Power Quality Improvement by using ELC in an Isolated Hydropower generation

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ABSTRACT - This paper applicable for improving power quality by regulation of voltage and frequency of an isolated Pico-hydropower generation. Based on a capacitor excited asynchronous generator and feeding linear load and electronic load controller. The electronic load controller based on a three phase uncontrolled diode bridge rectifier with a chopper and an auxiliary load. The 24 pulse ac-dc converter is designed and developed for harmonic current reduction to meet the power quality requirements. The complete electromechanical system is modeled and simulated in MATLAB using Simulink and simpower system block set. The simulated results are presented and compared with conventional 6-pulse and 12 pulse and 18 pulse to demonstrate the capability of the electronic load controller for regulating voltage and frequency of an isolated asynchronous generator driven by uncontrolled Pico-hydro turbine.

Keywords— Electronic load controller (ELC), isolated asynchronous generator (IAG), Pico-hydro turbine, six pulse diode bridge rectifier.

I. INTRODUCTION

THE isolated asynchronous generator (IAGs) have widely been recommended for remotely located community by harnessing available of renewable energy sources like micro hydro, wind and biogas. Because of having its brushless construction, small size no dc supply for excitation less maintenance cost and improved terminal performance.

The Soaring use of fossil fuels and their depletion over the last two decades combined with a growing concern about pollution of environment have led to a boost for renewable energy generation. This accelerated drive has led to a tremendous progress in the field of renewable energy systems during last decade. It has also resulted in a gradual tapping of the vast mini (100 kW to 1 MW), micro (10–100 kW), and Pico hydro (less than 10 kW) and wind energy potential available in isolated locations (where grid supply is not accessible). In most of the cases, these generating units have to operate at remote unattended site; therefore, maintenance-free system is desirable. In view of this, the isolated asynchronous generator (IAG) with a simple controller for regulating the voltage and frequency is most prominent option for such applications.

A number of research publications are available on voltage and frequency controllers for an IAG driven by uncontrolled Pico-hydro turbine for single-phase [1] as well three phase power applications. Most of these proposed controllers are reported as electronic load controllers (ELCs) that maintain the constant power at the generator terminal, to regulate constant voltage and frequency. The value of excitation capacitor is selected to generate the rated voltage at desired power. The basic principle of controlling the constant power at the generator terminal is to employ an ELC and operate it in a way so that the total power (absorbed by the load controller and consumer load) is constant. If there is less demand by the consumer, the balance of generated power is absorbed by the ELC. The energy consumed by the ELC may be utilized for useful work like water heating, space heating, cooking, battery charging, and baking, etc.

Various types of ELCs based on controlled (thyristorized) or uncontrolled six-pulse rectifiers with a chopper and an auxiliary load are reported in the literature [2]. These controllers provide effective control but at the cost of distorted voltage and current at the generator terminals, which, in turn, derate the machine. Moreover, the harmonic current injection at generator terminal is not within the prescribed limits by IEEE standards [3]. These harmonics cause additional losses in the system, resonance, and failure of the capacitor bank. In a phase-controlled thyristor-based ELC, the phase angle of back-to-back-connected thyristors is delayed from 0◦ to 180◦ as the consumer load is changed from zero to full load . Due to a delay in firing angle, it demands additional reactive power loading and injects harmonics in the system. In the controlled bridge rectifier type of ELC [4], a firing angle is changed from 0◦ to 180◦ for single phase and 0◦ to 120◦ for three phase to cover the full range of consumer load from 0% to 100%. In this scheme, six thyristors and their driving circuits are required, and hence, it is complicated, injects harmonics, and demands additional reactive power. Some of ELCs have been proposed that are having quality of the active filter and employs pulse width modulation (PWM) voltage source converter along with the chopper and auxiliary load at dc link [5]–[6] to eliminate the harmonics and provide the functions of voltage and frequency regulation.

However, such types of controllers make the system costly and complex with complicated control algorithm and simplicity requirement by the isolated system is lost. Therefore, in this paper, a simple ELC is proposed that regulates the voltage and frequency without any harmonic distortion at the generator terminals. The Conventional controller consists of a six pulse rectifier, a chopper, and an auxiliary load. The six pulse rectifier-based ELC has negligible harmonic distortion in the generated voltage and current.

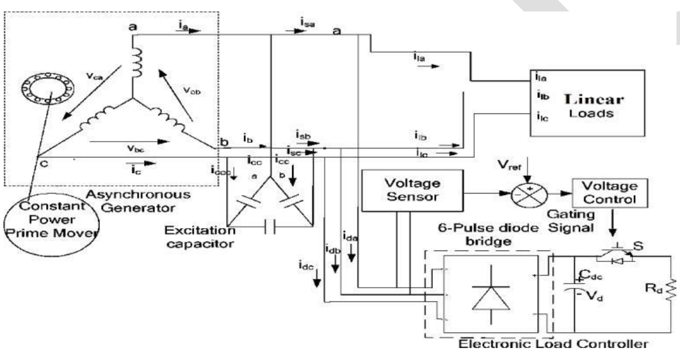


Fig. 1(a).Six-pulse diode bridge ELC.

