (ANN) for stand alone MT power plants. In addition, they presented a comparison between the performance of the MT when using traditional PI and ANN controllers. MT has three control loops, namely; the power, the temperature, and the speed control loops. In addition the MT is connected to a synchronous generator (SG) which includes a voltage control loop. An ANN with four inputs and four outputs is used to replace the four PI control loops in the MT and the SG models. Three test measures have been used to compare the performance of the MT with PI and ANN controllers, absolute mean error (AME), root mean square error (RMSE), and standard deviation error (SDE).

In April 2008, Kasal, and Singh [26] proposed a decoupled voltage and frequency controller (DVFC) for an isolated asynchronous generator (IAG), also known as the self-excited induction generator (SEIG), used in constant power applications such as pico hydro uncontrolled turbine driven IAG for feeding three-phase four-wire loads. The proposed controller is used to control the voltage and frequency at the generator terminal independently. The proposed decoupled controller is a combination of a STATic synchronous COMpensator (STATCOM) for regulating the voltage and an electronic load controller (ELC) for controlling the power which in turn maintains the system frequency constant. The STATCOM is realized using a 4-leg insulated gate bipolar transistor (IGBT)-based current controlled voltage-sourced converter (CC-VSC) and a self-supporting dc bus, while the ELC consists of a three-phase diode bridge rectifier, a chopper switch and an auxiliary load. The proposed generating system is modeled and simulated in MATLAB along with Simulink and power system blockset (PSB) toolboxes.

In June 2008, Youssef, Wahba, Hasan and Sebakhy [27] described the role of three-phase self-excited induction generators (SEIG) in renewable energy sources such as wind and hydraulic energy. Their main disadvantage is poor voltage and frequency regulation under varying load and speed. They introduced a new and simple method for voltage and frequency control of three-phase unregulated speed induction generators in the islanding mode. The method uses a constant voltage constant frequency (CVCF) PWM converter without regulating the DC capacitor voltage. The capacitor voltage is left changing with the loading conditions and the AC side voltage is regulated by controlling the modulation index. This eliminates the need of an auxiliary switch in the DC side which reduces the cost and also reduces the high frequency current components flowing in the DC capacitor and that increases its life time. The proposed technique is tested under step changes in load and prime mover speed. The proposed technique gives the same response as the old technique but without the use of DC side switch.

In June 2008, Singh, Kasal, Chandra, and Haddad [28] proposed an investigation on a controller, which regulates the voltage and frequency of an isolated asynchronous generator (IAG) driven by an uncontrolled pico hydro turbine to feed 3-phase 4-wire loads. The proposed controller is having capability to regulate the voltage and frequency in decoupled manner. A STATCOM (static synchronous compensator) is used to control the reactive power to regulate the voltage, while frequency regulation is achieved by active power control through an electronic load controller (ELC). The voltage regulator (VR) consists of an IGBT (insulated gate bipolar junction transistor) based three single-phase voltage source converters (VSCs), which are connected to each phase of the generator through three single-phase transformers. An advantage of this three-phase four wire topology is that DC link voltage can be maintained at optimum level. Frequency regulator (FR) consists of a diode bridge rectifier with a chopper switch and an auxiliary load. The proposed controller with an IAG system is modeled and simulated in MATLAB using power system block set (PSB) and Simulink toolboxes. Simulated results have demonstrated that proposed voltage and frequency controller for an IAG driven by uncontrolled pico hydro turbine offers the functioning as a harmonic eliminator, a load balancer and a neutral current compensator.

In July 2008, Singh, Kasal, Chandra, and Haddad [29] proposed a voltage and frequency control of an isolated asynchronous generator feeding 3-phase 4-wire loads in constant power applications where terminal voltage, excitation capacitor, speed and generated power of the generator remain constant under all operating conditions. The proposed controller functions as an improved electronic load controller (IELC) to regulate the frequency and control the reactive power to regulate the terminal voltage. The proposed controller consists of 4 -leg IGBT (Insulated Gate Bipolar Junction Transistor) based VSC (Voltage Source Converter) which is connected to the each phase of the generator through interfacing inductors and there is an auxiliary load with a chopper at the self regulated DC bus of IELC. The controller provides the function of a voltage regulator, a harmonic eliminator, a load balancer and a neutral current compensator while the chopper and auxiliary load at the DC bus are used to regulate its voltage. The complete system is modeled and simulated in MATLAB along with Simulink and PSB (Power system Block set) toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system driven by uncontrolled pico hydro turbine and feeding 3-phase 4-wire linear/non-linear balanced/un-balanced loads.

