Indian Journal of Science and Technology, *Vol 10(31), DOI: 10.17485/ijst/2017/v10i31/113857, August 2017*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Control Topologies for 3-Phase SEIG used in Small Hydro Power Plant Feeding Isolated Domestic Load in Remote Mountainous Region

Umesh C. Rathore[1] and Sanjeev Singh[2]

[1]ABV Government IET Pragatinagar, Shimla – 171202, Himachal Pradesh, India; rathore7umesh@gmail.com
[2]SLIET University, Longowal, Sangrur – 148106, Punjab, India; sschauhan.sdl@gmail.com

Abstract

Objectives: This paper is to highlight the various control topologies used in 3-phase Self-Excited Induction Generator (SEIG) used in pico-hydro power generation system feeding isolated load. **Methods/Statistical Analysis:** The various topologies of these controllers which are also known as Electronic Load Controllers (ELC) include conventional as well as STATCOM based controllers using various power electronics devices for power system parameters regulations and power quality control. The Self-excited induction generators are most suitable for pico and micro hydro power generation systems feeding isolated load due to their advantages over conventional synchronous generators. **Findings:** In isolated mode of operation of self-excited induction generators, a suitable control is necessary to maintain the voltage & frequency of the generated output within permissible limits under varying loading conditions. This is achieved by using an Electronic Load Controller (ELC) and dump load in the system. The main aim of the control strategy is to control the voltage output of SEIG and to maintain the desired frequency of the generated output. These electronic load controllers regulate the dump load in the system so that total load seen by SEIG remains constant under varying consumer load conditions and thus maintaining the frequency of the system. From the analysis of various types of these controllers, it is found that simplest of the electronic load controller is conventional diode rectifier based ELC. However, it suffers with the problems of harmonics in the circuit. Modern ELCs use voltage source converters along with different transformer configurations for better power quality control and better voltage and frequency regulations under different operating conditions. **Improvements:** Fast computational capabilities of DSP are also used to control the STATCOM switches and chopper circuit in ELC for better and fast control. The use of different transformer configurations such as star-delta and zigzag type provide neutral path for 3-phase, 4-wire system apart from eliminating the 3rd harmonics in the system.

Keywords: Electronic Load Controller, Pico-Hydro, Power Quality, Self-Excited Induction Generator, Voltage & Frequency Control

1. Introduction

The world energy scenario prevalent presently demands for the harnessing of renewable energy potential available in abundance to meet the ever increasing demand of electrical energy across the globe. It will also help in minimizing the adverse effects on environment caused by various conventional energy sources. Advancement in technology and growing concern on environmental issues worldwide; have paved the way for harnessing of alternate sources of energy such as wind, hydro, geothermal, tidal, biomass, etc. Renewable energy sources based power plants are best suited to rural and remote areas to meet the electricity and other energy demand of inhabitants residing in these areas. Hydro energy is the most reliable and cost effective renewable energy source. Small hydro power plants are suitable

**Author for correspondence*

to meet the power requirement of remote mountainous regions. These are environment friendly and require less investment as compared to large hydro power plants. Induction generators with their numerous advantages over conventional synchronous generators are most suitable in converting these renewable energy sources into useful electrical power. Due to their simpler construction, robustness and small size per generated kW, the induction generators are suitable for small hydro power and wind energy conversion systems.[1] The self-excited induction generator is most suitable for renewable energy conversion system involving small power plants operated in isolated mode and which are not connected to the grid. In isolated mode of operation of induction generators, a suitable control is required to maintain the voltage & frequency of the generated output under permissible limit under varying loading conditions. This is achieved by using an Electronic Load Controller (ELC) along with the dump load. Most of the small hydro power plants are located in the remotest part of the mountainous region feeding isolated load in small populated area having demestic electrical load comprising of lighting and heating. The daily load requirement varies during 24 hours in these areas as most of the electrical load comprises of lighting and heating is switch according to the requirement. Figure 1 shows the averaged dailiy electrical loading pattern as the per data collected from three 11kV feeders feeding the rural villages located in remote mouitanous regions during a full year.

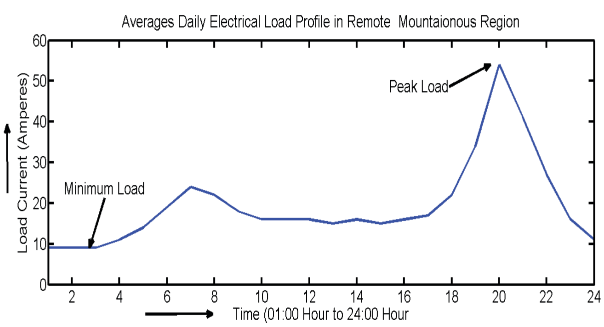

Figure 1. Electrical loading pattern in remote rural regions.