II. SYSTEM CONFIGURATION

Fig. 1(a) shows the isolated Pico hydro generating system that consists of an IAG, excitation capacitor, consumer loads, and conventional ELC (six-pulse diode rectifier along with the chopper). The diode bridge is used to convert ac terminal voltage of IAG to dc voltage. The output dc voltage has the ripples, which should be filtered, and therefore, a filtering capacitor is used to smoothen the dc voltage. An insulated gate bipolar junction transistor (IGBT) is used as a chopper switch providing the variable dc voltage across the auxiliary load. When the chopper is switched ON, the current flow through its auxiliary load and consumes the difference power (difference of generated power and consumer load power) that results in a constant load on the IAG, and hence, constant voltage and frequency at the varying consumer loads.

The duty cycle of the chopper is varied by an analog-controller-based proportional– integral (PI) regulator. The sensed terminal voltage is compared with reference voltage and error signal is processed through PI controller. The output of PI controller is compared with fixed frequency saw tooth wave to generate the varying duty cycle switching signal for the chopper switch. According to the principle of operation of the system, the suitable value of capacitors is connected to generate rated voltage at desired power. The input power of the IAG is held constant at varying consumer loads. Thus, IAG feeds two loads (consumer load + ELC) in parallel such that the total power is constant.

Pgen = PELC + Pload

Where Pgen is generated power by the IAG (which should be kept constant), Pload is consumed power by consumers, and PELC is the power absorbed by the ELC.

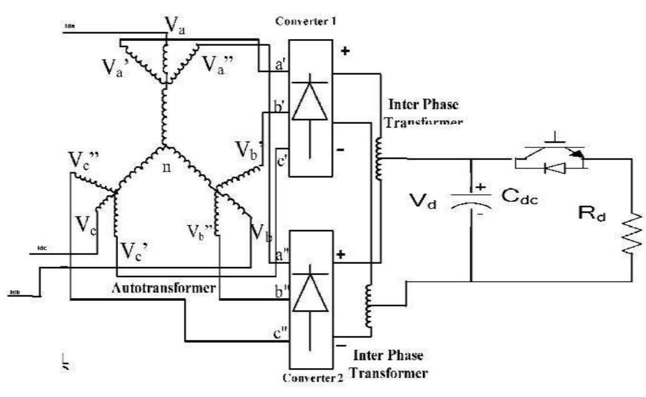


Fig. 1(b). Twelve-pulse diode bridge ELC.
In the above fig.1(a) the constant prime mover

shaft was connected to asynchronous generator shaft. In this paper uncontrolled Pico hydro turbine used as a constant prime mover. These turbine characteristics and asynchronous parameters have given in APPENDIX. And the excitation capacitor bank value is depends on generator output parameters.

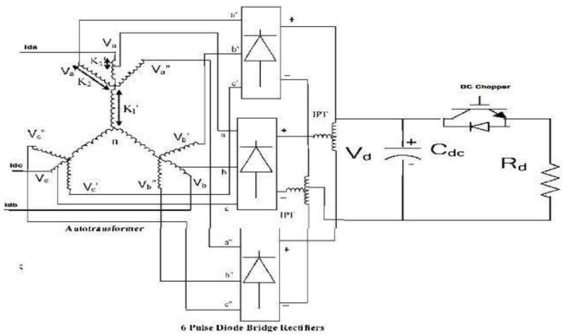


Fig. 1(c). Eighteen-pulse diode bridge ELC.

A three phase linear load is as consumer load. The three phase supply is connected to the three phase diode full bridge rectifier and capacitor also connected across this bridge for filtering of the dc output voltage, its value depends on load. An IGBT is used as

chopper switch providing the variable dc voltage across the auxiliary load (Resistive Load). The voltage sensor is sensed the voltage and compare with reference voltage to give PI controller for providing gating signal. A. 7.5KW, 415V, 50HZ asynchronous machine is used as an IAG and the ELC is modeled using available power electronics block set like diode bridge rectifier and a chopper with auxiliary resistive load. Simulation is carried out in MATLAB version of 7.8 above at discrete step of 50E-6. Detailed simulation and analysis of ELCs are given in the fallowing section.

IV. SIMULATION STUDY

Here, transient waveforms of the generator voltage (Vabc), generator current (Igabc), capacitor currents (Icabc), consumer load current (Ilabc), ELC current (Ida,Idb,Idc), rms value of the generated voltage (Vrms), frequency (f), speed of the generator (wg), variation in the load power (PLaod), ELC power (PELC), and generated power (Pgen) are given under the sudden application and removal of the consumer loads for ELCs in Figs.5 respectively.

