Hybrid Neuro Fuzzy Control Based Isolated Asynchronous Generation Connect to Non-Linear Load

L. Dinesh B. Raja sekhar L. Vijay
Assistant Professor, Department of Electrical and Electronics Engineering, ANITS College, Sangivalasa, Andhra Pradesh, India

Abstract
This paper deals with a hybrid neuro fuzzy control to isolated asynchronous generator (IAG) connected to non linear load. The proposed method 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 modeled 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
Keywords: Adaptive linear element (adaline), integrated electronic load controller (IELC), isolated asynchronous generator(IAG), small hydro generation, small hydropower generation, fuzzy.

1. INTRODUCTION

Because of increasing concerns for the growing demand of electrical energy and the fast depletion of fossil fuels, the need for low-cost stand-alone generating plants becomes inevitable in remote locations. Electricity generation from locally available small hydro heads, wind, and solar-energy sources is an alternate solution for environment-friendly energy generation.The reduction in cost may be obtained by utilizing run-of-the-river schemes and an integrated electronic load controller (IELC) to regulate the inherent voltage and frequency in isolated asynchronous generators (IAGs) for small hydro applications. The asynchronous generators are preferred as compared with synchronous generators due to the advantages of low

cost, ruggedness, brushless-rotor construction with least maintenance, and no requirement for a dc supply. As the asynchronous machine is isolated, its reactive power is supplied by a voltampere reactive (VAR) generating unit connected across its terminals, which is generally met by capacitor banks. The rating of a capacitor bank is so selected that when driven at rated speed, it should produce the rated voltage at no load . Major setbacks of such stand-alone small hydroelectric power generation systems are the regulation of terminal voltage and frequency under load perturbations compared with any other conventional generators, along with power-quality problems. Therefore, the use of an IELC with a suitable control scheme becomes necessary for an uncontrolled small hydro turbine-driven generator for power generation

In this paper, the control strategy is a neural-network (NN)- based least mean square (LMS) known as adaptive linear element (adaline) algorithm of an IELC, which has capability of controlling the voltage and its frequency in an integrated manner. The adaline is used to extractthe positive-sequence fundamental-frequency component of the load currents to estimate the reference source currents through tracking of the unit vectors together with tuning of the weights.

The dc-bus voltage of the voltage-source converter (VSC) of IELC with this type of control strategy is less sensitive to load fluctuations. IELC is used to control the active power (indirectly, to control the frequency) and the reactive power (to control the terminal voltage) of the IAG, and the six-leg VSC also acts as a harmonic eliminator and a load balancer. A set of zigzag three single-phase transformers is used to adjust the voltage to bring the dc-link voltage to an optimum
level. The advantage of using the zigzag transformer is to mitigate the zero-sequence currents and triplen harmonics in the primary winding itself, thus reducing the rating of the devices of the VSC. The reduction in the kilo volt ampere rating of the VSC is on the order of 14% as compared with three singlephase VSC topology without the zigzag transformer, and its neutral terminal is used for nonlinear and linear unbalanced loads where the neutral current is compensated in the primary windings of the zigzag/three single-phase transformers, keeping the secondary windings free from zero-sequence currents and triplen-harmonic currents. A unipolar switching is used in case of the six-leg VSC (consisting of three H-bridge VSCs), which has the advantage of effecting the doubling of the switching frequency of a pulsewidthmodulation (PWM) voltage as compared with bipolar switching, which is used in a three-phase three-leg VSC for any given switching frequency. In a four-leg VSC topology, the fourth-leg rating is observed on the order of 150% of the other three legs.

with nonlinear loads, and the overall VSC rating is larger compared with this proposed topology due to the flow of zero-sequence currents and triplen-harmonic currents into the VSC. In a three-leg VSC with midpoint-capacitor topology, the balancing of the voltages of the capacitors is a complicated task. Additional PWM circuit, voltage sensor, current sensor, and analog-to-digital converter channels are required in the four-leg VSC topology and the three-leg VSC with midpoint-capacitor topology.

II. SYSTEM CONFIGURATION AND PRINCIPLE OF OPERATION

The complete stand-alone system with an asynchronous generator, an excitation capacitor, linear and nonlinear consumer loads, and the proposed IELC is shown in Fig. 1. The proposed IELC is an arrangement of six-leg insulated-gate bipolar junction- transistor-based VSC along with a dc-bus capacitor, a chopper switch, and an auxiliary load on its dc link. The IELC is connected at the point of common coupling (PCC) through the interfacing inductors. The dc-bus capacitor is used to reduce the voltage ripples and provides a self-supporting dc bus for the VSC. A three-phase star-connected capacitor bank is used for the VAR requirement of the IAG, and the value of this capacitor bank is selected to generate the rated voltage at no load. The IAG generates constant power, and when consumer-load power changes, the dc chopper of the IELC consumes the difference in the active power (i.e., the generator and the load) by the auxiliary load. The IELC regulates the terminal voltage due to changes in consumer loads. Thus, the voltage and the frequency of an IAG system are not affected and remain constant during frequent changes in the consumer loads.