From the loading pattern as shown in Figure 1, it is clear that during the evening time between 6 PM to 10 PM, load is maximum with peak loading at 8 PM. While the load is minimum during night till early morning and which is about 20% of the maximum load. This loading pattern becomes crucial in the case if the rural isolated load is fed from a pico/micro hydro power plant and which is not connected to the grid. Under such condition a suitable load-frequency control is required to maintain the voltage and frequency within permissible limits. Under such varying load conditions, the use of suitable technologies on power generation such as the use of self-excited induction generators along with suitable control is beneficial due to their adaptability to variation in load and keeping its voltage and frequency constant. Generally the frequency in isolated induction generators is kept constant by using resistive dump load so that load seen by the induction generator is always constant under all loading conditions. This is achieved using various control schemes involving different types of electronic load controllers which also help in maintaining the power quality standards under different types of loading conditions.

This paper presents the various topologies of electronic load controllers which are efficiently used in 3-phase SEIG in pico-hydro power generation system feeding isolated domestic load. These topologies include power electronics based conventional electronic load controller, latest ELCs involving voltage source converter with different configurations and improved power quality, and DSP based ELCs. The usefulness and performance of these ELCs have been evaluated for their applications in 3-phase SEIG system feeding isolated load.

2. Three Phase Self-Excited Induction Generator

All Induction generators are best suited for renewable energy conversion systems as compared to the synchronous generators due to their advantages of reduced cost and size, ruggedness, brushless in squirrel cage construction, absence of separate D.C. source, ease of maintenance and self protection against severe overloads and short circuit conditions. The induction generators are most suitable for small hydro power plants and in wind energy conversion systems. Induction generators have outstanding performance as a motor or generator and have the same constructional features with slight improvement in its efficiency and excitation techniques in case of generator.[2] In case of induction generator the rotor speed is more than the synchronous speed, while in induction motor, the rotor speed is slightly less than the synchronous speed. Output induced voltage in induction generator is proportional to the relative difference between the electrical synchronous rotation and the mechanical rotation of rotor within a speed slip factor. Broadly, the induction generators are classified as self-excited induction generator (SEIG), Doubly Fed Induction Generator (DFIG) and Permanent Magnet Induction Generator (PMIG).[3] In case of self-excited induction generator, magnetization current for excitation is provided by an external circuit as shown in Figure 2 or by the system to which it is connected because induction generator consumes reactive power rather than supplying it.

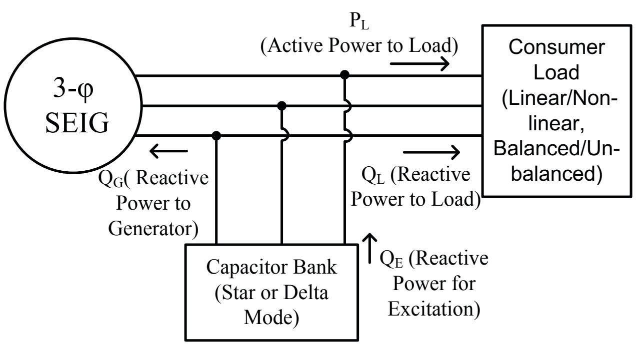

Figure 2. Excitation circuit in 3-φ SEIG.

The excitation circuit in SEIG includes the capacitor bank connected either in star or delta mode. Capacitors in self excited induction generators serve the purpose of providing leading reactive power to supply the magnetizing current.[1,3] The capacitor bank remains connected to the stator terminals of induction generator as it supplies required kVAr demand for its continuous operation. The residual magnetic field in the rotor initiates a voltage across the induction generator terminals when rotor speed exceeds the synchronous speed. This in turns further augments the capacitor current to continue rise in voltage as capacitors reinforce the magnetic field and system builds up an increasing excitation which results in further increase in terminal voltage. Residual magnetism is necessary to build up the generator voltage. There must be some residual magnetism present in the rotor. In the absence of residual magnetism, the voltage will not build up in induction generator. The minimum capacitance is inversely proportional to the square of speed and also inversely proportional to the maximum saturated magnetizing reactance and the terminal capacitance required under the loaded condition of the generator. It is significantly higher than the corresponding no load value as it is affected by load impedance, power factor and induction machine speed. The maximum power output from the isolated SEIG depends upon its terminal capacitance and the speed of the generator. There must be a threshold speed below which no excitation is possible, whatever the value of capacitor may be and this speed is called the cut off speed.

