Comparative analysis of Solar Generation System With 21- CHB-MLI integrated SAPF based ANN and AGPSO tuned PI controller to enhance power quality

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Abstract

This paper represents comparative analysis of artificial neural network (ANN) and AGPSO tuned PI controller based power quality improvement solar generation system. Now a day's Power quality is a major problem due to non-liner load based on power electronics. SAPF is solution to overcome such power quality issues in dynamic manner. With the use of both soft computing controllers based Shunt active power filter, it is tried to reduce harmonics (distortions), compensate reactive power, enhance power quality and power factor correction of supply voltage. System comprises 21-Level cascaded H-bridge inverter supplied from photovoltaic panel, series coupling inductor and self-supported DC (capacitor) bus. Voltage harmonics of supplied voltage from PV is reduced by 21-level cascades H-bridge inverter in which switching signal is generated by carrier based in phase level shifted pulse width modulation technique. Incremental conductance (IC) MPPT technique is incorporated to maximize PV panel output. Phase locked loop based unit template generation and Levenberg-Marquardt algorithm trained ANN and AGPSO tuned PI controller based DC bus voltage regulation is utilized for current quality improvement in SAPF. Comparative results show the effectiveness of ANN controller than AGPSO tuned PI controller. Suggested model is simulated in Matlab/Simulink 2016(b) for effectiveness.

Keywords: SAPF (shunt active power filter), THD, ANN (artificial neural network), AGPSO algorithm, PCC.

1. Introduction

Increased use of non-linear load applications by industrial and domestic consumers tends to power quality issue in distribution network [1]. It causes fluctuations in consumer side and non-linearity in generation side. Non-linear loads like regulating speed drives, semiconductor switches, arc furnace, personal computer (PC), converters (AC-AC cyclo-converter, AC-DC rectifier, DC-DC chopper), switch-mode power supply (SMPS) etc. are produce harmonics and affect power quality. Losses due to these non-linear loads are increased and produce unwanted trouble in commutation system [2].

The integration of renewable energy sources (RESs) with the existing power systems forms the modern power system. RESs are the eco-friendly sources of power. However, the unpredictability of RESs is the main concern for the researchers.

Renewable energy sources (RES) offer liking to being pollution free. Solar, hydro, Bio-fuel, and wind are key source of non-conventional energy. Solar and wind are very profitable, among all RES. Electricity production via PV has growing speedily over last decades in India. It has various advantages such as less cost, pollution free, low maintenance cost and never-ending accessibility during day [3-4].

Incremental conductance MPPT scheme is applying in our system to maximize output power obtained from PV panel; this method is based on conductance (I/V) of PV array [5-7].

Energy consumption is increasing day by day, for reliable supply energy loss must be decreased. Use of multilevel inverter in power system can fulfill this requirement. It supplies harmonic less AC voltage with better quality for industrial and commercial applications. Multilevel inverter can supply loss less voltage which is compulsory for energy saving. Multilevel voltage source inverter can provide various voltage levels with less harmonic distortion by increasing levels of inverter [8-10]. In suggested system we are applying 21-level cascaded H-bridge inverter which can reduce voltage harmonics up to a great extent.

Now a day's non-linear loads utilization approximately 9% to 10% of total load in power system in the form of power electronics elements in industrial, commercial, and domestic applications. It is essential to reduce this power quality problem to enhance reliability of system and reduction in loss. Shunt active power filter (SAPF) is one of finest methods to mitigate current harmonics and improve power factor in power system [11-12].

Basic principle of SAPF is to produce harmonics current of equal magnitude but in opposite phase, that are present in the system. SAPF is a closed loop structure which can compensate reactive power and improves quality of the supplied power by the source. APF performance can be determined by accuracy and compensation time to mitigate fluctuations from load current. Traditional methods of compensation like power line conditioners, passive power filters contain slow transient response. In SAPF gate turn off thyristors and static induction thyristors are used to assemble active power filter. Present time various controller like proportional integral controller, fuzzy logic controller, artificial neural network controller, genetic control algorithm are gradually used for improve the performance of the APF's in dynamic and steady state

conditions. SAPF can offers fast compensation even with vigorously changing non-linear loads [13].

