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Power Quality Enhancement in STATCOM connected Distribution Systems based on Gravitational Search Algorithm

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Abstract: The power quality (PQ) issue is get new measurement because of power system rebuilding and moving pattern towards distributed generation. PQ comprises of an expansive number of unsettling influences, for example, voltage sags, swells, harmonics, notch, flicker and so forth. To conquer these issues identified with the PQ, FACTS gadgets are presented. A distribution static compensator (D-STATCOM) is one of the FACTS gadgets makes it productive answers for enhancing the PQ in distribution system. So as to diminish the PQ issues, the D-STATCOM exhibitions are enhanced. In this paper, a Gravitational search algorithm (GSA) is proposed for enhancing the execution of D-STATCOM and remunerating the PQ. The algorithm is a recent improvement in the territory of nature enlivened calculations for worldwide streamlining. The proposed strategy is utilized for extricating the reference current for repaying the D-STATCOM and controlling the dc link voltage. The proposed technique based D-STATCOM is utilized for reducing the harmonic disturbances. In addition, the load balancing and reactive power compensation is accomplished. The proposed technique is executed in MATLAB/Simulink platform and its execution is assessed. The execution of the proposed technique is contrasted and the FLC controller and ANN controller.

Keywords: D-STATCOM, GSA, power quality, voltage, FLC and ANN

1. Introduction

The fast growth and reputation of power electronics technology lead to wide use of industry loads which posses' power quality (PQ) issues [1]. The power quality is primarily exaggerated due to current harmonics introduced by the nonlinear loads into the distribution network. The PQ issues featured with harmonic distortion, low power factor and phase disproportion produce astonishing turbulence in the function of electrical equipment [2, 3]. Conventionally, static capacitors and passive filters have been employed to enhance PQ in distribution system. Nevertheless, these frequently have issues like fixed compensation, system parameters dependent performance and probable resonance with line reactance [4, 5]. Owing to this the capability to even out the transmission systems and to enhance PQ in distribution systems is showed [6]. Static synchronous compensator (STATCOM) is prevalently acknowledged as a consistent reactive power controller substituting traditional VAR compensators, like the thyristor-switched capacitor (TSC) and thyristor controlled reactor (TCR). This device endow with reactive power compensation, active power oscillation damping, flicker attenuation, voltage regulation [7, 8].

STATCOM is a component of Flexible AC Transmission Systems (FACTS) family that is associated in shunt with the power system [9, 10]. By controlling the magnitude of the STATCOM voltage, the reactive power interactions between the STATCOM and the transmission line control the quantity of shunt compensation in the power system [11-13]. The STATCOM is a power electronics device depends on the law of injection or absorption of reactive current at the point of common coupling (PCC) to the power network. The benefit of the STATCOM is that the compensating current does not depend on the voltage level of the

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PCC and thus the compensating current is not minimized as the voltage drops. The supplementary motive for choosing a STATCOM as an alternative of an SVC are on the whole superior operational features, faster performance, lesser size, cost minimization and the capability to give both active and reactive power, thereby providing flexible voltage control for power quality enhancement [14-16].

Providentially, hybrid multilevel method makes available a high-quality tradeoff between waveform quality and switching loss. The control technique is not appropriate for STATCOM system for the reason that the dc sources are substituted by capacitors in the STATCOM system [17, 18]. This shortage can be overcome by, different intelligent optimization algorithms known as heuristic methods are implemented to solve PQ issues. Several of the sound admired optimization methods are evolutionary programming (EP), genetic algorithm (GA), simulated annealing (SA), differential evolution (DE), particle swarm optimization (PSO) and artificial bee colony (ABC), etc. In recent times, a harmony search algorithm (HSA) was urbanized for instantaneous reduction of total cost, the voltage stability index and voltage profile and power loss using shunt capacitors, static VAR compensator (SVC) and STATCOM [19]. The most significant and recurrently happen PQ problems in wind power are sags, swells and harmonics. The Adaptive neuro fuzzy inference systems (ANFIS) based STATCOM alongside with the three phases harmonic filter are employed in the system to lessen the above specified power quality problems [20].The rest of the document flows through the following phases. The proposed control strategies are made cleared in section 3. The most recent research works are disputed in section 2. The results and discussion of the proposed strategy is described in section 4. The section 5 finishes the document.

2. Recent Research Works: A Brief Review

Numerous research works are already existed in literature which based on PQ problem compensating utilizing D-STATCOM. Some of them reviewed here.