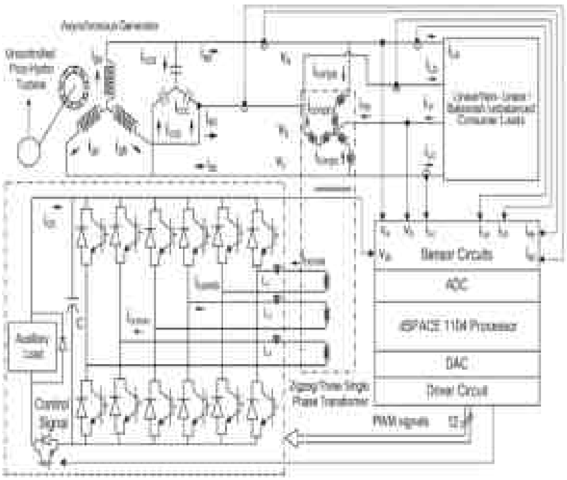

Fig. 1. Schematic diagram of IAG with IELC (consisting of six-leg VSC, auxiliary load, and zigzag/single-phase transformer).

Fig. 2 shows the NN-based control strategy of an IELC with the constant excitation capacitor of the IAG driven by uncontrolled small hydro turbine. This NN-based control strategy uses LMS algorithm and is also known as an adaline algorithm for the control of the IELC, which performs the estimation of reference source currents. The estimation of reference source currents is carried out using an adaline, which is a simple and fast method of fundamental load-current extraction. Six adalines are used to extract the three-phase positive-sequence fundamental-frequency active and reactive component of the load currents. The adaline algorithm with an online calculation of weights responds well for severe load changes. The $p-q$ and synchronous reference frame (SRF) theories need reasonable transformations and computations compared with this adaline-based technique. The other advantage of using an adaline-based technique is that it does not need low-pass filters, thus further reducing the computational burden. The proposed controller is simpler than the $p-q$ and SRF techniques.

CONTROL STRATEGY:

Fig. 1 shows the adaline-based control algorithm of the proposed IELC to regulate the frequency and voltage of the IAG. The basic equations of this control algorithm are given as follows.

A. In-Phase Component of Reference Source Currents:

Because the three-phase voltages at the IAG terminals (*va*, *b*, and *vc*) are considered sinusoidal, their amplitude is computed as

$$V_t = \{(2/3)\,(v_a^2 + v_b^2 + v_c^2)\}^{1/2}. \qquad (1)$$

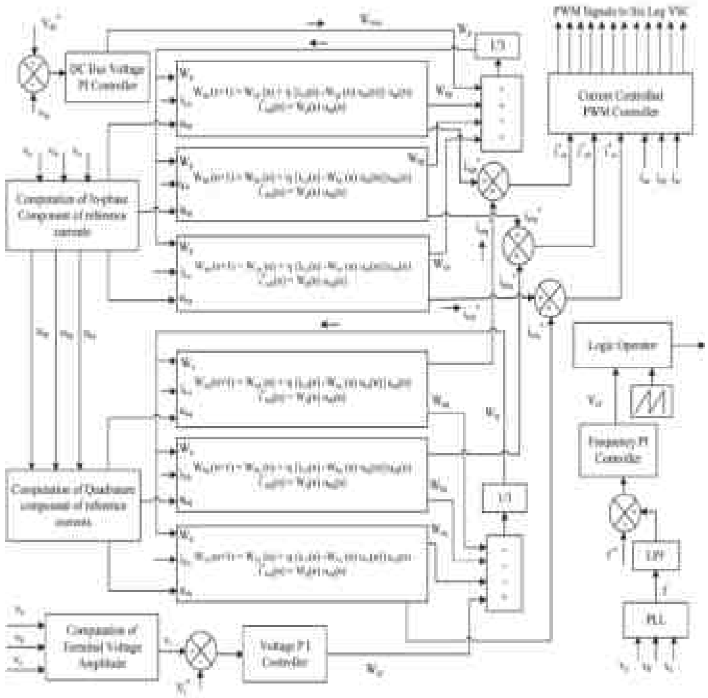

Fig. 2. Adaline control algorithm.

The unit vector in phase with *va*, *vb*, and *vc* are derived as

$$u_{ap} = v_a/V_t \quad u_{bp} = v_b/V_t \quad u_{cp} = v_c/V_t. \qquad (2)$$

The error in the dc-bus voltage of the VSC (*V*dcer(*n*)) of IELC at *n*th sampling instant is

$$V_{dcer(n)} = V^*_{dc(n)} - V_{dc(n)} \qquad (3)$$

where $V*dc(n)$ is the reference dc voltage and $Vdc(n)$ is the sensed dc-link voltage of the VSC.
The output of the proportional–integral (PI) controller for maintaining the dc-bus voltage of the VSC of the IELC at the *n*th sampling instant is expressed as

$$W_{loss(n)} = W_{loss(n-1)} + K_{pd}\{V_{dcer(n)} V_{dcer(n-1)}\} + K_{id}V_{dcer(n)} \qquad (4)$$

where *W*loss(*n*) is considered as part of the active-power component of the source current. *Kpd* and *Kid* are the proportional and integral gain constants of the dc-bus PI voltage controller.
Therefore, the average weight of the fundamental reference active-power component of the source current is given as

$$W_p(n) = \{W_{loss}(n) + W_{ap}(n) + W_{bp}(n) + W_{cp}(n)\}/3. \qquad (5)$$

The extraction of the weights of the fundamental activepower component of the load currents is based on LMS algorithm and its training through adaline. The weights of the active-power component of the three-phase load currents are estimated as

$$W_{ap}(n+1) = W_{ap}(n) + \eta\{i_{La}(n) - W_{ap}(n)u_{ap}(n)\}\, u_{ap}(n) \quad (6)$$

$$W_{bp}(n+1) = W_{bp}(n) + \eta\{i_{Lb}(n) - W_{bp}(n)u_{bp}(n)\}\, u_{bp}(n) \quad (7)$$

$$W_{cp}(n+1) = W_{cp}(n) + \eta\{i_{Lc}(n) - W_{cp}(n)u_{cp}(n)\}\, u_{cp}(n). \quad (8)$$