A. Operation of Six Pulse Bridge Rectifier

One of the most common circuits used in power electronics is the 3-phase line commutated 6-pulse rectifier bridge, which comprises 6 diodes in a bridge connection. Single-phase bridges will not be covered here because their operation can be deduced as a simplification of the 3-phase bridge. In the diode bridge, the diodes are not controlled from an external control circuit. Instead, commutation is initiated externally by the changes that take place in the supply line voltages, hence the name line commutated rectifier [7] as shown in fig.2. According to convention, the diodes are labeled D1 to D6 in the sequence in which they are turned ON and OFF. This sequence follows the sequence of the supply line voltage

The 3-phase supply voltages comprise 3 sinusoidal voltage waveforms 120° apart which rise to their maximum value in the sequence A – B – C. According to convention, the phase-to-neutral voltages are labeled VA, VB and VC and the phase-to-phase voltages are VAB, VBC and VCA, as shown in fig.3. These voltages are usually shown graphically as a vector diagram, which rotates counter-clockwise at a frequency of 50 times per second. A vector diagram of these voltages and their relative positions and magnitudes is shown below. The sinusoidal voltage waveforms of the supply voltage may be derived from the rotation of the vector diagram.

The bridge comprises two commutation groups, one connected to the positive leg, consisting of diodes D1–D3–D5, and one connected to the negative leg, consisting of diodes D4–D6–D2. The commutation transfers the current from one diode to another sequence and each diode conducts current for 120° of each cycle as shown in Figure 4. The commutation transfers the current from one diode to another in sequence and each diode conducts current for 120° of each cycle as shown in Figure 4. In the upper group, the positive DC terminal follows the highest voltage in the sequence VA–VB–VC via diodes D1–D3–D5. When VA is near its positive peak, diode D1 conducts and the voltage of the +DC terminal follows VA. The DC current flows through the load and returns via one of the lower group diodes. With the passage of time, VA reaches its sinusoidal peak and starts to decline. At the same time, VB is rising and eventually reaches a point when it becomes equal to and starts to exceed VA. At this point, the forward voltage across diode D3 becomes positive and it starts to turn on. The commutating voltage in this circuit, VB–VA starts to drive an increasing commutation current though the circuit inductances and the current through D3 start to increase as the current in D1 decreases. In a sequence of events similar to that described above, commutation takes place and the current is transferred from diode D1 to diode D3. At the end of the commutation period, diode D1 is blocking and the +DC terminal follows VB until the next commutation takes place to transfer the current to diode D5. After diode D5, the commutation transfers the current back to D1 and the cycle is repeated.

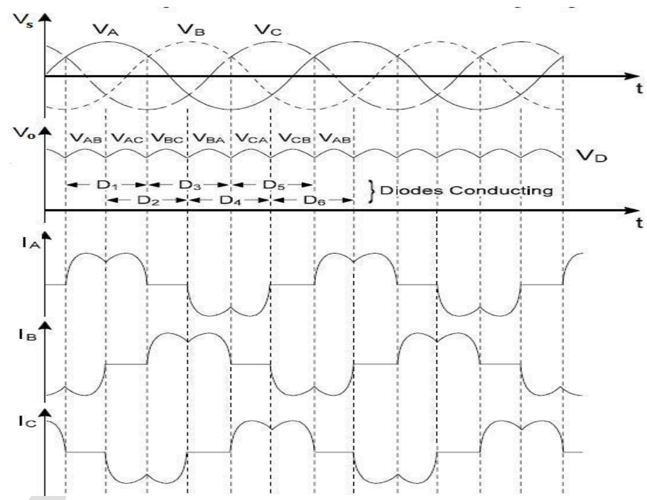
In the lower group, a very similar sequence of events takes place, but with negative voltages and the current flowing from the load back to the mains. Initially, D2 is assumed to be conducting when VC is more negative than VA. As time progresses, VA become

equal to VC and then becomes more negative. Commutation takes place and the current is transferred from diode D2 to D4. Diode D2 turns off and D4 turns on. The current is later transferred to diode D6, then back to D2 and the cycle is repeated. In Figure 4, the conducting periods of the diodes in the upper and lower groups are shown over several cycles of the 3-Phase supply. This shows that only 2 diodes conduct Current at any time (except during the commutation period, which is assumed to be infinitely short!!) and that

each of the 6 diodes conducts for only one portion of the cycle in a regular sequence. The commutation takes place alternatively in the top group and the