Soumya Mishra *et al.* [21] have anticipated a low ranking photovoltaic fed enhanced hybrid distributed static compensator (D-STATCOM) for the recompense of harmonics and reactive power. The system convince the load active power requirement with minimized power rating of the photovoltaic source for same load rating as contrasted with the standard L or LCL filters. The system was replicated and controlled by assuming the non-linearity of the system. A dc voltage droop regulator was utilized to control the power flow from solar system and to preserve dc link voltage. Switching pulses for inverter was produced by employing using sliding mode controller to make the system robust.

M.R.Qader [22] has depicted an innovated systematic scheme on the basis of optimal control and tracking with a PI (proportional integral) controller, to control complete flow of load and voltage sags/flickers; while neglecting harmonics concurrently, the preferred steady state behavior, and a linear quadratic tracker. Freshly developed FACTS (flexible alternating current transmission system) give steadfast solutions to turn away these problems in power quality. Owing to the enhancements in these solutions, some serious problems have been come to spectacle pertaining to power quality, dependability and durableness. The most effectual and potential expertise among lately developed FACTS devices were STATCOM and UPFC (unified power flow controller) that could appreciably improve the functions of power systems and connected power quality issues.

S.M.Abd-Elazim*et al.* [23] have projected a metaheuristic technique, the Cuckoo Search (CS) algorithm, depends on the life of a bird family for optimal design of STATCOM in a multi-machine surroundings. PV curves were demonstrated to evaluate the most excellent site of STATCOM. The STATCOM attributes tuning issues was transferred to an optimization problem which was unraveled by CS Algorithm. The performance of the CS depend STATCOM was contrasted with Genetic Algorithm (GA) based STATCOM and open loop STATCOM under different operating conditions and turbulence.

Abdul Balikci *et al.* [24] have explained a 3-phase, delta-connected, 5-level Static Synchronous Compensator with AC to DC converter for load balancing in three-phase systems. The level shifted carrier based sinusoidal pulse width modulation (SPWM) technique was employed as the switching method. This converter has fewer number of power switches than traditional H-bridge structure and it can be controlled from the standard PWM ports of microcontrollers. The control algorithm based on series decomposition of load current and reimbursement of its negative sequence element in addition compensation of imaginary component of positive sequence.

Bhim Singh *et al.* [25] have depicted the modeling and execution of a three-phase D-STATCOM utilizing STF (Self Tuning Filter) based IRPT (Instantaneous Reactive Power Theory) control algorithm for power quality enhancement. It was employed for harmonics neglect ion, load balancing and reactive power reimbursement at indistinct PCC (Point of Common Coupling) voltages under nonlinear loads. An adaptive fuzzy logic controller was employed to control the dc bus voltage of VSC based D-STATCOM to enhance the response and to minimize the overshoot and undershoot of traditional PI (Proportional-Integral) controller under unbalanced loading conditions and supply voltage fluctuations.

The universal appraisal presents the PQ issues connected to the STATCOM linked load based on the several methods such as Artificial Neural Network (ANN), Fuzzy Logic Control (FLC), GA, PSO, CS and ABC have been recommended. The ANN method possesses its own advantages and limitations. The performance of the system is enhanced by ANN based controller, but the key issue of this controller is the long training time, the selecting number of layers and the number of neurons in every layer. The FLC has received much concentration in control applications. In disparity with the traditional methods, FLC formulates the control action of a plant in conditions of linguistic rules pinched from the characteristics of a human operator rather than in terms of an algorithm amalgamated from a model of the plant. Nevertheless, it can be designed on the foundation of linguistic information achieved from the previous knowledge of the control system and gives superior performance outcomes than the traditional controllers; a hard work is foreseeable to get the effectual signals when designing FLC. Global optimization methods have been employed to STATCOM design issues. Optimal design of STATCOM via GA is grown but, it necessitate a very long run time depending on the size of the system. Furthermore, it gives rise to replicate revisiting of the similar suboptimal solutions. STATCOM attributes tuning utilizing PSO, but it caution from the partial optimism. Furthermore, the algorithm cannot work out the issues of scattering and optimization. Furthermore, the algorithm experience slow convergence in sophisticated search phase, weak local search ability and algorithm may show the way to probable setup in local minimum solutions. Robust methods have been also employed for STATCOM design, but these techniques are iterative, sophisticated and the system doubts should be performed in an extraordinary format. On the other hand, the order of the controllers is as far above the ground as that of the plant. This provides rise to multifaceted structure of such controllers and minimizes their applicability. ABC is developed to design STATCOM controller, but it is sluggish to converge and the procedures of the examination and development disagree with each other, so the two abilities should be well balanced for obtaining good optimization performance. A comparatively novel evolutionary calculation algorithm, called Bacteria Foraging (BF) scheme has been developed. The BF algorithm depends on random search instructions which may lead to delay in achieving the global solution. To conquer these issues we require an improved controller based optimization algorithm.In the paper, an enhanced control strategy is proposed to improve the performance of the D-STATCOM thereby improving the PQ of nonlinear load. The proposed control strategy is based on the GSA. The detailed analysis of the proposed method based D-STATCOM is described as below.

