Harmonic Reduction on Wind Energy Source with Custom Power Device

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Abstract: This project deals with 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 based distributed facts control 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 compensation. The results are compared with fuzzy based custom power device.

KEYWORDS: Active power filter (APF), ANN, Integrated Electronic Load Controller (IELC), Fuzzy logic controller.

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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 extract

the 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.

ASYNCHRONOUS GENERATORS AT SMALL HYDRO POWER STATIONS

Small hydroelectric power stations occupy a certain place in the energy balance of the country. Small hydroelectric power stations improve water supply of settlements, they are an important element of the system intended for creation of safe and favorable environment, as well as provide positive social impact. However, the pace of development of small hydropower stations nowadays is constrained by several economic and technical factors.

One of these factors is the type of generators installed at small hydroelectric power stations. They may be either synchronous or asynchronous machines. In a number of countries asynchronous generators(AG) are widely used for conversion of energy in installations of renewable power(especially wind power). Experience shows that for hydroelectric power stations with small installed capacity they have significant advantages over synchronous generators. This is due primarily to low cost, simplicity of construction and operation under normal conditions, resistance to external accidents, significant resource.

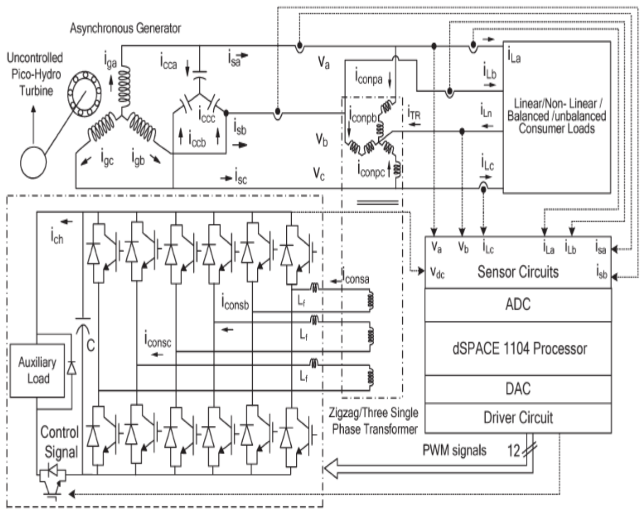

Fig. 1. Schematic diagram of IAG with IELC (consisting of six-leg VSC, auxiliary load, and zigzag/single-phase transformer).

But these generators have several disadvantages: inability to regulate voltage and reactive power consumption, emergence of active power fluctuations while rotor sliding, reactive power load surge during the start-up of the unit, the negative impact of which on the electrical distribution network is significantly increased with the increase of single power u.

This paper is devoted to investigation of operation modes of small hydropower stationsOperations with (AG) by reactive power in distributive networks.

ARTIFICIAL NEURAL NETWORKS

Artificial Neural Networks are relatively crude electronic models based on the neural structure of the brain. The brain basically learns from experiences. It is natural proof that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modeling also promises a less technical way to develop machine solutions. These biologically inspired methods of computing are thought to be the next major advancement in the computing industry. Even simple animal brains are capable of functions that are currently impossible for computers. Computers do rote things well, like keeping ledgers or performing complex math. But computers have trouble recognizing even simple patterns much less generalizing those patterns of the past into action of the future

Now, advance in biological research promise an initial understanding of the natural thinking mechanism. This research shows that brain stores information, as patterns. Some of these patterns are very complicated and allow us the ability to recognize individual faces from any different angles. This process of storing information as patterns, utilizing those patterns, and then solving problems encompasses a new field in computing. This field does not utilize traditional programming but involves the creation of massively parallel networks and the training of those networks to solve specific problems. This field also utilizes words very different from traditional computing, words like behave, react, self-organize, learn, generalize, and forgot. An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms neural networks are non-linearstatisticaldata modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. A neural network is an interconnected group of nodes, akin to the vast network of neurons in the human brain.