In July 2008, Singh, Kasal, Chandra, and Haddad [30] proposed an investigation on a voltage and frequency controller (VFC), which functions as an improved electronic load controller (IELC) for parallel operated isolated asynchronous generators (IAGs) in an autonomous micro hydro power generation system. In such type of micro hydro scheme whole generating system is isolated from the grid and supply electricity to the remote communities. The single point operation of these generators is realized, in such a manner that excitation capacitors, speeds, voltage, currents of generators remain constant under various operating loads conditions. The proposed controller consists of a 3-leg IGBT (Insulated Gate Bipolar Transistor) based voltage source converter (VSC) and a DC chopper with an auxiliary load at the DC bus of the VSC. The IELC controls the reactive and active power simultaneously for controlling the voltage and frequency under varying consumer loads. Along with voltage and frequency control through single point operation of IAGs driven by uncontrolled micro hydro turbines, the IELC meets the power quality standard an IEEE-519 and it keeps the total harmonic distortion (THD) of the terminal voltage and generator currents within the limit of 5%. Proposed electrical system along with its controller is modelled in MATLAB along with Simulink and PSB (Power System Block-set) toolboxes.

In September 2008, Singh, Kasal, and Gairola [31] described the power quality improvement in a conventional electronic load controller (ELC) used for isolated pico-hydropower generation based on an asynchronous generator (AG). The conventional ELC is based on a six-pulse uncontrolled diode bridge rectifier with a chopper and an auxiliary load. It causes harmonic currents injection resulting distortion in the current and terminal voltage of the generator. The proposed ELC employs a 24-pulse rectifier with 14 diodes and a chopper. A polygon wound autotransformer with reduced kilovolts ampere rating for 24-pulse ac-dc converter is designed and developed for harmonic current reduction to meet the power quality requirements as prescribed by IEEE standard-519. The comparative study of two topologies, conventional ELC (six-pulse bridge-rectifier-based ELC) and proposed ELC (24-pulse bridge-rectifier-based ELC) is carried out in MATLAB using SIMULINK and Power System Blockset toolboxes. Experimental validation is carried out for both ELCs for regulating the voltage and frequency of an isolated AG driven by uncontrolled pico-hydroturbine.

In October 2008, Singh and Rajagopal [32] developed the SRF (synchronous reference frame) controller for an electronic load controller (ELC) for islanded asynchronous generator (IAG) system in pico hydro plant applications. An implementation of ELC for IAG system is carried out using an asynchronous generator, excitation capacitors, voltage source convertors with a dc link capacitor, a chopper, star/delta transformer, consumer loads and an auxiliary load at dc bus. The IAG system with ELC provides a viable and cost-effective solution to achieve power quality improvement, voltage and frequency control, harmonic elimination and load balancing for feeding nonlinear loads.

In October 2008, Murthy, Bhuvaneswari, Gao, and Gayathri [33] described the analysis of dynamic and steady state performance of a self excited induction generator (SEIG) with digitally controlled electronic load controller (ELC) feeding single phase loads. The excitation capacitors, electronic load controller, 1-phase load in conjunction with the d-q model of the 3-phase induction machine taking into account the saturation effect are used to predict the dynamic behavior of the SEIG. The digital control is realized by means of PIC18F252 microcontroller which provides a better performance with increased operational flexibility. Both simulation and hardware results have been presented for the digitally controlled ELC, which is more compact, reliable and cost effective for providing effective voltage regulation for field applications.

In October 2008, Singh, and Kasal [34] proposed a decoupled voltage and frequency controller (DVFC) for isolated asynchronous generator (IAG) used in pico hydro power generation for feeding 3-phase, 4-wire loads. The proposed controller is used to control the voltage and frequency through control of active power and reactive power at the generator terminal independently. The decoupled controller is a combination of a static compensator (STATCOM) consisting VSC with star delta transformer for regulating the voltage and an electronic load controller (ELC) for controlling the active power which in turn controls the system frequency constant. The STATCOM is realized using IGBT (Insulated Gate Bipolar Junction Transistor) based current controlled voltage source converter (CC-VSC) and a self supporting DC bus, while ELC consists of 3-phase diode rectifier, Dc chopper switch and an auxiliary load. The neutral point of the load is created using T-connected transformer. The proposed generating system is modeled and simulated in MATLAB along-with Simulink and PSB (Power System Blockset) toolboxes. The simulated results are presented to demonstrate the capability of generating system for feeding 3-phase 4-wire loads.