bottom group. The DC output voltage VD is

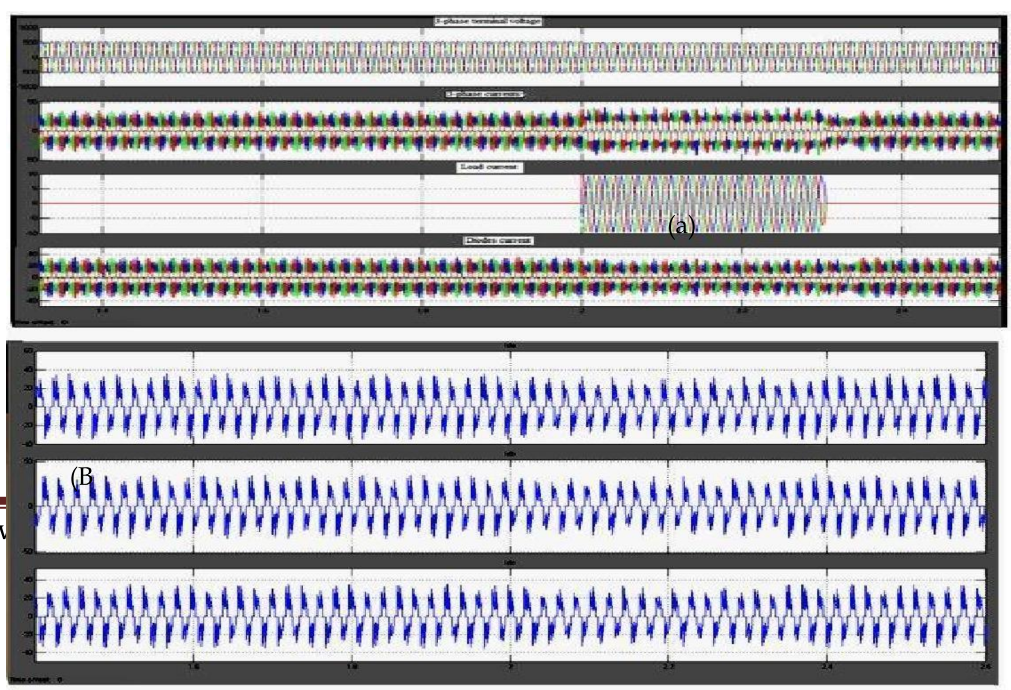
not a smooth voltage and consists of portions of the phase-to- phase voltage waveforms. For every cycle of the 50 Hz AC waveform (20 msec), the DC voltage VD comprises portions of the 6 voltage pulses, VAB, VAC, VBC, VBA, VCA, VCB, etc, hence the name 6-pulse rectifier bridge.

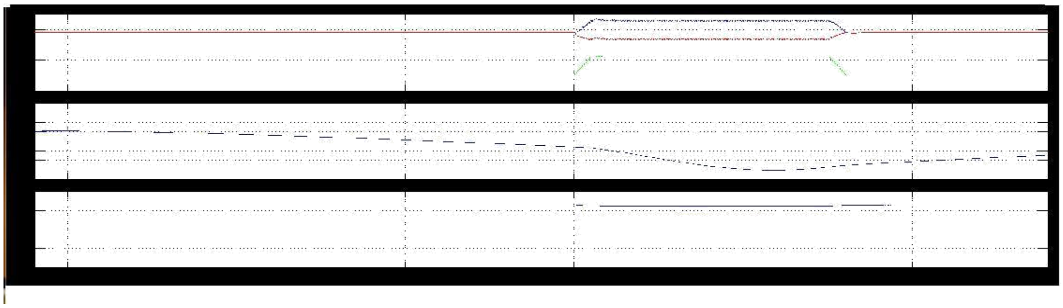


As fig. 4 the average magnitude of the DC voltage may be calculated from the voltage Waveform shown above. The average value is obtained by integrating the voltage over one of the repeating 120^{o} portions of the DC voltage curve. This integration yields an average magnitude of the voltage VD as follows.

VD=1.35*(RMS-Phase Voltage)*VD=1.35*VRMS

For example, if VRMS = 415 volts, VD = 560 volts DC





(c)

(A)Fig. 5 (a), (b) and (c) are the experimental transient waveforms, in (a) generator voltage, generator current, load current and diodes current respectively. In (b) phase a current, phase b current and phase c diode's current respectively. In (c) power, frequency and rotor speed graphs respectively.

Performance of Conventional Six-Pulse ELC

Fig. 5 shows the different transient waveforms of IAG with conventional ELC using six-pulse diode bridge rectifier. Initially, the consumer load is OFF and the ELC is consuming full 7.5 kW power to an auxiliary load. At 2s, a consumer load

that because of the nonlinear behavior of ELC due to six-pulse diode rectifier, the generator voltage and current are badly distorted,and when there is zero consumer load, situation becomes more Severe.

