Using NFC and modified CS Algorithm based unified power flow conditioner for compensating power quality problem

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Abstract— At the present time, the power quality (PQ) related issues are more absorbed in power electronic devices. For compensating PQ disturbances the different types of power devices are used. Unified power quality conditioner (UPQC) is one of the power electronics devices that are used for enhancing the PQ. To reduce the PQ disturbances, the performances of UPQC must be improved. In this paper, neuro fuzzy controller (NFC) with modified cuckoo search (CS) algorithm is proposed for improving the performance of UPQC, so as to reduce the power quality problem. Here, the error and change of error voltage of the system is applied to the neural network. The output of the neural network is optimized by the proposed algorithm. Using the output of proposed algorithm, the optimized fuzzy rule is generated and the discharging capacitor voltage is calculated from the bias voltage generator. The proposed technique is implemented in MATLAB working platform. The performance of the proposed method is evaluated and compared with the NN, NFC, FLC, ANFIS and ABC methods.

Index Terms— UPQC, Power quality disturbance, fuzzy logic controller, neural network, modified cuckoo search algorithm

1 INTRODUCTION

Electric PQ has become the concern of utilities, end users, manufacturers and all other customers [6] due to the deregulation approach. PQ problem is recognized as current or frequency of power system that results in the stop working or disoperation of customer device, any deviations in voltage [2] [3] [4] [8]. PQ problem mostly demonstrates due to the accommodation of power electronic loads such as rectifier, adjustable speed drives, programmable logic controllers, computers, printers, faxes, fluorescent lighting and most other office tools etc. which will cause the decline of voltage and current waveforms [5]. Most significant PQ problems are voltage sags, micro-interruptions, long interruptions, voltage spikes, voltage swells, voltage fluctuations, harmonic distortion etc. The sternest PQ problem is the Voltage sag that allocates 70% of all PQ problems [7]. Modern electronic apparatus and tools, such as microprocessors, microcontrollers, telecommunications equipment and responsive computerized equipments etc. are responsible to PQ problems. Hence, we need avoiding PQ problem as much as possible. In manuscript, to avoid PQ problem, there are combinations of Custom Power Devices (CPDs) such as Distribution Static compensator (DSTATCOM), the Dynamic voltage restorer (DVR), uninterruptible power supply (UPS), Solid State Transfer Switch (SSTS), UPQC etc. are explained [18].

For the development of power quality due to its fast reaction, high reliability and nominal cost, UPQC is a competent CPD [16] [17]. In power allocation plans, it can be used to improve the current and voltage-related PQ problems at the same time [11]. UPQC employs two inverters that are combined to a common DC link with an energy storage capacitor. The main components of UPQC are force and series inverters, DC capacitors, low pass & high pass filters and series transformer [12]. Series inverter is used to balance voltage related disturbance, by introducing opposite voltage in the line where shunt inverter is used to compensate current associated disturbance by providing opposite current that conclude the disturbance [9] [10] [13]. Low and high pass filter help in the reduction of harmonics in the system voltages and currents [14]. DC capacitor maintains the both inverters for competent and fast operation during turmoil. Yet, it has the disadvantage of high releasing time due to which it needs the assist of an appropriate controller for managing its voltage.

A NF controller is a control system based on the neural networks (NN) and fuzzy inference systems (FIS). NN is the artificial copy of human brain and doesn't need any mathematical model for its structural set of relations. FIS is realistic rules based copy is stimulated based on fuzzy rules and NN is toiled based on instruction dataset. The neural network training dataset are generated from the fuzzy rules. NN is relevant in real life functions like regression analysis, classification, data processing, robotics etc. In actual applications like industrial control, human decision making, image processing etc, Fuzzy logic is relevant. ABC optimization algorithm is a relatively new member of swarm intelligence. ABC efforts to copy usual performance of true honey bees [19] in food foraging. At first the ABC algorithm was enhanced for nonstop function optimization problems; yet it can moreover be efficiently applied to dissimilar other optimization problems [20]. The CS is a population based optimization algorithm and related to several others meta-heuristic algorithms start with an arbitrary first population which is obtained as host nests or eggs [40]. CS is used to improve voltage profile, which is the main criterion for power quality enhancement and mitigate power losses of the distribution network [21]. It is relevant in valid world functions like power systems, management, image classification etc. This paper is structured as follows: Section 3 describes about the problem formulation and proposed methodology. Previously, recent related research works are explained in Section 2. The simulation results are discussed in Section 4. Finally, the conclusion section is presented in the section 5.

2 Related Recent Researches: A Brief Review

An strategy based on cuckoo search (CS) which was used for optimal distributed generation (DG) allocation to enhance voltage profile and diminish power loss of the distribution network has been offered by Zahra Moravej et al. [21]. The voltage profile was the major criterion for power quality development. It was designated by two indices: voltage deviations from the target value which must be diminished and voltage variations from the initial network devoid of DG which must be exploited. The CS has been balanced with other evolutionary algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) and dissimilar cases have been examined for indicating the applicability of their suggested algorithm. Their results designate the improved presentation of CS compared with other techniques. In their suggested method, the meeting rate was not responsive to the parameters applied, so the fine alteration was not required for any specified problems.