η is the convergence factor, and it decides the rate of convergence and accuracy of estimation. The η value is so selected to make a tradeoff between the accuracy and the rate of convergence. The weight of the active-power component of the three-phase load currents are extracted using adaline in each phase. The observed practical value of η varies between 0.01 and 1.0. The three-phase fundamental reference active-power component of the source currents are computed as

$$i^*_{sap} = W_p u_{ap} \quad i^*_{sbp} = W_p u_{bp} \quad i^*_{scp} = W_p u_{cp}. \qquad (9)$$

B. Quadrature Component of Reference Source Currents:

The unit vectors in quadrature with *va*, *vb*, and *vc* may be derived using a quadrature transformation of the in-phase unit vectors *uap*, *ubp*, and *ucp* as

$$u_{aq} = -u_{bp}/\sqrt{3} + u_{cp}/\sqrt{3} \qquad (10)$$

$$u_{bq} = \sqrt{3}\, u_{ap}/2 + (u_{bp} - u_{cp})/2\sqrt{3} \qquad (11)$$

$$u_{cq} = -\sqrt{3}\, u_{ap}/2 + (u_{bp} - u_{cp})/2\sqrt{3}. \qquad (12)$$

The amplitude of the IAG terminal voltage and its reference value (*V*tref) are fed to a PI voltage controller. The voltage error *V*er is the amplitude of the ac voltage at the *n*th sampling instant

$$V_{er(n)} = V_{tref(n)} - V_{t(n)}. \qquad (13)$$

The output of the PI controller (*W*qv*(*n*)) for maintaining the amplitude of the ac terminal voltage to a constant value at the *n*th sampling instant is expressed as

$$W_{qv(n)} = W_{qv(n-1)} + k_{pa}\left\{V_{e(n)} - V_{e(n-1)}\right\} + k_{ia} V_{e(n)} \qquad (14)$$

where *Kpa* and *Kia* are the proportional and integral gain constants of the PI controller, *V*er(*n*) and *V*er(*n*−1) are the voltage errors in the *n*th and (*n* − 1)th instants, and *Wqv*(*n*−1) is the amplitude of the quadrature component of the reference fundamental current at (*n* − 1)th instant.

The weights of the reactive-power component of the three phase load currents are estimated as

$$W_{aq}(n+1) = W_{aq}(n) + \eta\left\{i_{La}(n) - W_{aq}(n)u_{aq}(n)\right\}u_{aq}(n) \qquad (15)$$

$$W_{bq}(n+1) = W_{bq}(n) + \eta\left\{i_{Lb}(n) - W_{bq}(n)u_{bq}(n)\right\}u_{bq}(n) \qquad (16)$$

$$W_{cq}(n+1) = W_{cq}(n) + \eta\left\{i_{Lc}(n) - W_{cq}(n)u_{cq}(n)\right\}u_{cq}(n). \qquad (17)$$

Therefore, the average weight of the fundamental reference reactive components of the generator currents is given as

$$W_q(n) = \left[W_{qv}(n) - \{W_{aq}(n) + W_{bq}(n) + W_{cq}(n)\}\right]/3. \qquad (18)$$

The three-phase fundamental reference reactive-power components of the currents of IAG are given as

$$i^*_{saq} = W_q u_{aq} \quad i^*_{sbq} = W_q u_{bq} \quad i^*_{scq} = W_q u_{cq}. \qquad (19)$$

C. Reference Source Currents:

The total reference source currents are the sum of the in phase and the quadrature components of the reference source currents as

$$i^*_{sa} = i^*_{saq} + i^*_{sap} \qquad (20)$$

$$i^*_{sb} = i^*_{sbq} + i^*_{sbp} \qquad (21)$$

$$i^*_{sc} = i^*_{scq} + i^*_{scp}. \qquad (22)$$

These reference source currents (*i* sa*, *i* sb*, and *i* sc*) are compared with the sensed source currents (*isa*, *isb*, and *isc*). The current errors are computed as

$$i_{saerr} = i^*_{sa} - i_{sa} \quad (23)$$

$$i_{sberr} = i^*_{sb} - i_{sb} \quad (24)$$

$$i_{scerr} = i^*_{sc} - i_{sc}. \quad (25)$$

These currents errors are amplified using the proportional controller by a gain "*K*" and which is given as

$$V_{cca} = K\ i_{saerr} \quad (26)$$

$$V_{ccb} = K\ i_{sberr} \quad (27)$$

$$V_{ccc} = K\ i_{scerr}. \quad (28)$$

These amplified current-error signals (*Vcca, Vccb, Vccc*) are compared with fixed-frequency (10-kHz) triangular wave to generate unipolar PWM switching signals to generate the gating signals for the six-leg VSC (each phase consists of three H-bridge VSCs) of the IELC. For switching on the H-bridge VSC of phase "a," the basic logic is

$$\begin{Bmatrix} V_{cca} > V_{tri}(\text{upper device of the left leg of phase a on}) \\ V_{cca} \le V_{tri}(\text{lower device of the left leg of phase a on}) \end{Bmatrix} \quad (29)$$

$$\begin{Bmatrix} -V_{cca} > V_{tri}(\text{upper device of the right leg of phase a on}) \\ -V_{cca} \le V_{tri}(\text{lower device of the right leg of phase a on}) \end{Bmatrix} \quad (30)$$

where *V*tri is taken as the instantaneous value of the fixed frequency triangular wave, and a similar logic is applied to generate the gating signals for the other two phases.