Main requirements for better performance of APF is fast detection of troubling signal with high reliability, reference signal with fast processing, and immediate dynamic response. ANN and soft computing algorithm tuned PI based controller satisfies these prime necessities to get better result from SAPF, and provide fast dynamic response in wide operating range while retaining stability in converter system [14]. Artificial neural network is combination of interconnected artificial neurons [15, 13].

To mitigate the source current THD with distorted voltage, neurons weight are adjusted. By appropriate adjustment of weights of neurons current THD is reduced under standard value of THD, as recommended by IEEE-519. Levenberg-Marquardt algorithm is used to train artificial neural network. ANN technique can mitigate large fluctuation in current by neural weight adjustments.

From literature work, it is observed that the particle swarm optimization (PSO) algorithm is used to design controllers for power system applications [16-18]. However, conventional PSO algorithm has numerous limitations. Thus, various variants of PSO have been proposed in the literature. After doing literature survey, it is found the autonomous groups PSO (AGPSO) algorithm is performed better than the existing PSO algorithm [19, 20]. So, this paper proposes AGPSO algorithm tuned PI controller for SAPF.

2 System description model

2.1. System Configuration

Basic arrangement of proposed quality improvement system using SAPF based on ANN controller and Soft computing technique (AGPSO) tuned PI for single phase PV generation is shown in Figure Figure 1. A non-linear load consists of inductive resistive (LL, RL) load with diode bridge rectifier is used to examine system performance. SAPF is connected with source line

through point of common coupling. Filter resistance and inductor are also connected between PCC and SAPF to reduce fluctuations in source current. Other side of DC is connected by a capacitor as self-supported DC voltage source. Phase locked loop (PLL) is used to generate unit template signal. Reference signal is directly affects SAPF compensation efficiency. DC link and reference voltage difference is directly fed to ANN controller and AGPSO tuned PI controller. Control unit is used to generate the switching signals of SAPF converter with the help of input data from ANN controller/AGPSO tuned PI controller, source current and voltage.
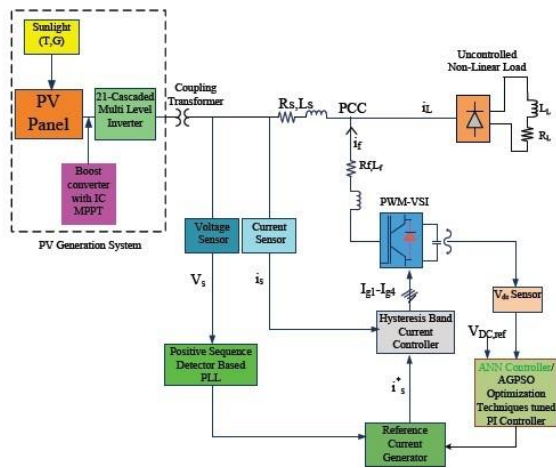
Figure 1: Schematic arrangement of quality improvement system

2.2. Incremental Conductance MPPT Algorithm

P&O technique is fails to maximize the power output under rapid change in atmospheric conditions, to overcome from this problem IC MPPT technique is incorporated. IC MPPT technique has the ability to stop the perturbation in operating point automatically when it reaches at maximum power point.

IC Algorithm is depicted in Figure Figure 2.