UPQC Yash Pal et al. have proposed a control strategy for a three-phase four-wire for an enhancement of different PQ problems [22]. The UPQC was accomplished by the integration of series and shunt dynamic power filters (APFs) and both APFs share a common DC bus capacitor. To obtain the reference signals for series APF, a unit vector template technique (UTT) based control method has been used while the ICosΦ theory has been utilized for the control of Shunt APF. Under a dissimilar mixture of linear and non-linear loads, in terms of power-factor correction, load balancing, source neutral current mitigation, voltage and current harmonics mitigation, mitigation of voltage sag and swell, and voltage dips in a three-phase four-wire distribution system, the appearance of the implemented control algorithm has been evaluated. Their simulation results have been accomplished by means of the MATLAB/Simulink, and it confirms that the proposed control system could sustain the functionality of the UPQC.

The shunt active filter (SHAF) was proposed by [S]. Mikkili et al. [23] which was used to get the power quality of the electrical network was better developed in this proposal by justifying the harmonics with the help of Types 1 and 2 fuzzy logic controllers (Types 1 and 2 FLC) using dissimilar fuzzy membership functions (MFs). DC-link voltage constant must be maintained to generate the compensating reference currents in this projected technique. Various were considered and the performance of their proposed control strategy has been evaluated for those source conditions in terms of harmonic mitigation and DC-link voltage regulation. The practicability of the proposed control strategy was sustained by the presentation of complete real-time results using real-time digital simulator.

K. Manimala et al. [24] have described the automatic classification of power quality incidents by means of Wavelet Packet Transform (WPT) and Support Vector Machines (SVM). The features of the interruption signals were eliminated by WPT and set to the SVM for competent classification. The two optimization techniques were used to their proposed classification system, such as, genetic algorithm and replicated annealing. In a fully automatic mode, their proposed scheme was recognized the top discriminative features and evaluated the top SVM kernel parameters. The competence of their proposed detection technique was compared with the conventional parameter optimization techniques like grid search method, neural classifiers like Probabilistic Neural Network (PNN), fuzzy k-nearest neighbor classifier (FkNN). They have proved that their proposed method was reliable and produces for all time better results.

A design of adaptive neuro-fuzzy inference system (ANFIS) for the turbine speed control for purpose of improving the power quality of the power production system of a split shaft microturbine has been presented by Yuksel Oguz et al. [25]. To improve the function presentation of the microturbine power generation system (MTPGS) and to reach the electrical output magnitudes in required quality and value (terminal voltage, operation frequency, power drawn by consumer and production power), a controller depended on adaptive neuro-fuzzy inference system was designed. It was observed from the reproduction results that with the microturbine speed control prepared with ANFIS, when the MTPGS was stimulated under dissimilar loading conditions, the terminal voltage and frequency values of the system can be determined in required operation values in a very little time exclusive of significant fluctuation and electrical production power in preferred quality can be accomplished.

3 Problem Formulation for proposed approach

Currently, PQ associated issues are of most concerned because of their significance in power operating tools. Nonlinear loads for instance, adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting and rectifiers, led to PQ problems. General PQ problems are voltage sag, voltage spike, voltage swell, harmonic distortion, voltage fluctuations, voltage unbalance and interruptions. If the system sustains the PQ, it will supply constant operation or in addition it offers unsteady operation. As a result preserving of PQ is an important one in power operating tool. From the associated research works, it illustrates that intellectual methods are implemented in different electrical and electronics applications. In the earlier papers, intellectual methods are being applied for developing the PQ problem compensating performance of UPQC. This method develops the presentation of UPQC in PQ problem compensation by optimizing the output of the NN which offers the PQ disturbance in terms of voltage to the bias voltage generator. Bias voltage generator is the sub-

ISSN 2229-5518

stitution for DC link capacitor which performs as a DC voltage source for two dynamic power filters of UPQC. DC link capacitor has the difficulty of widespread discharging time owing to which full compensation of the voltage disturbances is not feasible or getting impediment. To evade these matters, bias voltage generator is applied in the place of DC capacitor. For improved compensation of PQ problem, Bias voltage generator adjusts the DC link voltage quick and efficiently. Bias voltage generator has two inputs: reference voltage and calculated voltage from NF controller. The ABC algorithm is very proficient for multimodal and multidimensional fundamental functions. However, the convergence rate of the algorithm is reduced when functioning with constrained problems, composite functions and numerous non discrete functions. Therefore, the presentation of NFC with the UPQC is influenced. In this paper, NFC with modified CS algorithm is proposed, which is an enhancement over the existing controllers for developing the compensating performance of the UPQC.