The frequency error of the IAG voltage is defined as

$$f_{er}(n) = f^*_{(n)} - f_{(n)} \quad (31)$$

where *f** is the reference frequency (50 Hz in the present system) and "*f*" is the frequency of the voltage of the IAG. The instantaneous value of *f* is estimated using the phase-locked loop over the ac terminal voltages (*va*, *vb*, and *vc*), as shown in Fig. 2.

III. FUZZY CONTROLLER

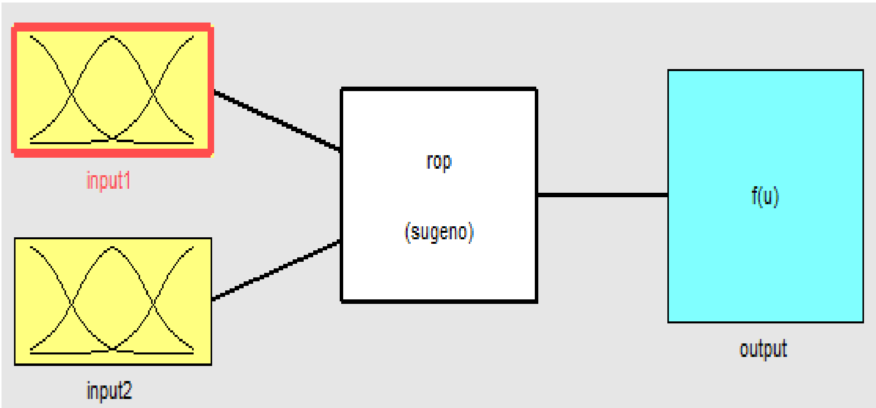

Fig 3. Fuzzy Inference System Editor.