A. ARTIFICIAL NEURONS AND HOW THEY WORK

The fundamental processing element of a neural network is neurons. This building block of human awareness encompasses a few general capabilities. Basically, biological neurons receive inputs from other sources, combine them in some way, perform a generally nonlinear operation on the result, and then output the final result. Within humans there are many variations on this basic type of neurons, further complicating man's attempts at electrically replicating the process of thinking. Yet, all natural neurons have the same four basic Components. These components are known by their biological names – dendrites, soma, axon, and synapses. Dendrites are hair-like extensions of the soma which act like input channels. These input channels receive their input through the synapses of other neurons. The soma then processes these incoming signals over time. The soma then turns that processed value into an output which is sent out to other neurons through the axon and the synapses

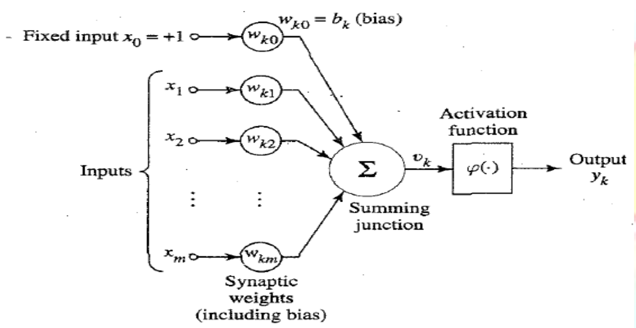

Fig 2: Artificial Neural Networks

Where x1, x2…..Xm are the m inputs
Wk1 , Wk2,…. Wkm are weights attached to the input links
For the above model

$$Uk = \sum_{j=1}^{m} (\text{Wkj Xj}) \qquad (6.1)$$

$$\text{Vk} = Uk + \text{bk} \qquad (6.2)$$

The bias bk has the effect of increasing or lowering the input of the activation function.

$$yk = \phi(\text{Uk} + \text{bk}) \qquad (6.3)$$

The weighted output signal vk is passed through an activation function and compared. If the output is greater than the activation function then vk is passed to the cell body(system) which is used to perform the required activity

CONTROL STRATEGY

Fig. 3 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

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

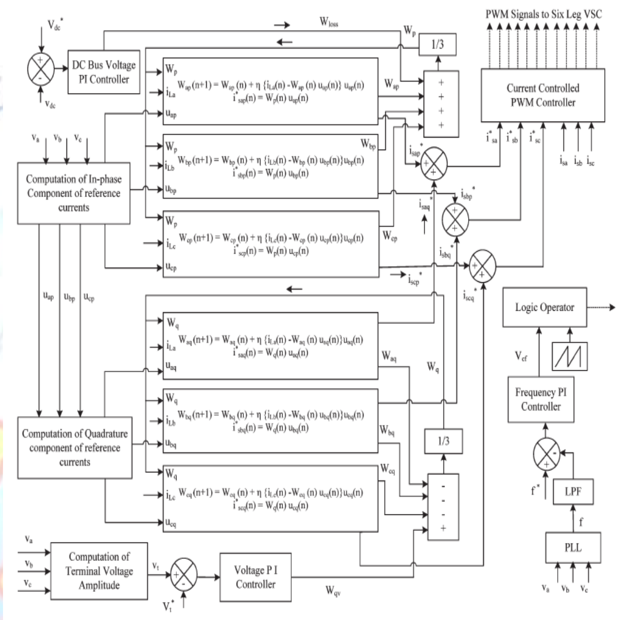

Fig.3. Adaline control algorithm.

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

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

where *V* ∗dc(*n*) is the reference dc voltage and *V*dc(*n*) is the senseddc-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

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

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

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

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 referenceactive-power component of the source currents are computed as