3.1. Need for Advancement in Proposed approach

As of now, various research works have been tried in the section of PQ maintenance and enhancement. Some devices such as DVR, UPS and many others are used for maintaining the quality power supply. But, these devices are capable of maintaining only the symmetrical or unsymmetrical power supplies, so the PQ is not maintained at all time. To avoid these problems, an enhanced NF controller [29] has been proposed. But, the system developed by [29] had drawbacks like they can only be applied to small networks. Hence, to overcome the issue involved in previous methods, we have proposed a NFC with modified CS optimization algorithm. In this paper, proposed method is used for regulating the DC link voltage and reducing the harmonics of the inverter. The NFC has combined neural network and fuzzy logic controller. Here, NFC is used to improve the voltage regulation and reduce the complexity. Then the error and change of error voltages are applied to the input of the neural network. The output of the neural network can be regulated by DC link voltage. The output performance of the neural network is optimized by using the proposed (modified CS) algorithm. Then the determined dc link voltage is applied to the regulation system of UPQC and the PQ problem is compensated.

3.2. Proposed (NFC- modified CS) method based UPQC

Enhanced NFC based UPQC controller for PQ maintenance in a single phase load connection which is illustrated in Fig.1. It consists of bias voltage generator which connects both Series Active Filter (SAF) and Shunt Active Filter (SHAF). Here, the inputs to the bias voltage generator are Reference Voltage (V_{ref}) and calculated Voltage (V_{cal}) which is calculated from NF controller based on proposed algorithm. A Synchronous Link Inductor (L_{SL}) is connected in series with SHAF to generate a voltage with respect to the PQ disturbance and a low pass filter is connected in series with SAF to pass low fre

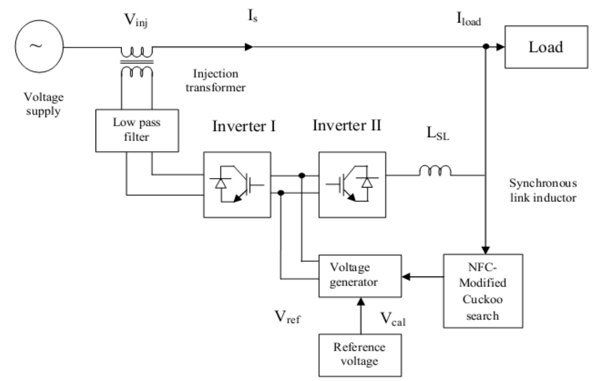


Figure 1: General structure of the proposed (NFC- modified CS algorithm) method based UPQC

frequency component and to reduce the high frequency component of specific voltage signal. Then, the output of low pass filter is applied to voltage injection transformer. Hence, the obtained output from injection transformer maintains PQ in the operating system. Injected voltage in phase by injection transformer is expresses as

$$V_{inj} = \sqrt[2]{V_{s1}^2 - V_{s2}^2} \quad (1)$$

$$V_{inj} = \frac{mV_{dc}}{2\sqrt{2}} \quad (2)$$

Where, V_{inj} is the injected voltage in the phase, V_{s1} is the pre voltage variation, V_{s2} is the post voltage variation, m is the modulation index and V_{dc} is the normal rated DC voltage respectively. The output voltage and current of single phase system can be expressed as follows,

$$V_{output} = A \cdot \sin(\omega t + \theta) \quad (3)$$

$$I_{output} = I_s \cdot \cos \omega t . \cos \theta \quad (4)$$

Where, A is the amplitude of output voltage, ω is the angular frequency and θ is the phase angle of output voltage at t=0. Using Equation 3 and 4 the sinusoidal output voltage and current are calculated. The PQ of the supply mainly depends on the output voltage of the system. Hence, in the paper the PQ of the system output voltage is maintained only during the time of system operation. Here, the voltage discharge capacitor of conventional UPQC is replaced by the bias voltage generator.

3.2.1. Utilization of FLC and NN using Bias voltage generator in proposed method

In this section, the bias voltage generator is used for eliminating the high discharging time of the DC link capacitor. The proposed optimization algorithm optimizes the output of the calculated voltage from NN controller so that the output of NF controller is able to inject the compensating voltage in the single phase line. Inputs to the NF controller are error voltage and change in error voltage of the device and are determined as shown below,

$$E(k) = V_{dc}(ref) - V_{dc} \quad (5)$$

$$\Delta E = E(k) - E(k-1) \quad (6)$$

Where, $E(k-1)$ is the previous state error. The error voltage and change of error voltage are calculated by using the above formula and the values are applied to the inputs of NF controller. FLC is an important part in the research of PQ enhancement and it contains three parts, such as fuzzification, fuzzy rules and defuzzification. Here, the input is error & change in error voltage (i.e., $E(k)$ & ΔE) and output is calculated voltage (V_{cal}^{f}) set are changed into a fuzzy sets. Then, the fuzzy rules are produced. It is known as fuzzy inference system (FIS). After a decision made, output which is in fuzzy set form is converted back to crisp set by defuzzification. This is the last phase of the FLC. Output of the FLC (V_{cal}^{f}) is generated by using centroid defuzzification method. Here, the linguistic variables of inputs and output are Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big and it is referred as NB, NM, NS, ZE, PS, PM, PB in the rules base. The developed fuzzy rules are tabulated in TABLE I. Using fuzzy rules, V_{cal}^{f} is determined.