We know that

$$P = VI \tag{1}$$

By applying chain law for derivative of products

$$\frac{\partial P}{\partial V} = \frac{[\partial(VI)]}{\partial V} \tag{2}$$

The condition for maximum power point

$$\frac{\partial P}{\partial V} = 0 \tag{3}$$

By rewriting the above equations in terms of V (array voltage) and I (array current)

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \tag{4}$$

Used incremental conductance MPPT algorithm produce switching pulse for DC to DC boost converter until MPP condition $\{(\partial I/\partial V) + (I/V) = 0\}$ is fulfilled.
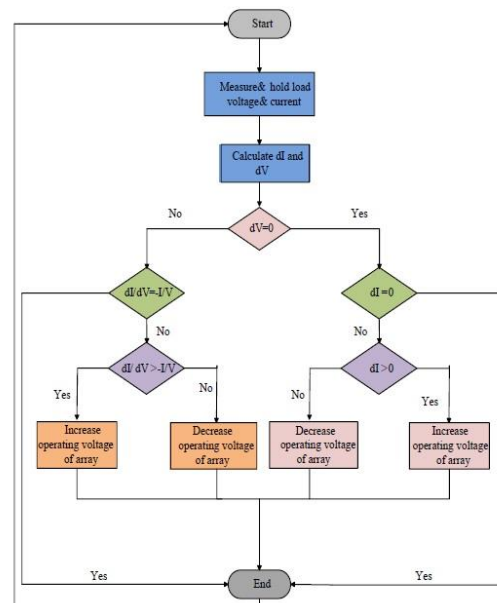

Figure 2: Incremental conductance algorithm for tracking MPPT

2.3. Active Power Filter (APF) Principle

Active power filter works on basic principle it generates harmonic current in opposite direction which is present in load current to reduce the harmonic components. Shunt active power filter is connected in parallel of any AC system at point of common coupling (PCC) to mitigate current harmonics. SAPF can maintain the source current balanced and sinusoidal irrespective of the load condition like non-linear balanced or unbalanced.

Block scheme of Control algorithm for SAPF with artificial neural network used in proposed system is shown in Figure Figure 3.
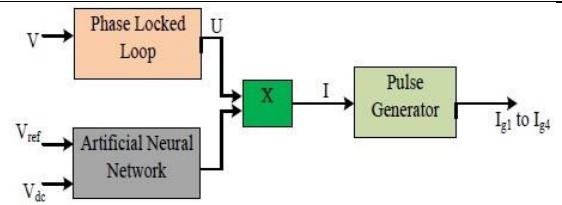

Figure 3: Basic arrangement of SAPF controlling using ANN

3 Artificial Neural Network

Artificial neural network works like human activities. Performance of ANN to solve problem is same as human neural performance. It calculates large data of simple and extremely interconnected elements to solve any problem. Various responses with exterior inputs are used as its processing data base. Mathematical responses of ANN system are non-linear. Results obtained from such non-linear responses can be more accurate than any former techniques.

Described ANN has various characteristics such as- simple in design, accurate results and self-learning capability. ANN can be used to reduce harmonic distortions from power system effectively.

SAPF DC bus voltage is controlled with artificial neural network is used in this paper to reduce current harmonics of system. A simple block arrangement of ANN system is depicted in Figure Figure 4.
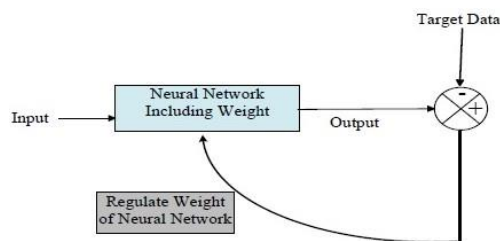

Figure 4: ANN control scheme

3.1. Mathematical Modelling of ANN Controller

Suggested ANN controlled system has various multilayer neural networks. It has one neuron in input layer, ten (20) neurons in hidden layer and one neuron in output layer of ANN.

Input vector is as follows:

$$I = [V_e(k)] \qquad (5)$$

At kth sampling period error signal is defined as:

$$V_e(k) = V_{dc}^* - V_{dc}(k) \qquad (6)$$

$$u_1 = V_e(k); \; u_2 = \frac{\delta u_1}{\delta k} \qquad (7)$$

Output error is shown as:

$$E(k) = V_{out}(k) - V_{out}(k-1) \qquad (8)$$

Controlling signal generated by neuron cell is as:

$$I(k) = I(k-1) + \sum \sum_{i=1}^{2} w_i(k)u_i(k) \qquad (9)$$

Neuron cell weight at $(k+1)^{th}$ sampling time is as follows:

$$w_i(k+1) = (1 - L_r)w_i(k) + \mu E(k)I(k)u_i(k), \qquad (10)$$

where μ =constant for convergence; L_r=learning rate.