3. Control Requirements in Three Phase SEIG System Feeding Isolated Load

The control mechanism is necessary in renewable energy conversion systems using self-excited induction generators to produce the desirable electrical output compatible with the power system to which it is connected or feeding isolated load under various operating conditions. With the rapid advancement in renewable energy conversion technology field of power electronics along with the widespread use of computational devices and artificial intelligence based tools, it has become easier to have proper control with increased reliability and efficiency in energy conversion systems. Modern power electronics based devices find widespread applications in control of machine drives. The amount of power supplied by the renewable energy sources varies significantly on the hourly, daily or seasonal basis. This variation means that power is not fully available all the time as it may be less than the full capacity or sometimes there may be an excess power. Also the consumer load on the system is also not constant. Therefore, control is required to carefully manage the power available with these sources for maintaining the reliability and quality of power.

The control requirement in small hydro power plant such as pico-hydro using self-excited induction generator is different as pico-hydro power plants are generally classified as constant power driven prime mover power plants because the water discharge and head remain constant. This results in constant availability of power at the output of self-excited induction generator. Therefore, the load connected at the output terminals of induction generator must remain constant for maintaining the requisite voltage and frequency of the generated output. Voltage in the SEIG system in isolated mode is maintained using voltage regulators involving power electronics based devices. Suitable control for frequency in standalone SEIG system is necessary due to the intermittent nature of the load. Therefore, electronic load controllers are used in SEIG system feeding isolated load in small hydro power generation system.[4-14] The main aim of the design of control strategy is to regulate or control the voltage output of the generator and to maintain the desired frequency of the generated output. This controller can consume both the real and reactive power. These controllers pick up the real and reactive power which is not used by the load, so that the load seen by the generator at its terminals is always constant which results in achieving desired constant voltage and constant frequency as any change in load is immediately compensated by these electronic load controllers.

4. Control Topologies of ELC Used in 3-Phase SEIG System Feeding Isolated Load

Various topologies of electronic load controllers used in constant power prime mover driven small hydro power generation systems include conventional controllers based on diode rectifier to latest electronic load controllers with improved power quality and reliability. These electronic load controllers are also classified according to the types of applications such as for 3-phase 3-wire or 3-phase 4-wire distribution system feeding isolated load. Other topologies are also based on the type of Voltage Source Converter (VSC) used in the circuit such as two-leg, three-leg or four-leg type. Different types of transformers are also used in 3-phase SEIG system feeding isolated load for harmonics eliminations. Based on the connections of these transformers either in non-isolated mode or isolated mode of configuration, the ELC topologies are also defined. Another classification of ELC is based on the use digital signal processors and various soft computing techniques used in the control scheme. The broad classification chart of these controllers is shown as in Figure 3.

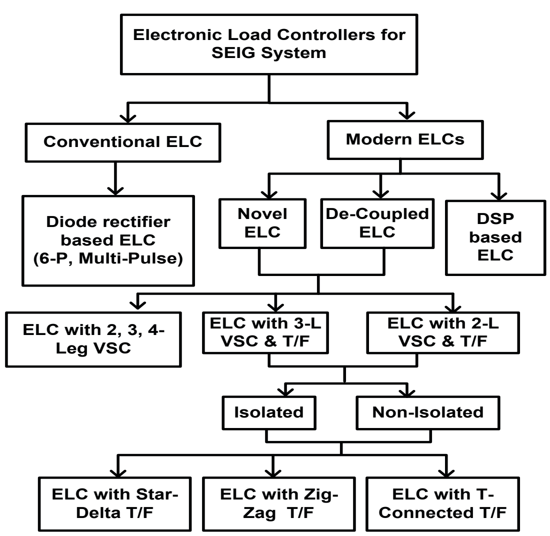

Figure 3. Broad classification of ELCs in 3-φ SEIG feeding isolated load.