Table I: Fuzzy rules for determining V_{cal}^{f}

E(k) / ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

3.2.2Training process of neural network (NN)

NN is the artificial intelligence technique for estimating the output based on its training and doesn't need any mathematical model for its structure. It has played a major role in the maintenance of PQ. The proposed feed forward NN diagram is illustrated in the Fig.2. It is used to determine the calculated voltage for bias voltage generator. It consists of three layers, such as input layer, hidden layer and output layer. In this paper, the back propagation NN training and weight adjustment are used. The training process of the back propagation is represented. The training process of the back propagation is represented. Here, initialize the inputs $E(k)$ & ΔE and weights of the network. Then the network output (V_{cal}^{NN}) is calculated and also, BP error (BP_{error}) is determined. The BP error is defined as subtracting the network output from target output. For finding the Δw, adjust the weight ($w = w + \Delta w$) of each neuron in the network. Repeat the above process until BP error gets minimized to a least value i.e., 10. $BP_{error} < 1$.

The working process of neural network has given here. The V_{cal}^{NN} NN is trained using back propagation in order to provide values for any error values. Here, the calculated voltage is optimized with modified CS algorithm to improve NN's performance in order that, effective compensation performance of the UPQC is achieved. Optimization done by modified CS algorithm is explained as below.

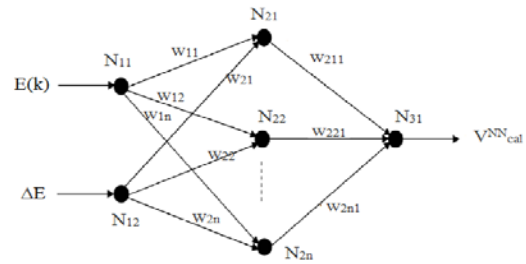


Figure 2: NN structure for proposed method.

3.3. Enhancement of NN output using proposed Algorithm

Step 1 Objective function

In this section, objective function is considered as an optimization problem. Here, the optimization problem is defined as follows,

$$\min(EV) = V_{ref} - V_{cal}^{NN} \tag{7}$$

Where, V_{ref} and V_{cal}^{NN} are denoted as the reference Voltage of the bias voltage generator and calculated voltage from NN. It had to be minimized by varying the V_{cal}^{NN} in the search space of its limits, so that the DC link voltage regulation performs well and quickly by bias voltage generator and thus improving the compensation performance of UPQC. This is achieved by optimizing output of the NF controller, i.e., V_{cal}^{NN}. Then NF controller output (V_{cal}^{NN}) is given as an input of proposed algorithm.

Step 2 Initialization

In this section, the host nests are randomly initiated. Here, nest is an array of size 'n'.

$$x_a = \{x_1, x_2, \ldots\ldots\ldots x_n\} \tag{8}$$

Here, x_a denotes the V_{cal}^{NN} and each nest x_a is a solution vector to the optimization problem. It can hold n number of variables, which are optimized so as to minimize the objective function.

Step 3 Creation of new cuckoo

A cuckoo randomly generates new solutions by using exponential function and determines the quality of solutions. The exponential function is represented as follows,

$$x_b^{t+1} = \left(\frac{w_i}{1+\exp(levy * w_{i+1})}\right) \tag{9}$$

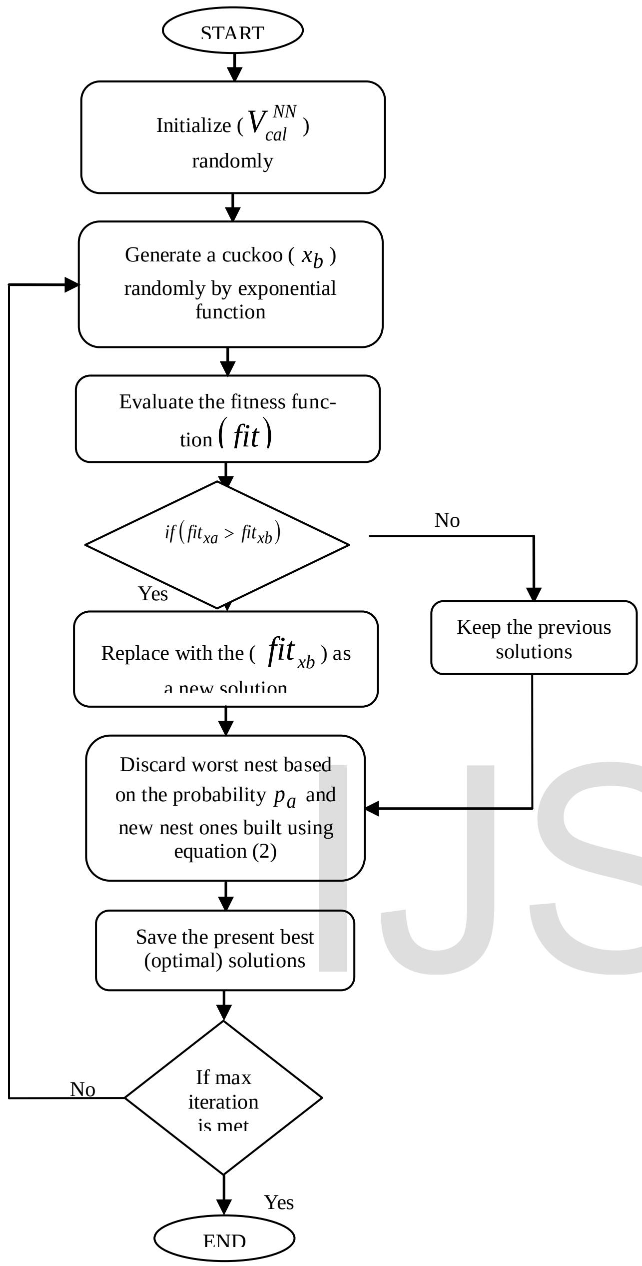
Where w_i is the weighting function of the neural network and the range of the weight is [0, 1] i.e., $w_i \in (0,1)$. The levy function is specified as the range between -230V to 230V. The cuckoo is evaluated using the objective function to determine the quality of the solutions. The exponential function is calculated for each iteration.