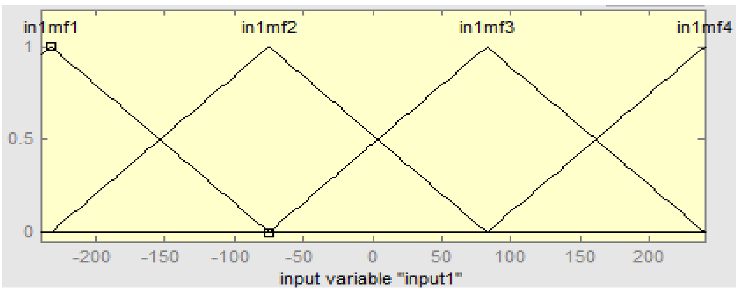

Fig 13. Membership Function of Input1

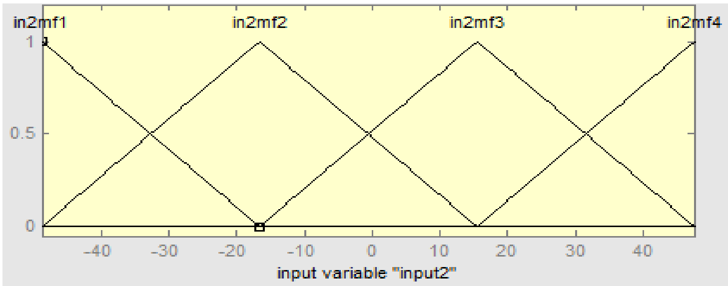

Fig 4. Membership Function of Input2

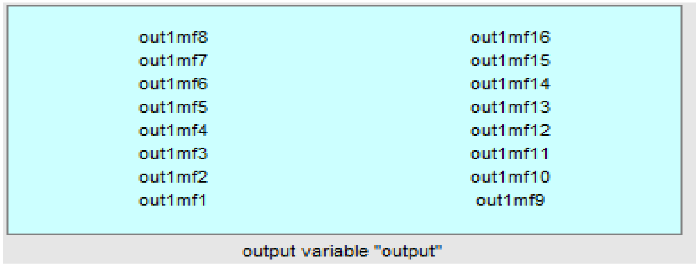

Fig 5. Membership Function of Output

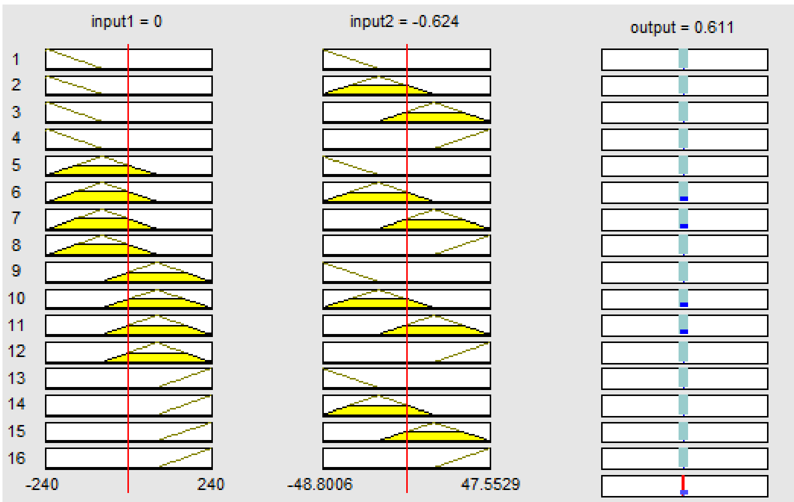

Fig 6. Rule View Editor

IV MATLAB IMPLEMENTATION

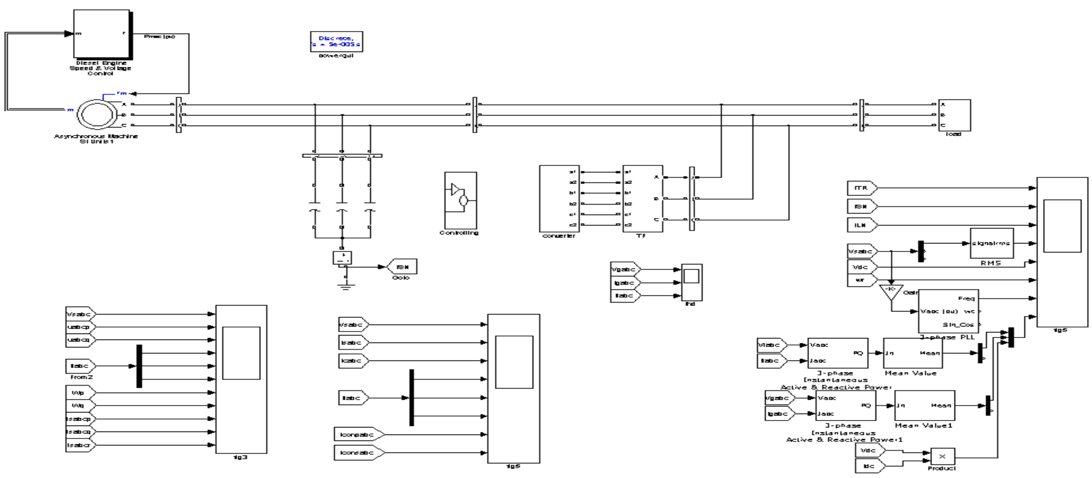
Fig 7.Matlab diagram of IAG with IELC.