4.1 Conventional Electronic Load Controller

Conventional diode rectifier based electronic load controller circuit as shown in Figure 4 consists of an uncontrolled 3-phase rectifier using 6 diodes, a filtering capacitor, a chopper circuit and a series of registers constituting the auxiliary or dump load. This type of controller is also called impedance controller. The uncontrolled rectifier converts AC terminal voltage of SEIG into DC voltage and filtering capacitor removes the ac ripples from rectified output. The chopper circuit consists of an Insulated Gate Bipolar Transistor (IGBT) which is used as electronic switch operated by a close loop controller based driver circuit. This driver circuit is used to switch ON or switch OFF the IGBT to connect the dump load according to the load requirement in such a manner that the total load seen by the SEIG terminal remain constant to maintain the required voltage and frequency of the output generated voltage.[4-6] The dump load consists of heating elements submerged in continuous flowing water to dissipate the extra power when the consumer load on SEIG is less. The advantage of this method is that it is the simplest method of control and there is no need of expensive turbine governor. However, there is wastage of energy as excess power is dissipated in the dump load circuit which could otherwise have been used for useful purposes such as lifting of water using water pump as load or useful heating applications.[7]

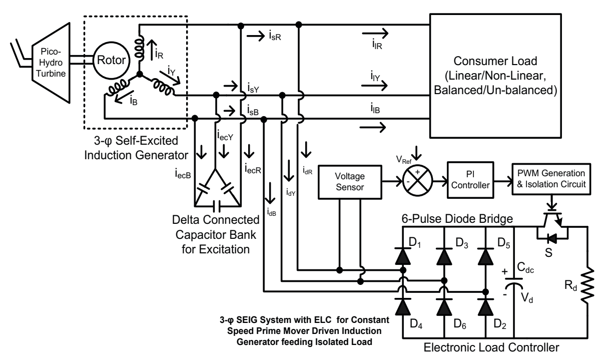

Figure 4. Conventional control scheme for 3-phase SEIG feeding isolated load.

4.2 Modern Electronic Load Controllers

The modern electronic load controllers have improved power quality, better control, harmonics elimination capability and they maintain desired voltage and frequency at various operating conditions.[8-12] It consists of Voltage Source Converter (VSC), chopper circuit and auxiliary load. The various topologies of three-phase three-wire novel electronic load controller are based on number of VSC legs used in the circuit. Based on it, these are classified as 4-leg, 3-leg, 2-leg VSC based electronic load controller. In three-leg voltage source converter based NELC as shown in Figure 5, output of the voltage source converter is connected through AC filtering inductor to terminals of SEIG. The DC bus capacitor is used in self supporting DC bus. The DC chopper circuit controls the connected dump load depending upon the requirement according to connected consumer load which is variable in nature.

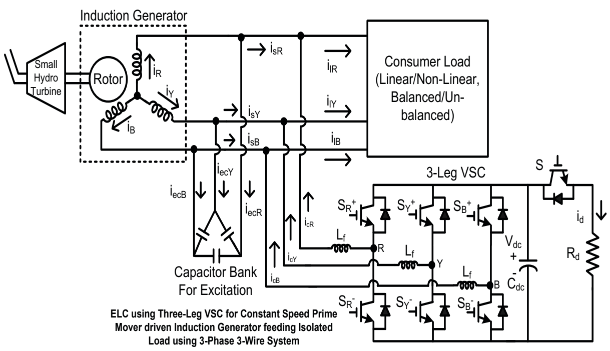

Figure 5. Three-Leg VSC based novel electronic load controller.

Another topology of modern ELC is of de-coupled type. De-coupled ELC is a combination of conventional diode rectifier based ELC and VSC based ELC. In this case ELC maintain the desired voltage & frequency like conventional controller, while the voltage source converter serves the purpose of voltage regulation, maintaining power quality by eliminating harmonics and load balancing. It is further classified into 2-leg VSC and 3-leg VSC type. Advantage of this type of configuration is that the rating of Voltage Source Converter (VSC) is comparatively low in this as the auxiliary active power flows only during the unbalanced load period. However, the circuit components increases in this case as dump load circuit is fed through separate rectifier circuit. Figure 6 shows the 3-leg VSC based de-coupled ELC topology used in 3-phase SEIG system feeding isolated load.[8-10]

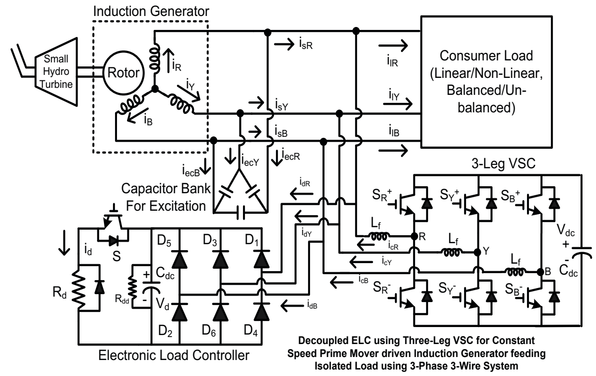

Figure 6. Three-Leg VSC based de-coupled electronic load controller.