Step 4 Fitness function

Here, the fitness function (F) of all the nests are evaluated by using the following formula,

$$fitness\ \ function\ (F) = \min(EV) \tag{10}$$

From the above condition, the quality of the solutions is measured. A nest is selected among n randomly, if the quality of new solution in the selected nest is better than the old solutions, it is replaced by the new solution (cuckoo). Otherwise, keep the previous solution as a best solution.



Step 5 Discard worst nest
In this part, the worst nests are discarded based on their probability p_a values and new ones are built using the equation (2). After that, rank the best solutions based on their quality. Then identify the present best solutions as optimal solutions.
Step 6 Stopping Criterian
This process is repeated until the termination iteration reached. Here, the best solution is optimized V_{cal} . From the output of hybridization techniques (FLC & ANN), we can evaluate the values with the help of mean operation. The following formula is used for calculating theV_{cal}.

$$V_{cal} = \frac{v_{cal}^{f} + v_{cal}^{NN}}{2} \qquad (11)$$

Using the above equation, the compensating performance of UPQC is improved. The DC link voltage of the UPQC is varied based on the load variation. Here, DC voltage regulation is achieved by using the output of NF controller based modified cuckoo search algorithm via bias voltage generator. The input of the bias voltage generator is V_{ref} and the calculated voltage V_{cal}., which is obtained from NF controller based on modified cuckoo search algorithm. Bias voltage generator is used to discharge the inverter diodes quickly. The harmonics of inverter output voltage is eliminated by the low pass filter, and then the low pass filter output is applied to injection transformer. The output of injection transformer is the delivered and enhanced voltage of the system. The detailed analysis is described in the following section.

4. RESULTS AND DISCUSSION

In this section, the proposed (NFC-Modified CS) method is implemented in MATLAB platform. Here, the error and change of error voltage of the system is applied to the neural network. The output of the neural network is optimized by the proposed algorithm. Using the output of proposed algorithm, the optimized fuzzy rules are generated and the discharging capacitor voltages are calculated from the bias voltage generator. The proposed method is used to improve the performance of UPQC for compensating the power quality problems. The performance of the proposed controller is tested with power quality problem. The performance of the proposed controller is analyzed, which is based on the reference voltage and line voltages. The analyzed outputs of the proposed method are compared with neuro fuzzy controller (NFC), neural network (NN), fuzzy logic controller (FLC), ANFIS and ABC methods. The proposed method based unified power flow conditioner simulated diagram is illustrated below.

4.1. Evaluation of Performance analysis and metrics

Here, the implementation parameters are represented, which is specified as their values and that are described as follows:

DC Voltage (V_{dc}) : $\pm 230V$
Reference Voltage (V_{ref}) : $\pm 230V$
Error Voltage $(e(n))$: - 230V to +230V
Change of error voltage (Δe) : - 230V to +230V

In different time instants, the reference voltage and line voltage with PQ problem are determined. The PQ affected line voltage can be improved using the proposed controller and the existing technique controller. Then the proposed method performances are compared with NFC, NN, FLC, ANFIS and ABC methods. Then evaluate the better results from the comparison analysis. Here, the reference voltage and line voltage with PQ problems are illustrated in Fig. 4 and 5. Then the line voltage with PQ problems are defined at the time instant T= 0.17, 0.05, 0.19, 0.11, 0.04 sec and clearing time of the PQ problem is calculated. The enhanced PQ line voltages are evaluated using the proposed method and illustrated in the Fig. 5(a). Similarly, the enhanced PQ line voltages are evaluated in the NN, FLC, NFC, ANFIS and ABC techniques.