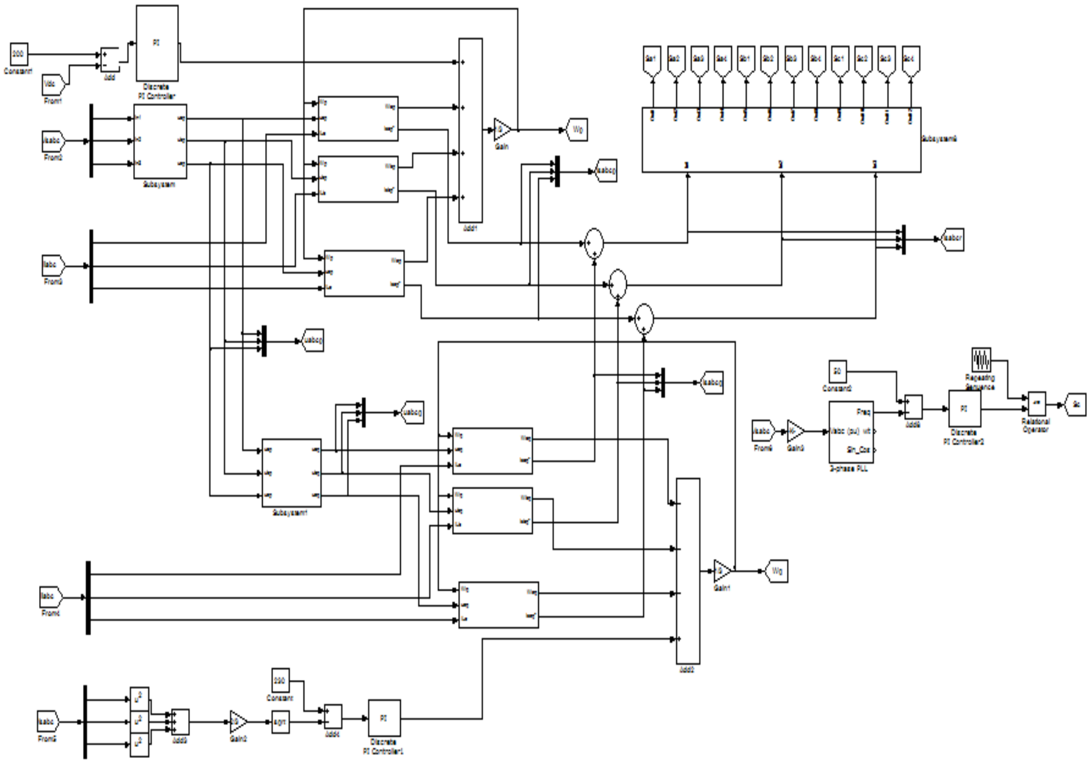

Fig. 8.ANN Load Control With PI Controller

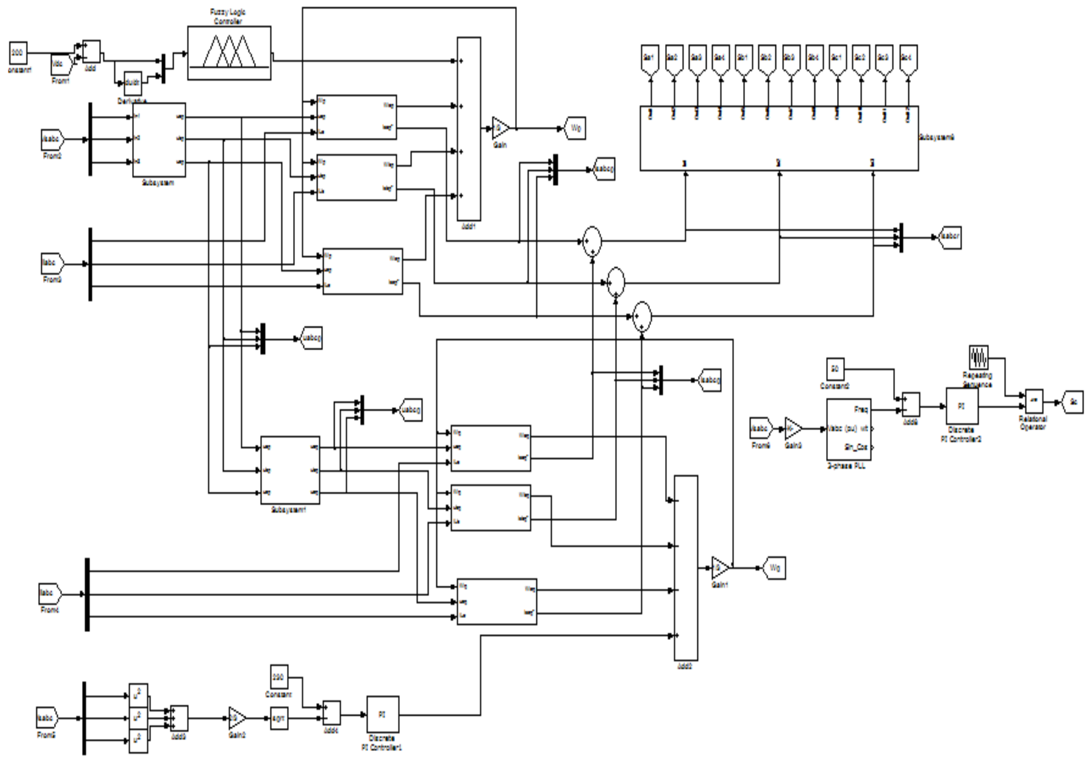

Fig. 9.ANN Load Control With FUZZY Controller

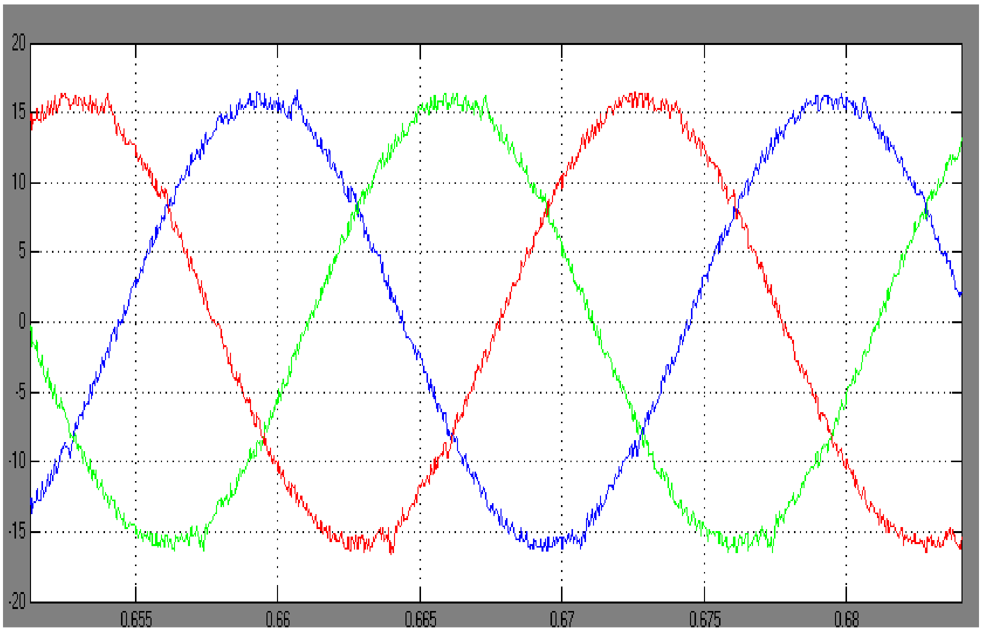

Fig. 10. Source Current With PI Controller

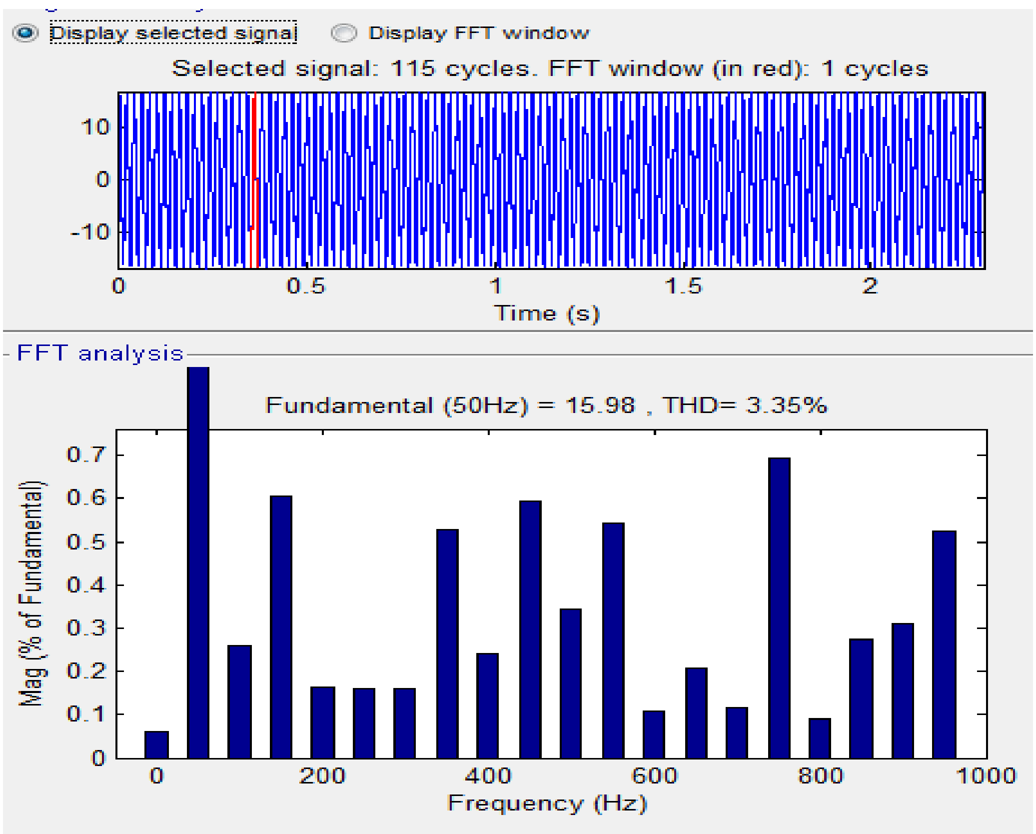

Fig 11.THD of Source Current with PI controller Compensation

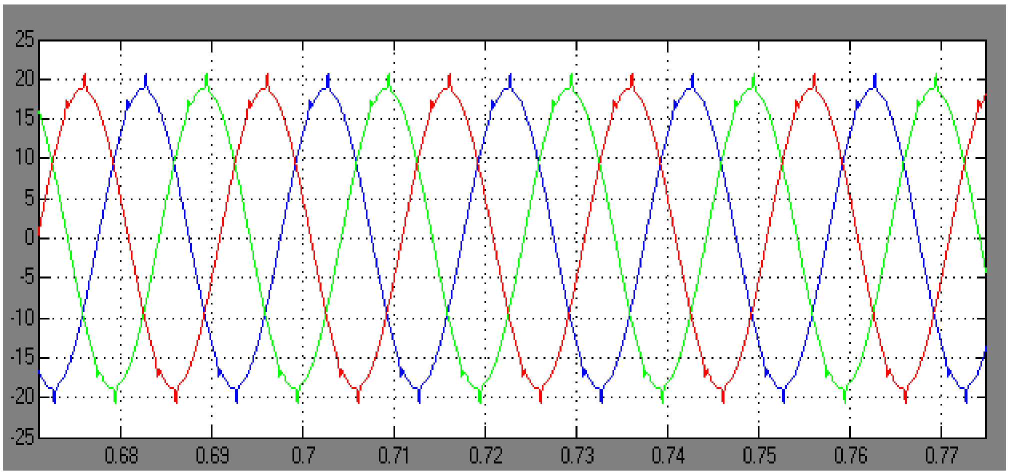

Fig 12. Source Current With Fuzzy Controller

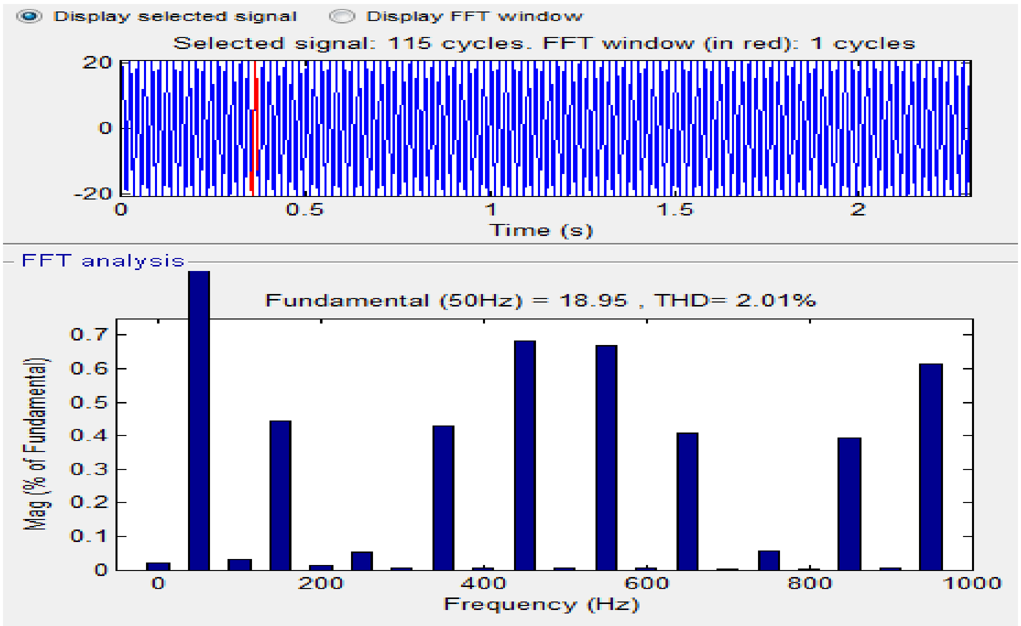

Fig.13.THD of Source Current Fuzzy Controller

Conclusions

A stand-alone uncontrolled hydro turbine-driven asynchronous generator has been modeled, and its performance has been simulated with an adaline-based control algorithm of an IELC. The performance of the IAG has been studied under different loading conditions to demonstrate the capability of the proposed IELC with **NN-based control algorithm**. It was observed that the IELC results in a satisfactory performance under different loading conditions along with the frequency and its voltage control, load balancing, and **harmonic elimination** of three-phase four-wire loads. This type of controller was found to be simple, easy to control, and less sensitive to load perturbations. A PI controller is used for dc bus voltage to track the error, the harmonics reduced up to 3.35 % and a fuzzy controller is replaced with PI controller, the harmonics reduced to 2.01%.

References

[1] J. B. Ekanayake, “Induction generators for small hydro schemes,” *Power Eng. J.*, vol. 16, no. 2, pp. 61–67, Apr. 2002.