In November 2008, Kasal, and Singh [35] proposed a decoupled voltage and frequency controller (DVFC) for isolated asynchronous generator (IAG) used in pico hydro power generation for feeding 3-phase, 4-wire loads. The proposed controller is used to control the voltage and frequency through control of active power at the generator terminal independently. The decoupled controller is a combination of a static compensator (STATCOM) consisting VSC with zig-zag transformer for regulating the voltage and an electronic load controller (ELC) for controlling the active power which in turn controls the system frequency constant. The STATCOM is realized using IGBT (Insulated Gate Bipolar Junction Transistor) based current controlled voltage source converter (CC-VSC) and a self supporting DC bus, while ELC consists of 3-phase diode rectifier, chopper switch and auxiliary load. The proposed generating system is modeled and simulated in MATLAB along-with Simulink and PSB (Power System Blockset) toolboxes. The simulated results are presented to demonstrate the capability of generating system for feeding 3-phase 4-wire loads.

In December 2008, Kasal, and Singh [36] proposed an electronic load controller (ELC) for a stand alone pico hydro power generating system employing an isolated asynchronous generator (IAG). The proposed controller consists of an electronic load controller (ELC), using two leg IGBT (insulated gate bipolar junction transistor) based voltage source converter (VSC), a DC chopper and an auxiliary load at its DC bus. The neutral terminal for the consumer loads is created using a zig-zag transformer. A VSC and a zigzag transformer are connected in shunt with the stator terminals of IAG. The control algorithm of the ELC is developed to control the system voltage and frequency under varying consumer loads. The proposed IAG system is modeled and stimulated in MATLAB using Simulink and PSB toolboxes.

In May 2008, Xue, Chang, and Guo [37] described the importance of wind/hydrogen/diesel cogeneration systems for the energy supplies of remote communities in terms of economic and environmental factors. For such a weak grid, a power electronics-based dump load controller is usually deployed for frequency regulation to balance the generation and demand. They proposed a two-leg IGBT-based load controller, which can be operated in low power, medium power, and high power operation modes. A bumpless transfer technique is proposed to smoothly switch between neighboring operation modes. Analysis, simulation, and prototyping test results are presented.

In August 2009, Morishita, Suzuki2, Ohtsuj, Fukumot, and Higuchi [38] developed a robust Digital Controller for Constant Voltage Control (CV control) of our electronic load which had a very fast response of current. Thee derived two types of control object. As a result, they showed faster response of current and more stable than existing circuit of CV control. To achieve faster CV control, you will adapt CV control to much further cases of application.

In December 2009, Singh, and Rajagopal [39] developed an integrated electronic load controller (IELC) for an isolated asynchronous generator (IAG), used in constant power pico hydro power generation for feeding three-phase four-wire loads. The IELC is realized using a star/delta transformer and three-leg insulated gate bipolar transistors (IGBTs) -based current controlled voltage source converter (VSC) with a DC capacitor, a chopper switch and an auxiliary load. The proposed IELC is used to control the voltage and frequency of IAG in integrated manner. The proposed IELC with the generating system is modeled and simulated in MATLAB along with Simulink and simpower system (SPS) toolboxes. The simulated results are presented for the IAG with IELC for feeding three-phase four-wire linear/nonlinear (balanced/unbalanced) loads with the neutral current compensation to demonstrate its performance.

In December 2009, Singh, and Rajagopal [40] proposed the design of an isolated star/hexagon transformer based ELC (electronic load controller) to regulate voltage and frequency of an isolated asynchronous generator (IAG) driven by a stand-alone uncontrolled pico-hydro turbine feeding three-phase four-wire loads. The proposed ELC is used to control frequency and voltage of IAG despite frequent change in consumer loads. Such an ELC is having a capability of feeding the power to the consumer loads, more than the IAG power rating. This is realized using an isolated star/hexagon transformer with a voltage source converter (VSC) and a battery at its DC bus. The proposed generating system with ELC is modeled and simulated in MATLAB along with Simulink and Simpower system (SPS) toolboxes. The obtained results are presented to demonstrate the performance of an IAG feeding three-phase four-wire loads with the neutral current compensation.