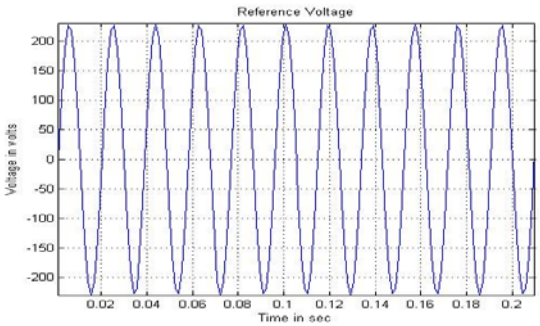


Figure 4: Reference Voltage

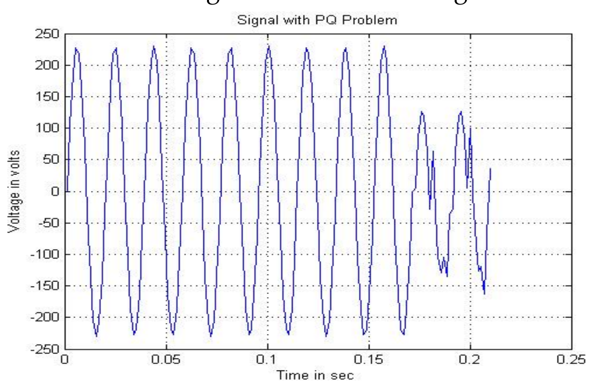


Figure 5: Line voltage with PQ problem at T=0.17 sec

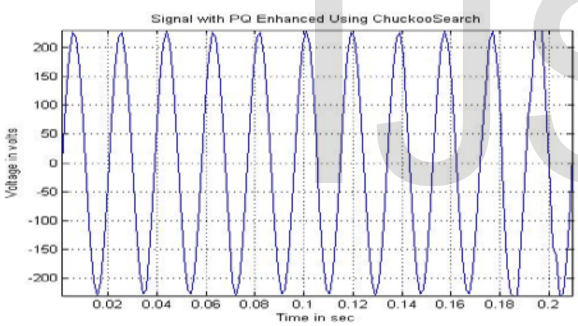


Figure 5(a): The line voltage with enhanced PQ at T=0.17 sec in proposed method

In the time instant T= 0.19 sec, the PQ problems are occurring in proposed method, NN, FLC, NFC, ANFIS and ABC methods. The clearing time of these methods are 0.2, 0.21, 0.21, 0.21, 0.21 and 0.21 (all values in seconds) respectively. In the proposed method, the clearing PQ problem duration is 0.1 seconds. From the time instant, the PQ problems are highly cleared with the use of proposed method when compared to other techniques. Then the PQ problems are occurring in NN, NFC, FLC, ANFIS and ABC at 0.05 seconds then clearing at 0.07, 0.07,0.07,0.07 and 0.07 seconds respectively. In the proposed controller, the PQ problems are occurring at 0.05 seconds and clearing at 0.062 seconds so that the total PQ problem duration is 0.012 seconds. Moreover for all the time instants, the performances of the proposed method are evaluated. Similarly, the clearing time of the PQ problems in NN, NFC, FLC, ANFIS and ABC methods is measured with all the different time instant (T=0.17, 0.11, 0.04 seconds) and their performances are evaluated. Then performance of the proposed method is compared with the other methods.

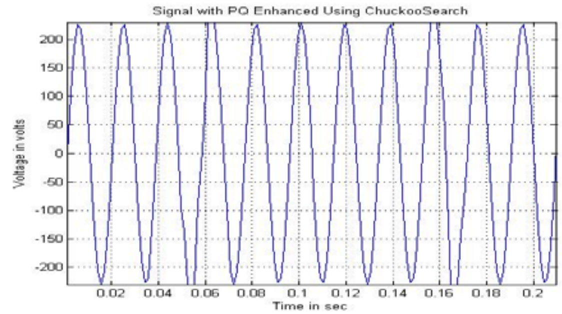


Figure 6: The line voltage with enhanced PQ problem at T=0.05 sec in proposed method

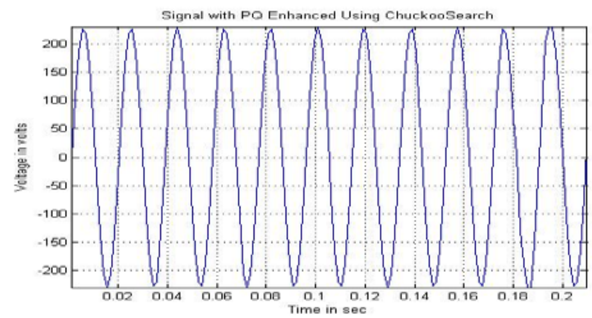


Figure 7: The line voltage with enhanced PQ problem at T=0.19 sec in proposed method

From the above performances, the existing techniques took more time to solve the PQ problem when compared to the other method. Here, the proposed and existing technique processes are noted and it shows that the proposed controller is used for solving the PQ problems in an efficient time manner.

The RMS voltage of the proposed and existing method is calculated from the above illustrations and tabulated in table II. Moreover, the RMS voltages of the existing methods get decreased compared to the proposed method, when the PQ problem occurred. Then the Root Mean Square (RMS) voltage (V_{rms}) of enhanced voltage is calculated as follows:

$$V_{rms} = \frac{V_p}{\sqrt{2}} \quad (12)$$

Where, V_p is the peak voltage value. The RMS voltage value is used to estimate the PQ enhancement of the operating system.