[2] J. M. Elder, J. T. Boys, and J. L. Woodward, “Self-excited induction machine as a low cost generator,” *Proc. Inst. Elect. Eng.*, vol. 131, pt. C, no. 2, pp. 33–40, Mar. 1984.
[3] S. Rajakaruna and N. N. Maw, “Unregulated performance of an induction generator in an isolated micro hydro power plant,” in *Proc. 7th IPEC*, Nov. 29–Dec. 2, 2005, pp. 1–6.
[4] J. Bjornstedt and O. Samuelsson, “Voltage and frequency control for island operated induction generators,” in *Proc. IET CIRED Smart Grids Distrib. Conf.*, 2008, pp. 1–4.
[5] G. Dastagir and L. A. C. Lopes, “Voltage and frequency regulation of a stand-alone self-excited induction generator,” in *Proc. IEEE Elect. Power Conf.*, Montreal, QC, Canada, Oct. 2007, pp. 502–506.
[6] F. Profumo, B. Colombo, and F. Mocci, “A frequency controller for induction generators in stand-by mini hydro power plants,” in *Proc. IEEE Elect. Mach. Drives Conf.*, Sep. 1989, pp. 256–260.

[7] Y. Zidani and M. Naciri, "A numerical analytical approach for the optimal capacitor used for the self excited induction generator," in *Proc. Power Electron. Spec. Conf.*, Jun. 2001, vol. 1, pp. 216–220.
[8] B. Singh, G. K. Kasal, and S. Gairola, "Power quality improvement in conventional electronic load controller for an isolated power generation," *IEEE Trans. Energy Convers.*, vol. 23, no. 3, pp. 764–773, Sep. 2008.
[9] W. Jun and Y. Bo, "A novel electronic load controller: Theory and implementation," in *Proc. ICEMS*, 2001, vol. 2, pp. 1276–1278.
[10] J. M. Ramirez and M. E. Torres, "An electronic load controller for the self-excited induction generator," *IEEE Trans. Energy Convers.*, vol. 22, no. 2, pp. 546–548, Jun. 2007.