Variation in weight $(\Delta w_i(k))$ at k^{th} stage can be determined with the help of equation (8) and (9).

$$\Delta w_i(k) = \Delta w_i(k+1) - w_i(k) \qquad (11)$$

$$= -L_r[w_i(k) - \eta E(k)u_i(k)u(k)/L_r] \qquad (12)$$

Pre-synaptic and post-synaptic signals function is denoted as F_i.

It is denoted by below equation:

$$\Delta w_i(k) = F_i\left(I_{isp}(k), u_i(k)\right) \qquad (13)$$

$$\frac{\delta F_i}{\delta w_i} = w_i(k) - \eta E(k)u_i(k)u(k)/L_r \qquad (14)$$

Variation in weight of kth stage is represented as:

$$\Delta w_i(k) = -L_r \frac{\delta F_i(k)}{\delta w_i(k)} \qquad (15)$$

Reference signal is generated using it. ANN controller output is fed to SAPF for controlling the gate signal of converter. With appropriate triggering of SAPF converter we can enhance system performance by reducing source current harmonics.

4 AGPSO Algorithm

Here, optimization parameters are PI controller gains K_p and K_i, peak overshoot, rise time, settling time and steady-state error are the constraints that mean optimality of PI controller. Performance standard select in proposed research is integral square error (ISE) that make well both positive and negative errors uniformly. The objective function to be optimized is expressed as below:

$$J_{ISE}(K_p, K_i) = \int_0^t (\Delta V_{dc})^2 \qquad (16)$$

Suggested research proposes the implementation of AGPSO technique to detect the optimized gain values of PI controller planned to regulate VSI DC-link voltage regulation as Figure Figure 5.
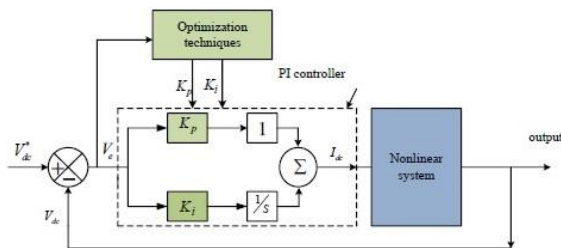

Figure 5: PI controller design with AGPSO optimization technique

The mathematical formulation of AGPSO is given as:

The conventional PSO algorithm has modernized the particles location (x) and velocity (V) with respect to the iterations as [20]

$$V_i^{t+1} = wV_i^t + c_1 \times rand \times \left(p_{best,i} - x_i^t\right)$$
$$+c_2 \times rand \times \left(g_{best,i} - x_i^t\right) \qquad (17)$$

$$x_i^{t+1} = x_i^t + V_i^{t+1} \qquad (18)$$

Where c_1, c_2 and w are the design parameters.

The p_{best} and g_{best} are two variables, which are used to store the best solutions found so far by individual particle and complete swarm, respectively.

The following modifications are adapted in AGSPO algorithm to improve the performance in comparison to the conventional PSO algorithm:

Group 1:

$$c_1 = 2.5 - \left(2\log\frac{(t)}{\log(T)}\right);$$
$$c_2 = \left(2\log\frac{(t)}{\log(T)}\right) + 0.5 \qquad (19)$$

Group 2:

$$c_1 = -\left(\frac{2t^3}{T^3}\right) + 2.5; \; c_2 = \left(\frac{2t^3}{T^3}\right) + 0.5 \qquad (20)$$

Group 3:

$$c_1 = 2exp(-(4t/T)^2) + 0.5;$$
$$c_2 = 2exp(-(4t/T)^2) + 2.2 \qquad (21)$$

Group 4:

$$c_1 = 2.5 + 2\left(\frac{t^2}{T^2}\right) - 2(2t/T);$$
$$c_2 = 0.5 - 2\left(\frac{t}{T}\right)^2 + 2(2t/T) \qquad (22)$$

Where T is the number of maximum iteration, and t is the current iteration.