3. Overview of D-STATCOM with proposed control algorithm

In the paper, the GSA method is proposed for enhancing the performance of D-STATCOM. Figure 1 portrays a schematic diagram of a three-phase VSC based DSTATCOM linked to a three phase biased voltages of AC mains feeding nonlinear loads with a source impedance. The three phase source voltages, source currents and load currents are characterized as $V_S^a, V_S^b, V_S^c, I_S^a, I_S^b, I_S^c$ and I_L^a, I_L^b, I_L^c respectively. Consequent to that, the projected controller is engaged for calculating the reference currents ($I_{ca}^*, I_{cb}^*, I_{cc}^*$) with the help of the inverter to produce the compensation currents (I_{ca}, I_{cb}, I_{cc}). The dc bus voltage (V_{dc}) of VSC utilized in DSTATCOM and the inductors are L_1, L_2, L_3 utilized. Competence of the compensator relies on the precision of extracted basic dynamic power and reactive power sections of load currents. Interfacing inductors (Lf) are related to AC revenue of the VSC for lessening ripple in recompensing currents [26]. A three phase preparation related capacitor and a resistor as an inactive swell channel is used at PCC parallel to the loads to greater frequency switching noise at PCC voltages brought on due to the swapping of VSC. The DSTATCOM recompensing currents are inoculated to cancel the reactive power constituents and harmonics of the load currents [27]. For a fruitful operation of DSTATCOM, it is significant to uphold constant DC capacitor voltage of VSC of DSTATCOM. It is recognized using a GSA based PI controller. The comprehensive investigation of the projected GSA based p-q method is used for extracting the reference currents for extenuating the PQ. Following to this, the gate signals for the D-STATCOM are produced.

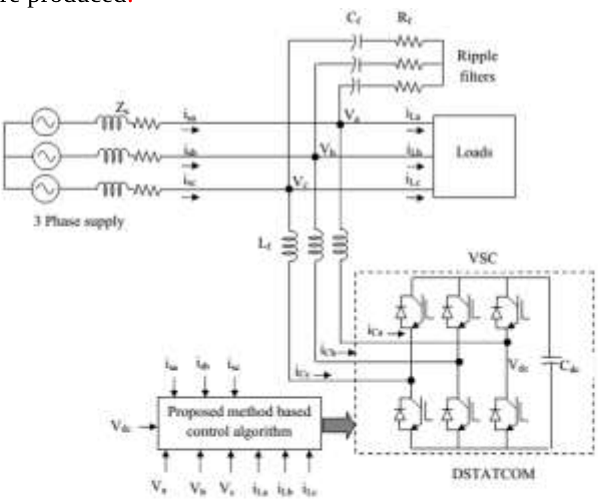


Figure 1. Block diagram of proposed method based D-STATCOM

The three phase voltages are specified as the following,

$$v_a(t) = V_{a1}\sin(\omega t + \phi_{a1}) + \sum_{n=2}^{\infty} V_{an}\sin(n\omega t + \phi_{an}) \tag{1}$$

$$v_b(t) = V_{b1}\sin(\omega t + \phi_{b1} - \frac{2\pi}{3}) + \sum_{n=2}^{\infty} V_{bn}\sin(n\omega t + \phi_{bn} - \frac{2\pi}{3}) \tag{2}$$

$$v_c(t) = V_{c1}\sin(\omega t + \phi_{c1} + \frac{2\pi}{3}) + \sum_{n=2}^{\infty} V_{cn}\sin(n\omega t + \phi_{cn} + \frac{2\pi}{3}) \tag{3}$$

The above-mentioned equations (1), (2), and (3) signify the phase voltages of D-STATCOM. The phase current and load current is resolute. At this fact, the D-STATCOM estimates the basic rudiments of the load current and compensates harmonic current and reactive power. The comprehensive investigation of the extraction of reference current is designated in the following.