B. Proposed 12-pulse and 18-pulse ac–dc Converters

This section deals with the autotransformer arrangements for 12-pulse and 18-pulse ac–dc converters-based harmonic mitigators. Various issues related with the design of suitable autotransformers for these configurations alongwith the design intricacies of a reduced rating passive tuned filter for effective harmonic filtering is given here.

i. Design of the Proposed 12-Pulse AC–DC Converter

The detailed winding diagram of the autotransformer-based magnetics is shown in Fig.6 for a 12 pulse, and the vector diagram of the phase voltages is shown in Fig

The phase angle between supply voltages Va,Vb,Vc and converter 1 input voltages Va', Vb',Vc' is +150, and that between the supply voltages Va,Vb,Vc and converter 2 input voltages Va", Vb",Vc" is -150 resulting in 300 phase shift between the two converters input ac voltages, fulfiling the criterion for the 12-pulse rectification.

To ensure an independent operation of two rectifier groups, two interphase transformers (IPT), which are relatively small in size, are connected at the output of the rectifier bridges.

With this arrangement, the rectifier diodes conduct for 120 per cycle. Moreover, the autotransformer arrangement yields equal leakage reactance in series with each line of the rectifier bridges, which contributes to equal current sharing. A tuned passive shunt filter is connected at the input of the autotransformer.

To achieve the 12-pulse rectification, the following conditions have to be satisfied.

Two sets of balanced three-phase line voltages are to be produced at 300 out of phase with respect to each other.

The magnitude of these line voltages should be equal.

The supply voltages are fed to the autotransformer windings connected in star. From these voltages, two sets of three-phase voltages (phase shifted through +150 and -150) are produced. The number of turns required for +150 and -150 phase shift are calculated as follows.

Consider phase "a" voltages as

Va'= K1Va - K2Vb, Va" =K1Va - K2Vc…..(1)

The phasor diagram shown in Fig. 4 represents the relationship among various phase voltages. Assume the following set of voltages

$$V_a = V\angle 0^\circ, V_b = V\angle{-120^\circ}, V_c = V\angle 120^\circ$$
$$V_a' = V\angle{+15^\circ}, V_b' = V\angle{-105^\circ}, V_{c'} = V\angle 135^\circ$$
$$V_a'' = V\angle{-15^\circ}, V_b'' = V\angle{-135^\circ}, V_c'' = V\angle 105^\circ$$

where, V is the root mean square (rms) value of phase voltage. Using above equations, K1 and K2 can be calculated. These equations result in K1=0.816 and K2 =0.298 for the desired phase shift in the autotransformer. Thus,

$$V_a' = 0.816V_a - 0.298V_b, V_a'' = 0.816V_a - 0.298$$

Thus, the autotransformer uses two auxiliary windings per phase. A phase-shifted voltage (e.g., Va') is obtained by making the following arrangements:

tapping a portion (0.816) of "a" phase voltage;

connecting one end of approximately 0.298 of "b" phase voltage (e.g., Vb) to this tap.

ii. Design of the Proposed 18-Pulse AC–DC Converter

To achieve the 18-pulse rectification, the following conditions have to be satisfied.

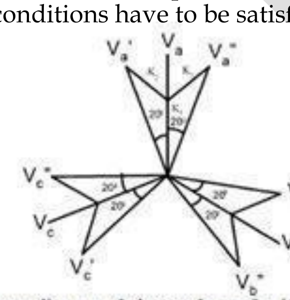


Fig 8 Vector diagram of phase voltages for 18-pulse-based proposed harmonic mitigator.

Three sets of balanced three-phase voltages are to be produced, which are 200 out of phase with respect to each other.

The magnitude of these line voltages should be equal.

Fig.8 shows the vector diagram of phase voltages for an 18-pulse converter. From the supply voltages, two sets of three-phase voltages(phase shifted through +200and -200) are produced. The number of turns required for +200and -200 phase shift are calculated as follows.

Consider phase "a" voltages a

The phasor diagram shown in Fig. 8 represents the relationship among various phase voltages. Assume the following set of voltages:

$$V_a = V\angle 0^\circ, V_b = V\angle{-120^\circ}, V_c = V\angle 120^\circ \quad (7)$$
$$V_a' = V\angle{+20^\circ}, V_b' = V\angle{-100^\circ}, V_c' = V\angle 140^\circ \quad (8)$$
$$V_a'' = V\angle{-20^\circ}, V_b'' = V\angle{-140^0}, V_c'' = V\angle 100^\circ \quad (9)$$

where V is the rms value of phase voltage.