5 Simulation results discussion

Modeling and optimization of projected system has been simulated using MATLAB/SIMULINK platform R2015a. Proposed organism is investigated with diode rectifier based uncontrolled nonlinear load. Carrier based in phase level shifted pulse width modulation technique is applied to 21- level cascaded multilevel inverter. The simulation time is taken 0 sec to 0.5 sec for system with artificial neural network controller as well as AGPSO algorithm tuned PI controller. Various parameters used during simulation are displayed in Table Table 1 and Table 2. Parameters of PV panel to supply 21-level multilevel inverter are depicted in Table Table 1, and SAPF parameters, load, source, and transformer are mentioned in Table Table 2. ANN structure with input layer hidden layer and output layer is shown in Figure Figure 6.
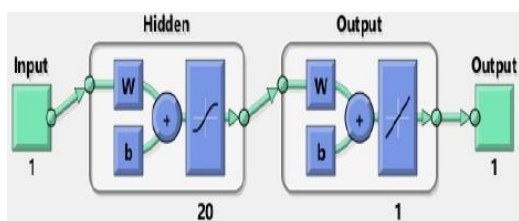
Figure 6: ANN structure

Algorithm is coded in MATLAB programming environment. Hysteresis controller is generating gating pulse for SAPF inverter after application of step signal at 0.1sec.

Photovoltaic array output direct voltage and current with application of solar irradiation 750 W/m^2 and temperature 25^{0}C are shown in Figure Figure 7 from top to bottom curve respectively. Current/voltage and power/voltage curve of Solar system is depicted in Figure Figure 8. MPPT power point voltage (V_{mpp}), current (I_{mpp}), V_{oc} and I_{sc} are illustrated in Figure Figure 9.

Table 1: PV panel parameters

Name	200 W panel
No. of PV panels	10
Maximum Power (PM)	200 W
Voltage at MPP	26.3 V
Current at MPP	7.61 A
Short circuit current (Isc)	8.21 A
Open circuit voltage (Voc)	32.9 V
Temp coefficient of VOC	-0.36099 %/DegreeC0
Temp coefficient of ISC	0.102 %/DegreeC0
No of parallel strings	4
Series module per string	5

Table 2: Active filter simulation data

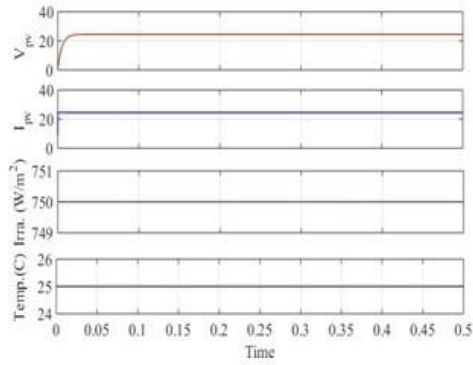| Various Simulation parameters		Values
Source side	Ls	0.2 ohm
	Rs	0.5e-3 mH
SAPF	Rf	0.3 ohm
	Lf	4e-3 mH
Non-linear load (Diode)	Rl	10 ohm
	Ll	100e-3 mH
Transformer	V_1, V_2(RMS)	625V, 325 V
	R_1, R_2(pu)	0.31, 0.31
	L1,L2(pu)	0.8, 0.8
DC link Capacitor	Cdc	1000e-6 µF
SAPF on Time		0.1 s
Simulation Time		0 to 0.5 s