In June 2010, Du, Qi, Luo, and Zhang [41] described that fuel cell(FC) stack is the power source of fuel cell electric vehicles. Its output current and power usually need to be controlled during testing. Electronic load controller (ELC) has often been introduced in FC testing system to control the DC bus. The desired characteristics of such loads include high power, high reliability, high speed of dynamic response and low cost. In this paper, a high performance ELC for FC stack testing was designed according to the test requirement of FC stack's output characteristics. To ensure continuous input current, the main circuit employed a dual-parallel buck with input LC filters. To suppress the resonance caused by input filters, the transfer function of input current to the duty cycle was obtained by using averaged model. Then the closed-loop control for variable-current mode was achieved. Based on FC stack's polarization curve, variable-power mode was also achieved, and the function of under-voltage protection was realized. This ELC had been successfully applied in 60kW FC stack testing system, and achieved good accuracy and dynamic characteristics.

In August 2010, Singh, Rajagopal, Chandra, and Haddad [42] proposed a decoupled electronic load controller (DELC) for an isolated asynchronous generator (IAG), used in constant power pico hydro power generation for feeding three-phase four-wire loads. The proposed DELC is used to control the voltage and frequency in the decoupled manner. The proposed decoupled electronic load controller is combination of a voltage regulator (VR) for regulating the voltage and a conventional electronic load controller (ELC) for regulating the active power (i.e. frequency). The VR is realized using a star-delta transformer and H-bridge current controlled voltage source converter (VSC) with a capacitor on its dc bus and an ELC is a combination of a three phase diode bridge rectifier with a chopper switch and an auxiliary load. The proposed electronic load controller with the generating system is modeled and simulated in MATLAB along with Simulink and power system blockset (PSB) toolboxes. The simulated results are presented for three-phase four-wire linear/nonlinear loads with the neutral current compensation to demonstrate its performance.

In August 2010, Torres, Chan, Ramirej, and Como [43] proposed the design of an improved electronic load controller for a self-excited induction generator (SEIG) on stand alone applications. With constant input power and a fixed value of capacitance, the generated voltage varies with the applied load. In applications of up to 100 kW, uncontrolled turbines are preferred, which maintain the input power constant, thus requiring the generator output power to be maintained constant at varying consumer loads. A dump load in shunt with the consumer load is necessary to maintain the electrical load constant at generator's terminals. They proposed an improved ELC scheme whose control strategy is simple and reliable. Series-inverted IGBT switches are used to control the connection or disconnection of the dump load The ELC proposed was tested under critical situations in which it provided an excellent voltage and frequency regulation. Lastly a harmonic analysis was carried out to determine the total harmonic distortion.

In October 2010, Mahato, Singh, and Sharma [44] described the transient analysis of a three-phase self-excited induction generator (SEIG) feeding single-phase inductive load with an Electronic Load Controller (ELC) used in stand-alone micro-hydro power generation employing uncontrolled turbines. A complete mathematical model of the total system has been developed. The dynamic model of the SEIG using a three-phase star-connected induction machine is developed based on stationary reference frame d-q axes theory, with three capacitors connected in series and parallel with the single-phase load. The effect of cross-saturation is also incorporated in the model. The implemented ELC consists of a rectifier-chopper system feeding a resistive dump load whose power consumption is varied through the duty cycle of the chopper. Simulated results are compared with the experimental ones, obtained on a developed prototype of an SEIG-ELC system for the different transient conditions such as sudden application of load, sudden removal of load to validate the effectiveness of the proposed approach.

In October 2010, Rajagopal, Singh, and Kasal [45] proposed an implementation of an instantaneous reactive power theory-based electronic load controller (ELC) for regulating the voltage and frequency of an isolated induction generator system (IG) that can supply electricity in remote areas. This ELC provides the fundamental reactive power and compensates harmonics of load currents. The proposed ELC is a combination of voltage source converter (VSC) with a dc link capacitor, a chopper and an auxiliary load at its dc bus. It controls active and reactive powers of the small hydro plant thus regulating the voltage and frequency of IG system. This ELC also balances the currents of the IG system under unbalanced load currents and eliminates the harmonics of the load currents thereby acting both as a load balancer and a harmonic eliminator. The zigzag/star transformer optimises the dc bus voltage of VSC and acts as a neutral current compensator. The proposed IG along with its ELC is implemented on a 3.7 kW IG system.

In December 2010, Singh, Rajagopal, Chandra, and Haddad [46] developed an electronic load controller (ELC) for an isolated asynchronous generator (IAG) to feed 3-phase, 4-wire consumer loads in a small hydro power generation system. This ELC consists of ac capacitors, voltage source converter (VSC) with a dc capacitor, a chopper, an auxiliary load at its dc bus, a star/hexagon transformer, consumer loads and it is implemented using synchronous-reference-frame (SRF) theory. This ELC provides a viable and cost-effective solution to achieve voltage and frequency control, harmonic elimination and load balancing for linear and nonlinear loads. Test results are presented to demonstrate the effectiveness of ELC for the IAG system.