Using the above equations, K1 and K2 can be calculated. These equations result in K1 =0.7421 and

K2 =0.395 for the desired phase shift in the autotransformer. Thus,

$$V_a' = 0.7421V_a - 0.395V_b,$$
$$V_a'' = 0.7421V_a - 0.395V_c \quad (10)$$

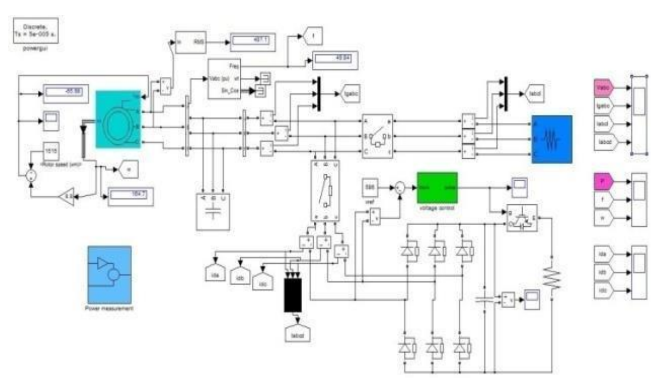
Thus, the autotransformer uses two auxiliary windings per phase. A phase-shifted voltage (e.g., Va') is obtained by using the following arrangements:

tapping a portion (0.7421) of "a" phase voltage;

connecting one end of approximately 0.395 of "b" phase voltage (e.g., Vb) to this tap.

Matlab Simulink Models and their Results

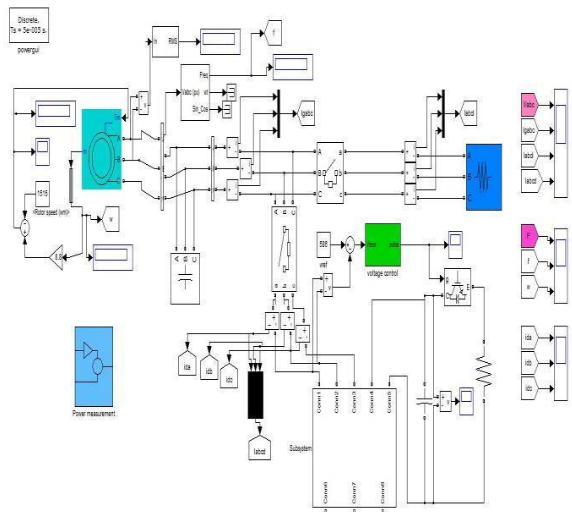
SIX PULSE ELECTRONIC LOAD CONTROLLER

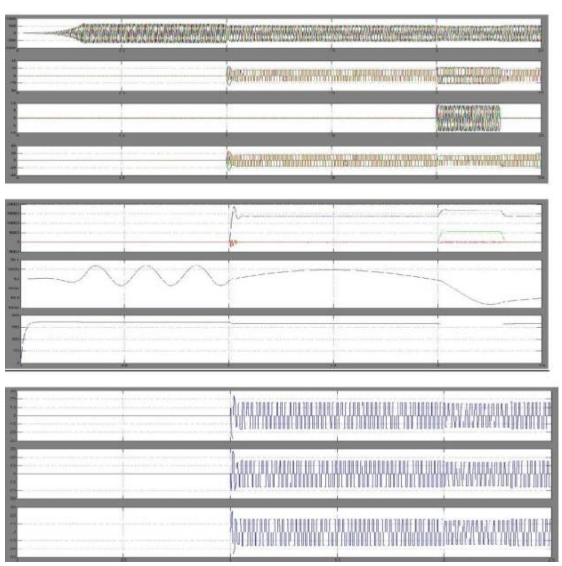


TWELVE PULSE ELECTRONIC LOAD

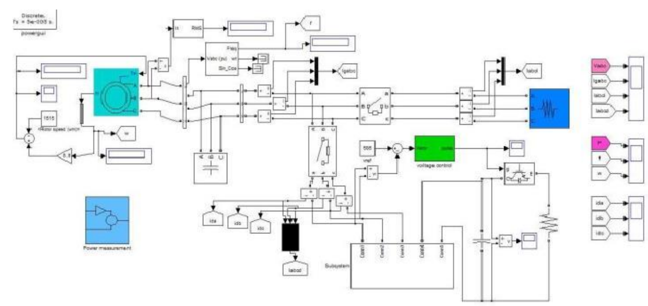
CONTROLLER AND OUTPUT

EIGHTEEN PULSE ELECTRONIC LOAD





CONTROLLER AND OUTPUT



1. Vabc 2. Igabc 3. Iabcl 4. Iabcd 5.Power 6. Freq 7. W(speed) 8. Ida 9. Idb

III. PROPOSED 24-PULSE ELC NFIGURATION

Fig. 2 shows the proposed reduced rating polygon connected autotransformer fed 24-pulse ac–dc-converter-based. ELC for an isolated pico-hydropower generation applications. This configuration needs one zero-sequence blocking trans- former (ZSBT) to ensure independent operation of the two rectifier bridges. It exhibits high impedance to zero-sequence currents, resulting in 120◦ conduction for each diode and also results in equal current sharing in the output. An interphase reactor tapped suitably to achieve pulse doubling has been connected at the output of the ZSBT. Two rectifiers output voltages Vd1 and Vd2 shown in Fig. 2 are identical but have a phase shift of 30◦ (required for achieving 12-pulse operation), and these voltages contain ripple of six times the source fre- quency. The rectifier output voltage Vd is given by