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

B. Quadrature Component of Reference Source Currents:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

MATLAB SIMULINK CIRCUITS AND RESULTS

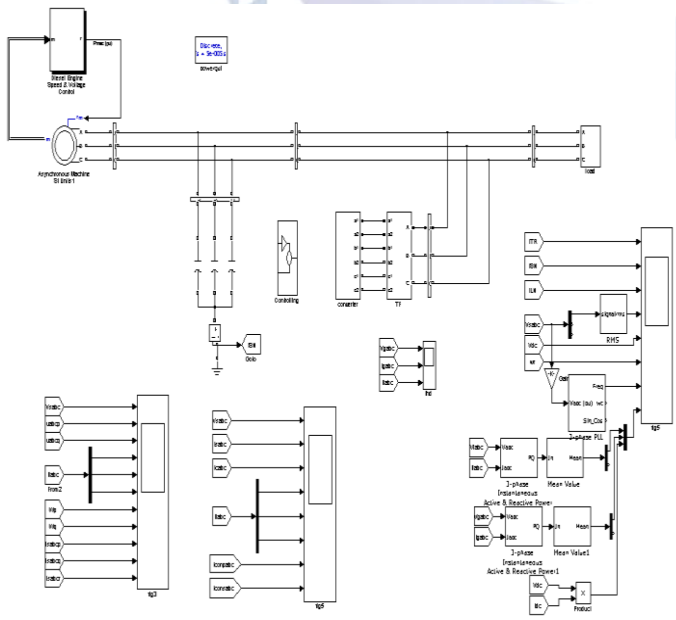

Fig.4. Simulink model of custom power device control with wind source

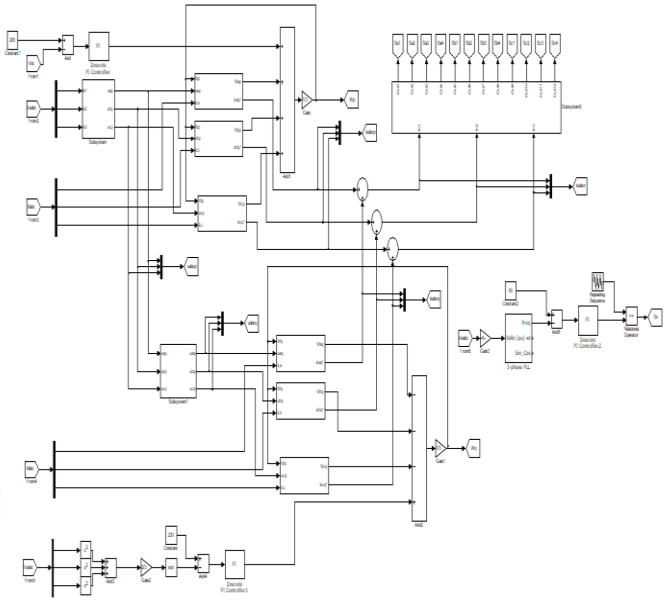

Fig.5. Simulink model of PI controlled custom power device

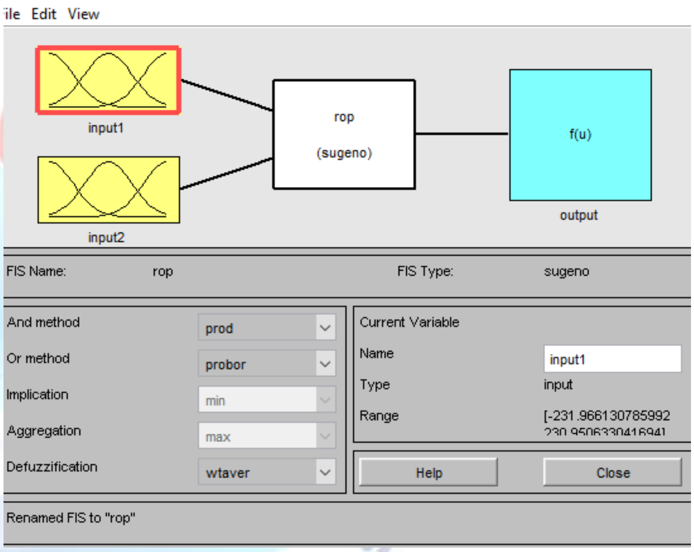

Fig.6. Fuzzy FIS system

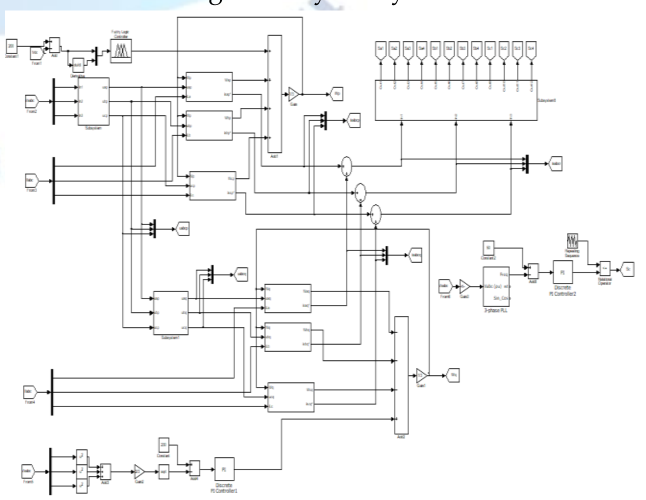

Fig.7. Simulink model of fuzzy controlled custom power device

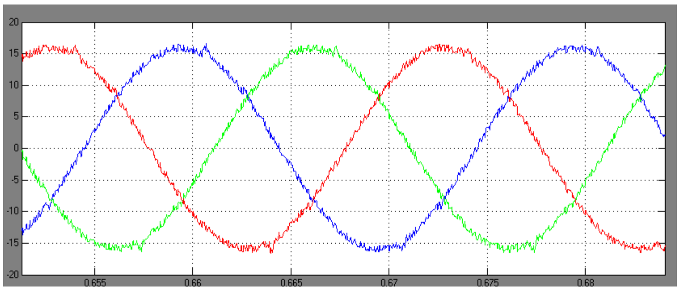

Fig.8. Source current using PI controller

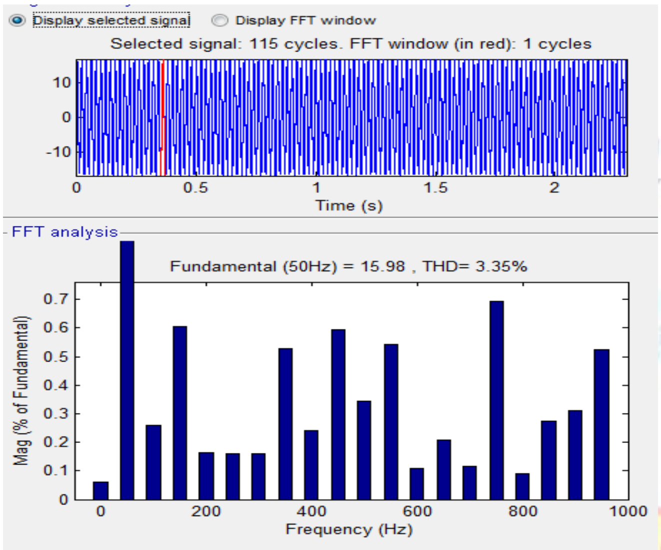