In December 2010, Rajagopal and Singh [47] developed an electronic load controller (ELC) for a standalone induction generator (IG) used in small hydro power generation. The proposed ELC is used to control the voltage and frequency of IG. This ELC is realized using a non-isolated T-connected transformer and three-leg insulated gate bipolar transistors (IGBTs) based current controlled voltage source converter (VSC), a capacitor, a chopper switch and an auxiliary load on its dc bus. The proposed ELC is implemented on a prototype of 3.7 kW 50 Hz IG. Test results of IG-ELC system are presented to demonstrate its performance for feeding three-phase four-wire loads with the neutral current compensation.

In December 2010, Singh and Rajagopal [48] proposed a neural-network (NN)-based integrated electronic load controller (IELC) for an isolated asynchronous generator (IAG) driven by a constant-power small hydro uncontrolled turbine feeding three-phase four-wire loads. The proposed IELC utilizes an NN based on the least mean-square algorithm known as adaptive linear element to extract the fundamental component of load currents to control the voltage and the frequency of an IAG with load balancing in an integrated manner. The IELC is realized using zigzag/three single-phase transformers and a six-leg insulated-gate bipolar-transistor-based current-controlled voltage-source converter, a chopper switch, and an auxiliary load on its dc bus. The proposed IELC, with the generating system, is modelled and simulated in MATLAB environment using Simulink and Simpower System toolboxes. The simulated results are validated with test results on a developed prototype to demonstrate the effectiveness of IELC for the control of an IAG feeding three-phase four-wire linear/nonlinear balanced/unbalanced loads with neutral-current compensation.

In January 2011, Rajagopal and Singh [49] described an implementation of an electronic load controller (ELC) using a digital signal processor (DSP) for regulating the voltage and frequency of an offgrid induction generator system (IG) that can supply electricity in remote areas of countries with high year-round rainfall. The proposed generating system consists of IG, ELC and nonlinear consumer loads. The ELC is combination of three-leg VSC with a dc link capacitor, a chopper and an auxiliary load at its dc bus. It regulates voltage and frequency of the small hydro plant, Besides this the ELC balances the IG system under unbalanced loading conditions and eliminates the harmonics of the loads thereby acting both as a load leveler and a harmonic eliminator. The proposed IG along with its ELC is implemented on a 3.7kW IAG system using a DSP.

In June 2011, Serban, and Marinescu [50] presented an aggregate load-frequency controller for an autonomous microgrid (MG) with wind and hydro renewable energy sources. A micro-hydro power plant with a synchronous generator (SG) and a wind power plant with an induction generator (IG) supply the MG. Both generators directly feed power into the grid without the use of additional power electronics interfaces, thus the solution becoming robust, reliable and cost-effective. An original electronic load controller (ELC) regulates the MG frequency by a centralized load-frequency control method, which is based on a combination of smart load (SL) and battery energy storage system (BESS). SL and BESS provides the active power balance for various events that such systems encounter in real situations, both in cases of energy excess production and energy shortage. Moreover, the proposed ELC includes an ancillary function to compensate the power unbalance produced by the uneven distribution of the single-phase loads on the MG phases, without the use of extra hardware components.

III. DISCUSSION

This paper presents the extensive review of the work in the area of load frequency control of small hydro power generating stations. The ELC eliminates the mechanical load controller for the small hydro power plants as mechanical speed governors are most costly (costs about 30% of total system cost) and least reliable part of small hydro plants. Singh [7] describes the transient analysis of SEIG with ELC supplying the static loads as well as 3-pahse induction motors (dynamic loads). Serban [16] describes the problems of harmonic current injection & also found that THD=41% & DF=.9% are less without smoothing capacitance (with smoothing capacitance THD=90%, DF=3% with a duty cycle of 80%). Singh [23] introduces STATCOM as a reactive power compensator. Singh [47] describes ELC using IcosΦ Algorithm. Singh [48] proposed neural network (NN) based ELC.

IV. CONCLUSION

This paper presents an overview and key issues of different research studies for ELC. Self-excited induction generators are found to be ideal as they are rugged, cheap and user friendly. Electronic load controller based on insulated gate bipolar transistor has better voltage regulation than based on thyristors so IGBTs are preferred over thyristors. It is clear, from the existing literature, that there are different solution methods for designing ELC. This paper describes step by step development in the area of ELC which provides relevant guidelines and references for the researchers intending to do additional study in the area of small hydro power generation.

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