Figure 7: PV parameter (i) Voltage (ii) Current (iii) Irradiance (iv) Temperature
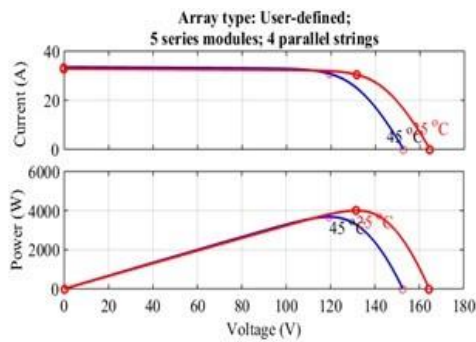

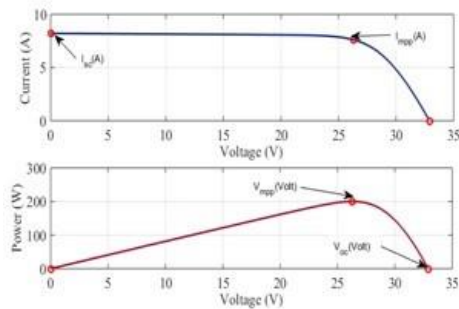Figure 8: PV current/voltage and power/voltage curve

Figure 9: Output I-V and P-V curves

PV output voltage is around 23 Volt which is feed cascaded 21 level h bridge inverter. Ten bridges cascaded configuration are used to attain 21 levels in output voltage with approximate amplitude 237 volt. Inverter controlling pulse for 21-level MLI is shown in Figure Figure 10. The stepped voltage with small voltage steps that results in good power quality and low-harmonic components is achieved at the inverter side with 21- step looking as sinusoidal waveform as Figure Figure 11. Performance index parameter of voltage THDv is depicted in Figure Figure 12.
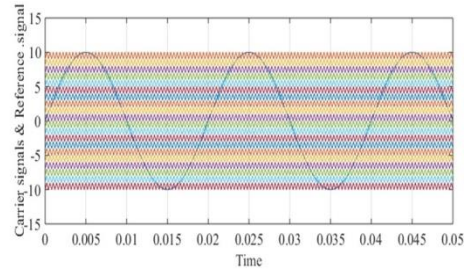
Figure 10: Inverter controlling pulse for 21-level MLI
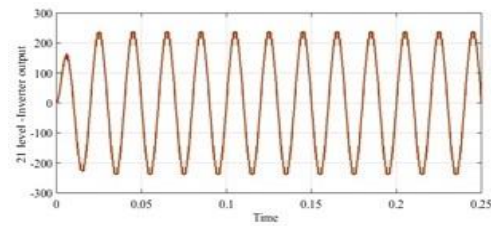
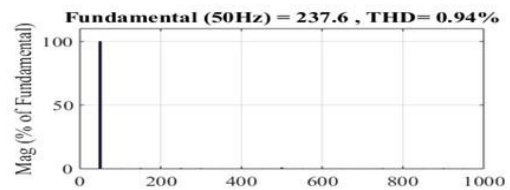Figure 11: Inverted AC output voltage from PV panel DC input

Figure 12: THD of output voltage (THDv) from multilevel inverter

Simulated performance of PV with nonlinear uncontrolled diode rectifier load is analyzed on MATLAB platform. Source current THDI is gotten very high. Hence, to improve waveform driven event THDI SAPF based on AGPSO tuned PI and Soft computing-based ANN controller is applied.

Transient performance with AGPSO tuned PI is shown in Figure Figure 13. It is noted that after applying step signal at 0.1 sec. Source current waveform becomes sinusoidal with improve from 29% to 2.87% as spectral graph Figure Figure 14.