Fig.9. THD of Source Current with PI controller Compensation

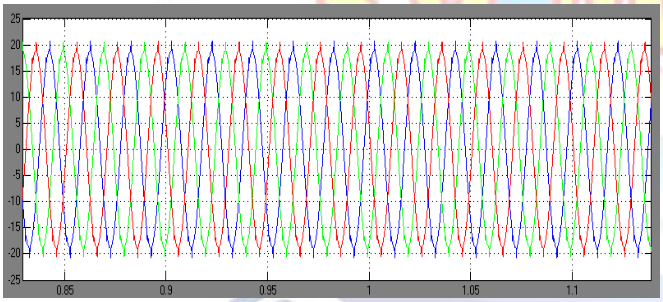

Fig.10. Source current using Fuzzy logic controller

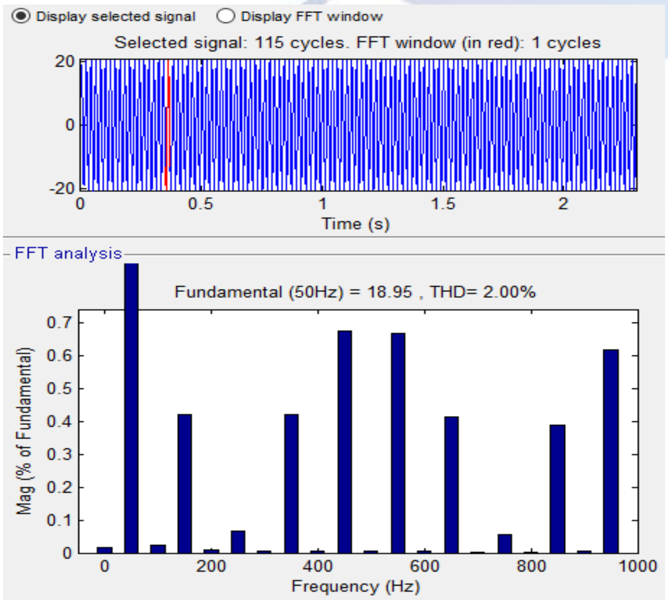

Fig.11. THD using fuzzy logic controllerCompensation

CONCLUSION

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 a custom power device control. The performance of the IAG has been studied under non linear 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 nonlinear 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. The above system is simulated using PI and fuzzy controllers and observed better results.

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