Table II: RMS voltages of proposed method, ABC-NFC, ANFIS, ANN, FLC and NFC

Time in sec at PQ error occurs	RMS Voltage when PQ issue occurs	RMS Voltage (in Volts) after PQ enhancement					
		Proposed method	ABC-NFC	ANFIS	NN	FLC	NFC
0.05	120.20	162.63	123.74	116.67	95.45	102.53	98.99
0.19	134.35	155.56	152.02	134.35	127.27	123.74	130.81
0.11	109.60	155.56	67.17	111.72	113.13	109.60	113.13
0.04	88.38	155.56	152.02	84.85	53.03	24.74	24.74
0.17	91.92	155.56	148.49	81.31	113.13	109.60	109.60

ISSN 2229-5518

4.1.1. Performance analysis using FFT

By using FFT analysis, the voltage magnitude of the proposed method and their waveforms are evaluated. Here, the input voltage and frequency is denoted as 230V and 50Hz respectively. The power quality disturbance signal is specified as the error signal. This power quality problem causes amplitude errors in the FFT analysis. From the above illustrations, the voltage signal is disturbed in the power quality problem at the different time (T=0.07 and 0.01 seconds) instants. When the PQ problem occurred, the RMS voltage is highly increased. After that, the PQ affected line voltage (RMS) variation is measured, which is specified at the range from 70 to 150 Hz. From the frequency 70 and 80 Hz, the RMS voltage magnitude is slightly varied and their variation values are measured. The variation of the voltage magnitude is 80V. Then compensating PQ problem, the voltage magnitude is highly reduced i.e., 570V. Now the RMS voltage magnitude is 230 V. After that, the line voltage is affected with PQ problem in the time instant (T=0.01 sec) is measured, then the RMS voltage is reduced. Hence, the proposed method highly reduces the PQ problem and their performances are illustrated in Fig. 8 (a).

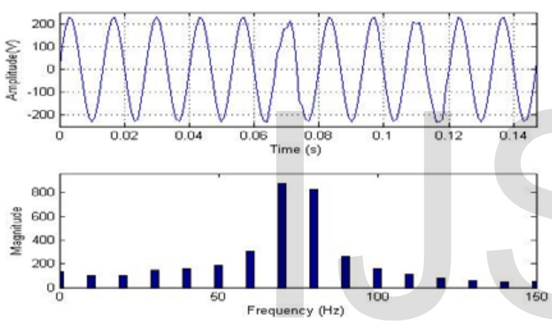


Figure 8(a): FFT analysis of compensating power quality at modified cuckoo search