ANN controller functioning is represented in Figure Figure 15 and Figure Figure 16. Target and regression as Figure Figure 15 is represent best relationship with R=1. The best validation performance with 362 epochs is illustrated in Figure Figure 16(a).
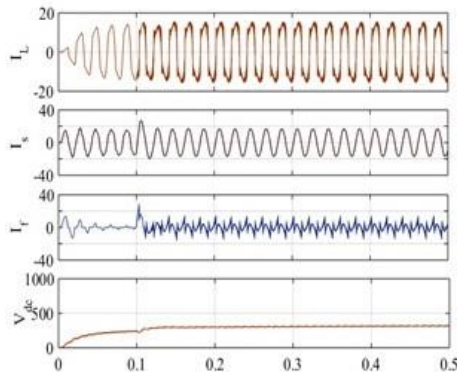

Figure 13: Filtering characteristics of SAPF with AGPSO based PI controller: (a)Load current; (b)Shunt active power filter current; (c)Source current; (d)DC link voltage
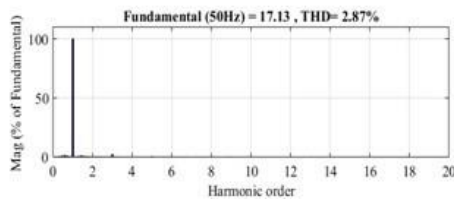

Figure 14: Source current THD after filtering using AGPSO tuned PI based SAPF
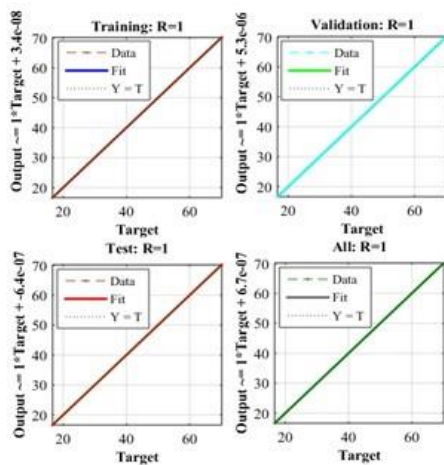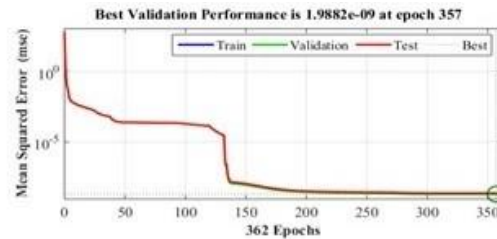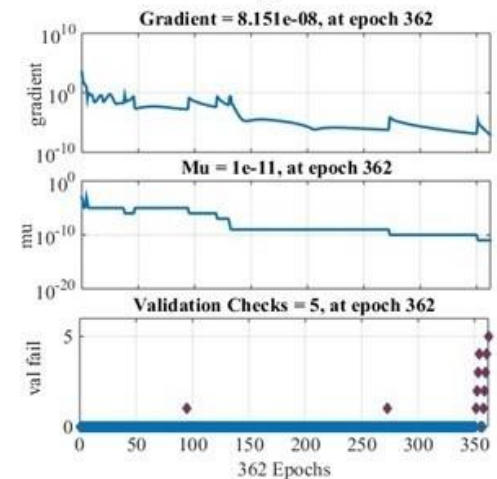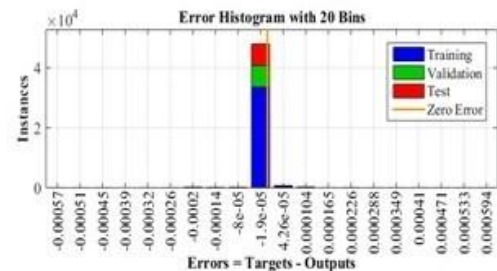

Figure 15: ANN Regression curves

Validation check 5 with 362 epochs is shown in bottom curve of Figure Figure 16(b). Gradient and Mu with 362 epoch can be examined in top and medium curve of Figure. Figure 16(b). Histogram is depicted in Figure Figure 16(c) with twenty bins. Output and target v/s input and error with input is depicted in Figure Figure 17.

Figure 16: ANN performance

Dynamic filtering appearance with ANN controller is depicted in Figure Figure 18. DC link is settled at desired reference level with minimum settling time. Filter current is flow after step signal application after 0.1 sec. The

source current distortion is compensated up to level 1.87% as bar FFT graph Figure Figure 19.