BIBILOGRAPHY

Lakhinana Dinesh born in 1989, in India. He received B.Tech degree in Electrical & Electronics Engineering from JNTU, Kakinada, India in 2010 and M.Tech degree from GITAM University in Power Systems & Automation, in 2012. His research interest includes Applications of Power Electronics to Power Systems, Power Quality, Power System Operation & Control, Power System Stability & Analysis.

Currently he is working as Assistant Professor in the Department of Electrical and Electronics Engg., Anil Neerukonda Institute of Technology & Sciences, Andhra University, India.

B Raja sekhar born in 1983, in India. He received B.Tech degree in Electrical & Electronics Engineering from Acharya Nagarjuna University, India in 2009 and M.Tech degree from Andhra University in Control systems. His research interest includes Applications of electrical technology, network theory.

Currently he is working as Assistant Professor in the Department of Electrical and Electronics Engg., Anil Neerukonda Institute of Technology & Sciences, Andhra University, India.

L Vijay born in 1981, in India. He received B.Tech degree in Electrical & Electronics Engineering from JNTU, Kakinada, India in 2010 and M.Tech degree from Andhra University in Control systems.. His research interest includes electrical machines, control systems, network theory.

Currently he is working as Assistant Professor in the Department of Electrical and Electronics Engg., Anil Neerukonda Institute of Technology & Sciences, Andhra University, India