$$V_d = 0.5\,(V_{d1} + V_{d2}). \quad (1)$$

Similarly, the voltage across interphase reactor is given by

$$V_m = V_{d1} - V_{d2} \quad (2)$$

where Vm is an ac voltage ripple of 12 times the source fre-quency appearing across the tapped interphase reactor, as shown in Fig. 2. This pulse multiplication arrangement for diode bridge rectifiers has been used for desired pulse dou- bling for line current harmonic reduction. The ZSBT helps in achieving independent operation of the two rectifier bridges, thus eliminating the unwanted short conducting sequence of the rec-tifier diodes.

The ZSBT offers very high impedance for zero-sequence current components. However, detailed design of the interphase reactor and ZSBT has been given in and the same procedure is used in this paper. To achieve the 12-pulse rectification, the necessary requirement is the generation of two sets of line voltages of equal magnitude that are 30◦ out of phase with respect to each other (either ±15◦ or 0◦ and 30◦). From the generator terminal voltages, two sets of three-phase voltages (phase shifted through +15◦ and −15 ◦) are produced. The number of turns or voltage fraction across each winding of the autotransformer required for +15◦ and −15◦ phase shift is calculated by referring Fig. 3 as follows:

$$V_{NS1} = V_{NS2}. \quad (3)$$

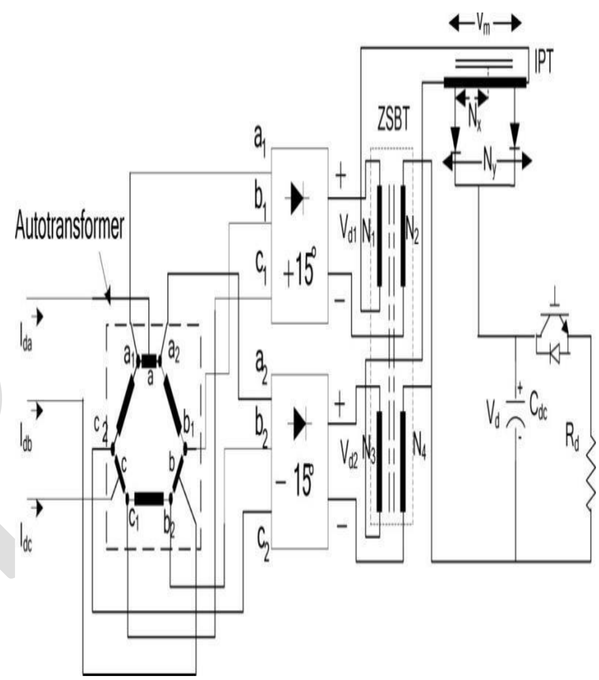


Fig. 2. Proposed 24-pulse ELC for

Where Vca is the vline voltage of 415 V The term VNs1 And V Ns2 Are the voltage induced across the winding and VNLL is the induced voltage across the long winding of polygon connected autotransformer . Detailed hardwere design of polygon connected autotransformer ,ZSBT, and interphase transformer (IPT) are Given in the Appendix along with the complete design of the proposed 24 pulse ELC.

IV. MATLAB-BASED MODELING

A 7.5 kW, 415 V, 50 Hz asynchronous machine is used as an IAG and the ELC is modeled using available power electronics blockset like diode bridge rectifier and a chopper with an aux-iliary resistive load and multiwinding transformers are used to create the desired phase shift for 24-pulse converter operation. Simulation is carried out in MATLAB version of 7.8 at discrete step of 1E−6. Detailed simulation and comparative analysis of both types of ELCs are given in following sections.

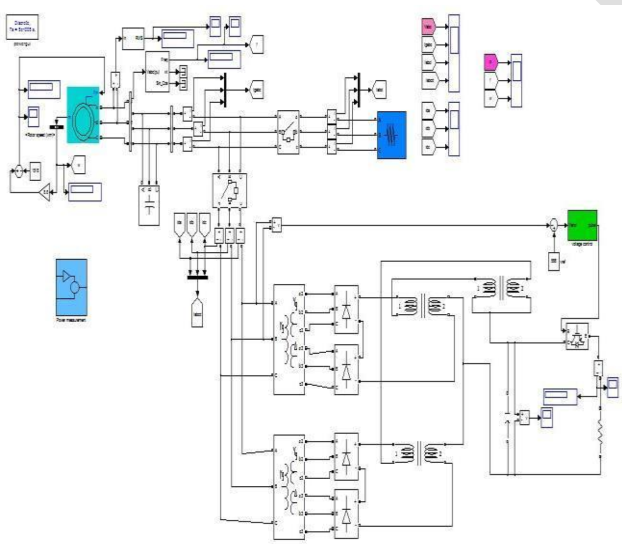


Fig. 6. Simulink model of IAG system configuration and control strategy of a chopper switch in a 24-pulse diode bridge ELC.