In case of AGPSO control algorithm based tuned PI controller dc link voltage settling time is more than ANN controller as shown in Figure Figure 20.
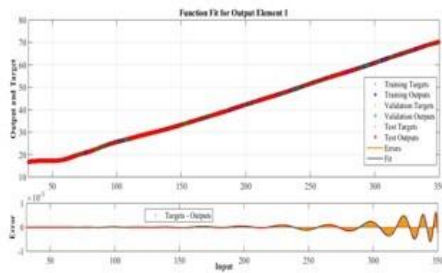

Figure 20: Comparative DC link voltage settling performance

Bar chart for comparative analysis without and with shunt active power filter with ANN/AGPSO tuned conventional PI controller is illustrated in Figure Figure 21.

Figure 17: Output and target/ input and error / input curve of ANN

Figure 21: Comparative study bar graph of % THD without SAPF and SAPF with different controller

Design specification for both studies is listed in Table Table 2: Active filter simulation data.

6. Conclusion

In designed solar energy generation system carrier based in phase level shifted pulse width modulation technique with 21- level cascaded multilevel inverter has been utilized to obtain Lower THD voltage signal. An artificial neural network and AGPSO tuned PI controller based shunt active power filter has been designed to mitigate source current harmonics and enhance power quality with improved power factor. Comparative performance assessment is done using both controllers. ANN controller can be operated successfully with derived equations. Transient result shows ability of proposed system is better with ANN controller for current quality improvement in case of non-
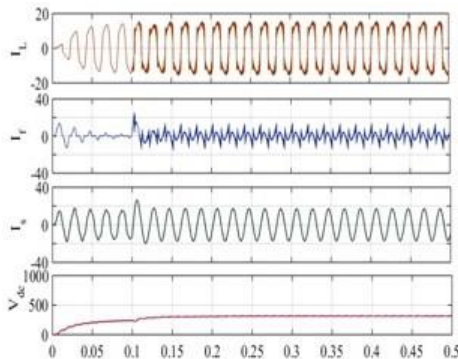

Figure 18: Filtering characteristics of SAPF with ANN controller: (a)Load current; (b)Shunt active power filter current; (c)Source current; (d)DC link voltage
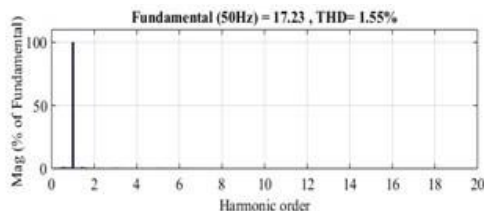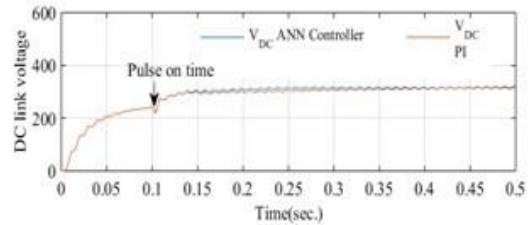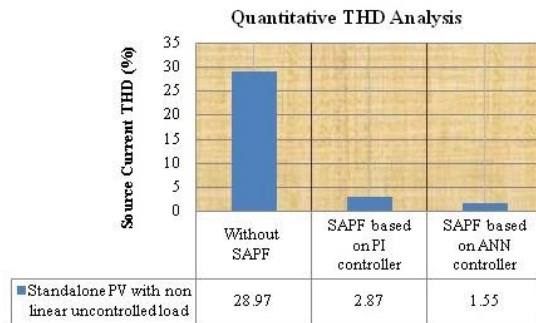

Figure 19: Source current THD after filtering using ANN controller based SAPF

linear uncontrolled rectifier load. Performance index parameter THD is achieved 1.87 % with ANN controller and 2.87% with AGPSO tuned PI controller. DC bus voltage regulation performance is better with artificial controller than heuristic algorithm tuned controller. FFT results are obtained from suggested system follows prescribed limitations of IEEE-519 standards.

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