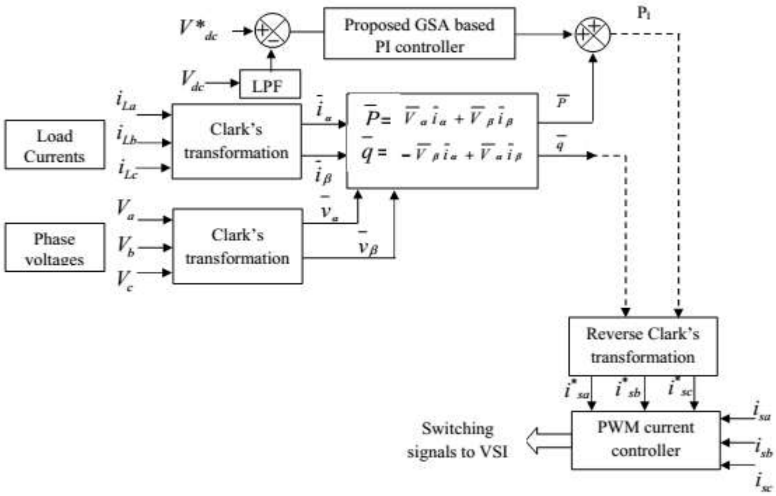


Figure 2. Proposed method based instantaneous reactive power theory

In this section, the reference currents are enchanting out with the help of engaging projected controller together with the I_d-Iq method. Here, the reference currents are produced via the I_d-I_q current component of the nonlinear load. To start with, the D-STATCOM voltages are assimilated from the instantaneous active and reactive current of the nonlinear load [28]. The three phase voltages elements (a, b, c) are deciphered into α-β-0 constituents using engagement of clark transformation. By engaging park transformation, the α-β-0 constituents are transformed into the d-q constituents [29] [30]. The transformation from α-β-0 constituents to d-q-0 components is exemplified as below:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/3 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{4}$$

In the two co-ordinates, the subsequent two equations are dogged.

$$v_\alpha(t) = \sqrt{\frac{3}{2}} V_1 \sin(\omega t + \phi_1) + \sqrt{\frac{3}{2}} \sum_{n=2}^{\infty} V_n \sin(n\omega t + \phi_n) \tag{5}$$

$$v_\beta(t) = -\sqrt{\frac{3}{2}} V_1 \cos(\omega t + \phi_1) - \sqrt{\frac{3}{2}} \sum_{n=2}^{\infty} V_n \cos(n\omega t + \phi_n) \tag{6}$$

The currents in the α and β co-ordinates, the oscillary constituents are removed with the help of the subsequent equation,

$$i_\alpha(t) = \bar{i}_\alpha(t) + \tilde{i}_\alpha(t) \tag{7}$$

$$i_\beta(t) = \bar{i}_\beta(t) + \tilde{i}_\beta(t) \tag{8}$$

The basic voltage and current constituents of the instantaneous power are assessed from the subsequent equations afterward the compensation,

$$\bar{p} = \bar{v}_\alpha(t)\bar{i}_\alpha(t) + \bar{v}_\beta(t)\bar{i}_\beta(t) \tag{9}$$

$$\bar{q} = -\bar{v}_\beta(t)\bar{i}_\alpha(t) + \bar{v}_\alpha(t)\bar{i}_\beta(t) \tag{10}$$

With the help of the subsequent equation, the reference currents are removed and quantified as the following,

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} \bar{v}_\alpha & -\bar{v}_\beta \\ \bar{v}_\beta & \bar{v}_\alpha \end{bmatrix}\begin{bmatrix} \bar{p} \\ \bar{q} \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -\frac{1}{2} & \sqrt{3}/2 & 1/\sqrt{2} \\ -\frac{1}{2} & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \\ i_0^* \end{bmatrix} \tag{12}$$

The reference currents are used to provide the switching pulses of the VSC. The parameter of the dc link voltage is attained with the help of the optimizing the gain parameter of the PI controller.

A. GSA for tuning the gain parameter of PI Controller

In the segment, the GSA is utilized for tuning the gain parameter of PI controller. The input of the GSA algorithm is the improvement of PI controller K_p and K_i. Afterward that, the objective performance is dogged, which is quantified as the average active power loss p_{loss} is diminished. The algorithmic stages to optimize the gain parameter of PI controller are specified in the subsequent segment.