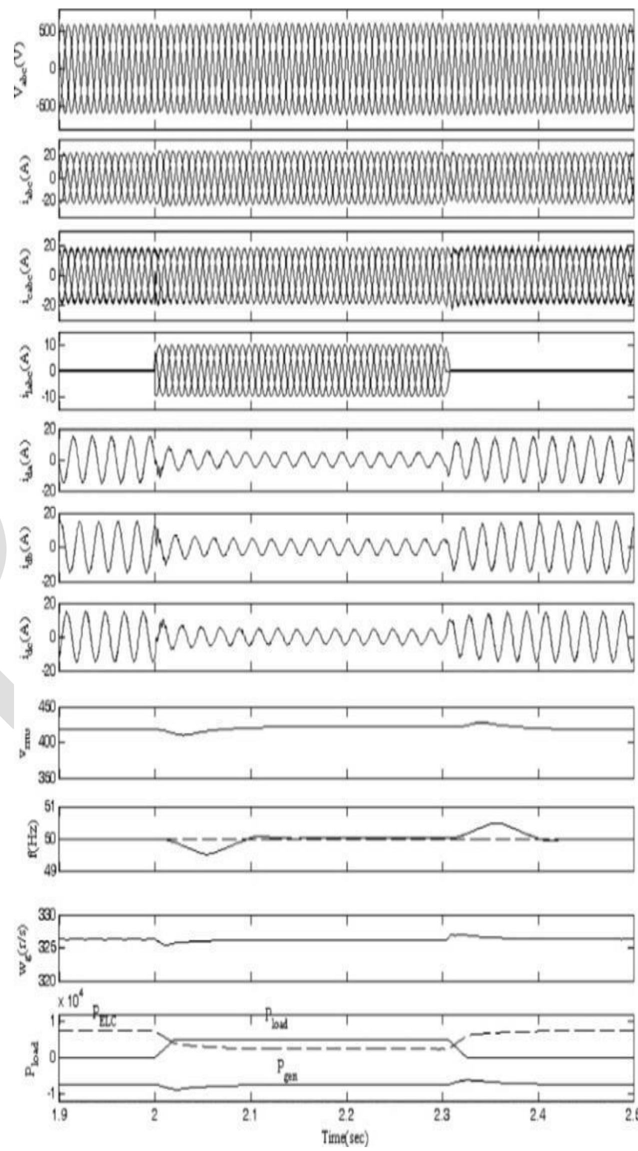


Fig. 7. Simulated transient waveforms on application and removal of consumer load using 24-pulse diode bridge rectifier-based ELC.

B. Performance of Proposed 24-Pulse ELC

Fig. 6 shows Simulink model of IAG system configuration and control strategy of a chopper switch in a 24-pulse diode bridge ELC and fig.7 show the transient waveforms of IAG using 24-pulse rectifier based ELC. In similar manner of conventional ELC, the proposed ELC controls the constant power at generator terminal with variation of consumer loads. Here, it is observed that the voltage and frequency are maintained at constant value, and at the same time, the distortion in the generator voltage and current is negligible compared to conventional ELC. Fig.7 shows the harmonic spectra of the ELC current, generator voltage, and generator current, which shows that because of 24-pulse operation of an ELC, its performance is improved in comparison to conventional ELC and the distortion in voltage and current of the generator is observed almost negligible which is 0.42% and 0.47%, respectively

CONCLUSION

The proposed ELC has been realized using 24-pulse con-verter and a chopper. A comparative study of both types of ELCs (6-pulse and 12 pulse and 18 pulse and 24-pulse configured ELC) has been demonstrated on the basis of simulation using standard software MATLAB and developing a hardware prototype in the laboratory environment. The proposed 24-pulse ELC has given improved performance of voltage and frequency regulation of IAG with negligible har-monic distortion in the generated voltage and current at varying consumer loads.

APPENDIX :

A.Parameters of 7.5kw, 415v, 50Hz, Y-Connected,

Four Pole Asynchronous Machine

Rs = 1Ω, Rr = 0.77Ω, Ls = Lr = 4.77e-3H

J = 0.1384kg.m2 Lm = 0.134H

B. Prime Mover Characteristics for 7.5kw Machine

Tsh = K1ωm–K2, K1 = 8.8, K2 = 1515

Auxiliary Load Equation Resistive load R = VL2/PL consumer Load Resistive load = 5kw

MAGNETICS RATING:

12-pulse-based converter: Autotransformer rating 12Kva, Interphase transformers 2.7kVA, passive filter 3kVA. 18-pulse-based converter: Autotransformer rating 9.8kVA, Interphsae transformers 2.1kVA, passive filter 1.5kVA.

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