4.4 Harmonics Eliminating Transformers based ELC Topologies

Various transformer configurations are also used along with ELC in 3-phase SEIG system to bypass the harmonic currents as well also to provide the neutral because in remote areas, majority of the domestic consumer load is single phase type which requires the use of neutral wire using 3-phase, 4-wire distribution system. In conventional distribution system fed from grid, delta-star transformer is used to convert 3-phase system into single phase system using 3-phase, 4-wire. In 3-phase SEIG system feeding dedicated load, the use of delta-star transformer or zig-zag transformers is useful in creating neutral conductor. It will also bypass harmonics through neutral in case of non-linear load on the SEIG terminals. The transformer configurations which are used for harmonics mitigations are star-delta, zigzag or grounding transformer and T-configurations. These transformer configurations provide independent path to flow of load neutral current, therefore the requirement of source neutral is not mandatory. Zigzag transformer configuration is most popular configuration in eliminating harmonics in 3-phase SEIG system feeding non-linear unbalanced load. Apart from by-passing the zero sequence currents, zigzag transformer also provide the neutral connection for connecting the load as shown in Figure 7. This connection has some of the features of the Y and the Δ connections, combining the advantages of both. The zigzag transformer contains six coils on three cores. The first coil on each core is connected contrariwise to the second coil on the next core. The second coils are then all tied together to form the neutral and the phases are connected to the primary coils. Each phase, therefore, couples with each other phase and the voltages cancel out. The zigzag transformer allows the three in-phase currents to easily flow to neutral. If three currents, equal in magnitude but 120° out of phase with each other, are applied to the three terminals, the ampere-turns in the windings cannot cancel and the transformer restricts the current flow to the negligible level of magnetizing current. Therefore, the zigzag winding provides an easy path for in-phase currents but does not allow the flow of currents that are 120°out of phase with each other. The zigzag connection in power systems also traps triple harmonic (3rd, 9th, 15th, etc.) currents and are installed near loads that produce large triple harmonic currents.[11,12]

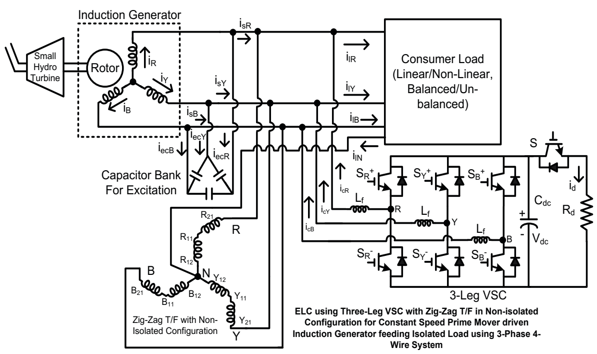

Figure 7. Zigzag transformer based ELC topology.

4.5 Processors based ELC Topologies for 3-Phase SEIG System Feeding Isolated Load

Digital signal processors are used in latest electronic load controller circuits due to their fast computational capabilities. These controllers also used modern control techniques use various adaptive control and soft computing techniques for better control and reliability.[13,14] DSP based electronic load controller consists of a three leg voltage source converter with a dc link capacitor, a chopper and an auxiliary load at its dc bus. Electronic load controller also balances the induction generator under un-balanced dynamic loading conditions and eliminates the harmonics, thus acting both as a load leveler and a harmonic eliminator. The gating signals for VSC switches and chopper switch are generated by DSP based on the system feedbacks in terms of system voltage, generated current, load current and DC link capacitor voltage. Figure 8 shows the application of digital signal processor in ELC used in 3-phase SEIG system feeding isolated load.