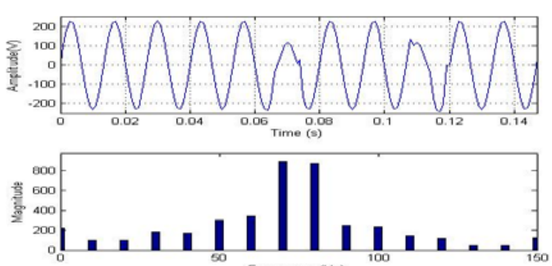


Figure 8(b): FFT analysis of compensating power quality at ABC

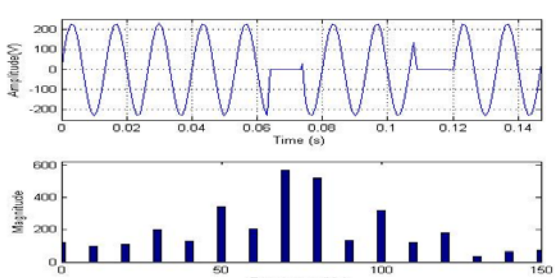


Figure 8(c): FFT analysis of compensating power quality at ANFIS

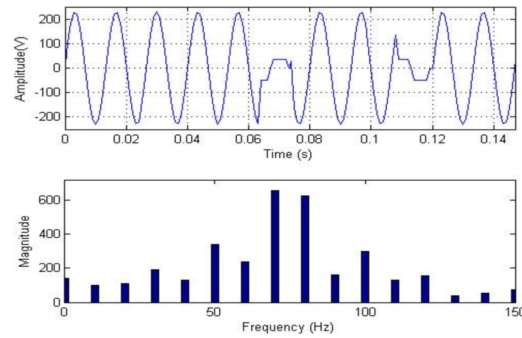


Figure 8(d): FFT analysis of compensating power quality at NFC

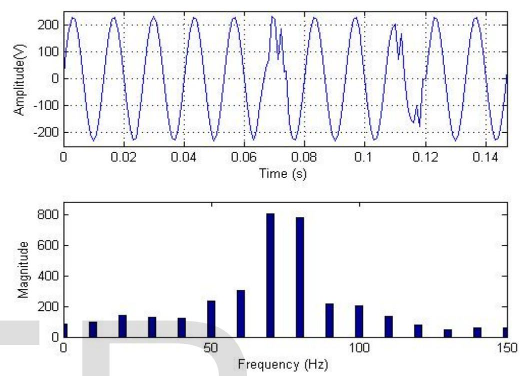


Figure 8(e): FFT analysis of compensating power quality at Fuzzy

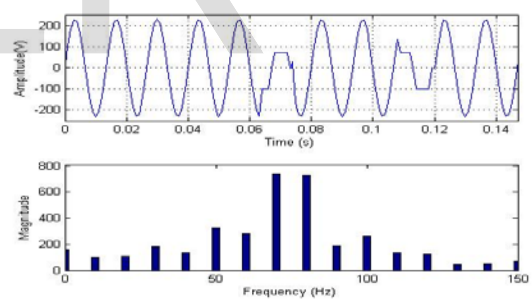


Figure 8(f): FFT analysis of compensating power quality at Neural Network

Similarly, the FFT analysis is used to evaluate the performance of the ABC, ANFIS, NN, FLC and NFC method. From the analysis, the voltage signal is disturbed in the power quality problem at the different time (T=0.07 and 0.01 seconds) instants. When the PQ problem occurred, the RMS voltage is highly varied i.e., increased. After that, the PQ affected line voltage (RMS) variation, which is measured in the ABC, ANFIS, NN, FLC and NFC methods that is specified at the range from 70 to 150 Hz. From the frequency 70 and 80 Hz, the RMS voltage magnitude is slightly varied and their variation values are measured. The variation of the voltage magnitude is 20, 20, 10, 60 and 80 (all values in p.u) respectively. Then by compensating PQ problem, the voltage magnitude is highly varied or reduced i.e., 570, 630, 560, 360 and 440 (all values in p.u) respectively. Now the RMS voltage magnitude is 230 V. After that, the line voltage is affected with PQ problem in the time instant (T=0.01 sec) which is measured and then the RMS voltage is reduced. The performance analysis of the existing methods is illustrated in the Fig. 8 (b, c, d, e and f). Therefore, the proposed method highly reduces their PQ problems, when compared to other methods and their performances are evaluated.

4.1.2. Performance deviation

The performance deviation is based on the RMS voltage of the proposed method and other methods. The proposed technique is analyzed with the performance deviation of ABC, ANFIS, NFC, FLC and ANN controller. The performance deviation between the proposed method and ABC controller can be calculated with the following formula,

$$Deviation(\%) = \frac{V_{rms}^{proposed\ method} - V_{rms}^{ABC} * 100}{V_{rms}^{proposed\ method}}$$

Similarly, the performance deviation can also be calculated between proposed method and ANFIS, FLC, NFC and ANN for different instances of occurrence of PQ issues and that are chosen for implementing the proposed controller and are tabulated in TABLE III.

Table III: Performance deviation of proposed method with ABC, ANFIS, ANN, FLC and NFC

Time (in sec)	Performance Deviation of Proposed Method				
	ABC	ANFIS	NN	FLC	NFC
0.05	23.91	28.26	41.30	36.95	39.13
0.19	2.27	13.63	18.18	20.45	15.90
0.11	56.81	28.18	27.27	29.54	27.27
0.04	2.27	45.45	65.90	84.09	84.09
0.17	4.54	47.72	27.27	29.54	29.54

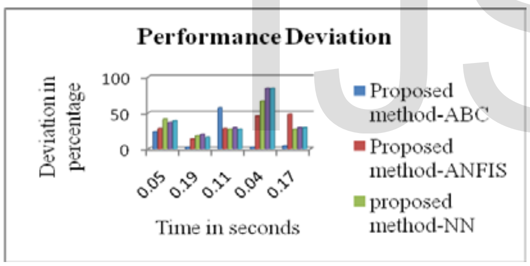


Figure 9: Performance deviation of proposed method with ABC, ANFIS, NN, FLC and NFC

In the proposed controller, the performance deviation are calculated and represented in Fig. 10. It can be deviated positively at a rate of 23.91% rather than ABC, 28.26% rather than ANFIS, 41.30% rather than NN, 36.96% rather than FLC and 39.13% rather than NF controller at T=0.05sec. Then at the time instant (T=0.19 sec), the proposed controller deviates at a rate of 2.27% rather than ABC, 13.64% rather than ANFIS 18.18% rather than NN, 20.45% rather than FLC and 15.91% rather than NFC. Similarly, the performance deviation of the proposed technique achieves a positive rate in solving the defined time (T=0.11, 0.04, 0.17 sec) instants. It can be shown that, the proposed controller can achieve a better performance of PQ issues compared with the ABC, ANFIS, FLC, NFC and ANN.

5. Conclusion

In this paper, the proposed (NFC-Modified CS) method based UPQC controller was proposed for compensating the PQ problem. The proposed controller was implemented in the MATLAB platform. The voltage sag PQ problems were considered for analyzing the performance of the proposed controller. In the proposed controller, the line voltage with the PQ problems occurred in the various time instants and evaluated their clearing time instants of the enhanced PQ problems. Then the FFT analysis is used in the proposed method, ABC, ANFIS, NN, FLC and NFC methods. Similarly, the occurring and clearing time of the PQ problems are measured with the ABC, ANFIS, NN, FLC and NFC methods and the outputs are compared. The proposed controller compensated the PQ problem in less time, when compared to the existing methods. Also, the PQ problem occurrences are defined with the different time instants (T=0.05, 0.19, 0.11, 0.04, 0.17 sec) the performance deviations were evaluated in the proposed controller with the ABC, ANFIS, NFC, NN and FLC techniques. The proposed technique achieves a positive rate in solving all the defined instants of occurrences of PQ issues. The comparative results showed that the proposed controller can achieve a better performance of PQ issues compared with the ABC, ANFIS, NN, FLC and NFC based controllers.

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