5. Conclusion

Various topologies of electronic load controllers used in 3-phase SEIG feeding isolated load have been presented in this paper. Specifically the broad classification of various types of electronic load controllers suitable for constant power prime-mover driven 3-phase SEIG feeding isolated load in pico-hydro power generation system have been presented. The simplest of the electronic load controller is conventional diode rectifier based ELC also known as impedance controller. However, it suffers with the problems of harmonics in the circuit. Modern ELCs use voltage source converters along with different transformer configurations for better power quality control and better voltage and frequency regulations under different operating conditions. Fast computational capabilities of DSP are also used to control the STATCOM switches and chopper circuit in ELC for better and fast control. The use of different transformer configurations such as star-delta and zigzag type provide neutral path for 3-phase, 4-wire system apart from eliminating the 3rd harmonics in the system. Widespread use of self-excited induction generators along with these control topologies can help in harnessing of maximum hydro power potential available in remote mountainous regions to meet the electricity demand of people residing in these remote areas with better power quality and reliability under all operating conditions.

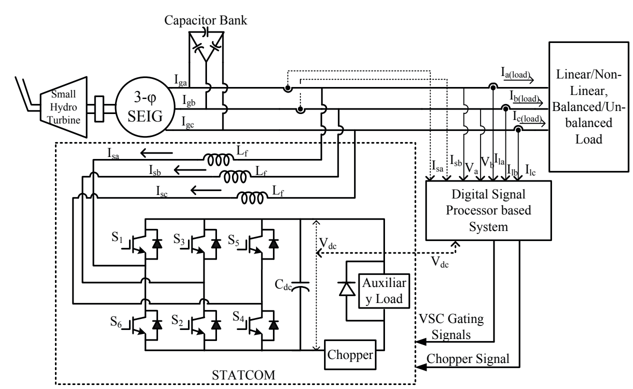

Figure 8. DSP based ELC topology for 3-phase SEIG system.

6. References

1. Simoes MG, Farret FA. Alternate Energy Systems: Design and Analysis with Induction Generators. 2nd ed. Boca Raton: CRC Press; 2008.

2. Bansal RC. Three-phase self-excited induction generators: an overview. IEEE Transactions on Energy Conversion. 2005; 20(2):292–9. Crossref
3. Chan TF. Capacitance requirements of self-excited induction generators. IEEE Transactions on Energy Conversion. 1993; 8(2):304–11. Crossref
4. Suarez E, Bortolotto G. Voltage-frequency control of a self excited induction generator. IEEE Transactions on Energy Conversion. 1999; 14(3):394–401. Crossref
5. Singh B, Murthy SS, Gupta S. Analysis and design of STATCOM-based voltage regulator for self-excited induction generators. IEEE Transactions on Energy Conversion. 2004; 19(4):783–90. Crossref Crossref
6. Ramirej JM, Torres E. An electronic load controller for self-excited induction generator. Proceedings of IEEE PES; 2007. p. 1–8.
7. Rathore UC, Singh S. Isolated 3-phase self-excited induction generator in pico-hydro power plant using water pump load in mountainous region of Himalayas. Proceedings of 2014 IEEE Global Humanitarian Technology Conference - South Asia Satellite (GHTC-SAS); 2014. p. 40–4.
8. Singh B, Kasal GK. Voltage and frequency controller for isolated asynchronous generators feeding 3-phase 4-wire loads. Proceedings of IEEE ICIT'06; 2006. p. 2773–8. Crossref
9. Singh B, Kasal GK. Analysis and design of voltage and frequency controllers for isolated asynchronous generators in constant power applications. Proceedings of IEEE PEDES'06; 2006. p. 1–7. Crossref
10. Singh B, Kasal GK, Gairola S. Power Quality Improvement in Conventional Electronic Load Controller for an Isolated Power Generation. IEEE Trans. on Energy Conversion. 2008; 23(3):764–73. Crossref
11. 11. Rajagopal V, Singh B. Improved electronic load controller for off grid induction generator in small hydro power generation. Proceedings of IEEE IICPE'10; 2011. p. 1–7.
12. Kasal GK, Singh B. Zigzag transformer based electronic load controller for an isolated asynchronous generator. Proceedings of IEEE PECON; 2008. p. 431–6.
13. Scherer LG, Tambara RV, Camargo RF. Voltage and frequency regulation of standalone self-excited induction generator for micro-hydro power generation using discrete-time adaptive control. IET Renew. Power Gener. 2016; 10(4):531–40. Crossref
14. Jayaprakash P. Singh, B, Kothari, DP. 2011. Digital Signal Processor Implementation of Isolated Reduced-rating Voltage Source Converter Using a Zigzag Transformer for 3-phase 4--wire Distribution Static Compensator. International Journal on Electric Power Components and Systems. 2011; 39(1):15–30. Crossref