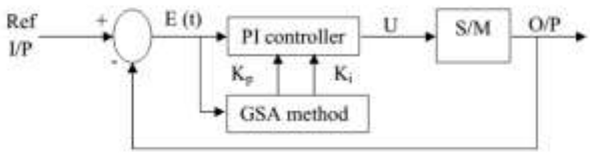


Figure 3. Gain tuning of PI controller using proposed method

The gain parameter of the PI controller is quantified with the help of the succeeding equations,

$$k_p(\delta) = k_p(\delta - 1) + \Delta k_p(\delta - 1) \tag{13}$$

$$k_i(\delta) = k_i(\delta - 1) + \Delta k_i(\delta - 1) \tag{14}$$

The error voltage is assessed with the help of the subsequent equation,

$$EV(\delta) = V_{dc}^*(\delta) - V_{dc}(\delta) \tag{15}$$

From the above mentioned equations, the Kp and Ki are assessed for attaining the optimal solutions. With the help of the equation (15) the error voltage is dogged and the alteration in error voltage is assessed. For attaining the optimal solutions, GSA algorithm is used to tune the gain parameters of PI controller. The comprehensive investigation of the projected technique is designated in the following.

Gravitational Search Algorithm

The maximum fresh character interested population-based stochastic search algorithm that is comprehensively used to decide the optimization issues is the gravitational search algorithm is. E. Rashedi [31] principally presented gravitational search algorithm to solve the optimization trouble chiefly for non linear troubles. The gravitational search algorithm is on the basis of Newton‘s theory. Newton‘s law of gravity describes that each and every element magnetize another element with the help of some gravitational force. The gravitational force between two elements is unswervingly proportionate to the product of their masses and inversely proportional to the square of the distance between them [32]. In presented algorithm elements restrained as objects and their presentation has evaluated with the help of their masses.

Every element in GSA encompasses linked with four qualifications: element location, its inertial mass, active gravitational mass and passive gravitational mass. The site of element provisions the solution of trouble while fitness utility is engaged for computing the gravitational and inertial masses. All population-based algorithms have two capabilities: examination and utilization. This algorithm uses examination aptitude at the formation to avoid inadequate finest trouble and after that application [33]. In the segment, a GSA is utilized for enhancing the function of PI controller and decreasing the power loss of the scheme. From the scheme, the inputs, dc link voltage, error voltage, change in error voltage and consistent outputs of the scheme are found out. On the basis of the output, the power loss is assessed. The inputs of the GSA are the error voltage ($EV(\delta)$) and their alteration in error voltage ($CEV(\delta)$) correspondingly. Here, the inputs are deliberated as the agents. The diminished power loss and their conforming gain parameters can be appraised from the inputs. The optimal outputs are strong-minded on the basis of appraised inputs. The process of the projected algorithm is momentarily elucidated as follows:

Procedure of proposed algorithm

Step 1: Initialization

In the segment, inputs are the error voltage and their alteration in error voltage, gain parameter initiated arbitrarily. Here, the inputs are deliberated as the agents. The position of agents is well-defined using the following equation,

$$\gamma = (\gamma_i^1, \ldots, \gamma_i^d, \ldots \gamma_i^n) \tag{16}$$

Where, n is the search space dimension of the issue, γ_i^d is the position of the i^{th} agent in the d^{th} dimension.

Step 2: Fitness Evaluation of All Agents

The fitness performance of agents is assessed as their minimum of power loss. Their consistent gain parameters from the minimized loss are also assessed. The fitness performance of the agent is considered as follows:

$$F_i = \min(P_l) \tag{17}$$

Where, $$P_l(\delta) = P_l(\delta - 1) + k_p[EV(\delta) - EV(\delta - 1)] + k_i EV(\delta) \tag{18}$$

From the above deliberated equation, the power loss is assessed.

Step 3: Force Evaluation

Here, the force of the agent is considered by the accomplishment of the subsequent functions. At first, the mass of agents are well-defined arbitrarily and regulate the forces of each agent. Here, the force performing on mass i from mass j can be unwavering by,

$$f_{ij}^d(k) = g(t)\left(\frac{M_i(k) * M_j(k)}{r_{ij}(k) + \in}\right)\left(\gamma_j^d(k) - \gamma_i^d(k)\right) \tag{19}$$

Where, $M_i(k)$ and $M_j(k)$ are masses of the agent i and j. Here, $g(k)$ is the gravitational constant, $\in$ is the small constant and $r_{ij}(k)$ is the euclidian distance within i^{th} and j^{th} agents.

Step 4: Computation of Gravitational constant

In the stage, the gravitational constant of the agent is appraised with the help of the subsequent formula,

$$g(k) = g_0 * e^{\left(\frac{-\alpha k}{t_r}\right)} \tag{20}$$

From the above-displayed equation, t_r are the total iterations of the algorithm, g_0 is the primary value and α is the user quantified constant.

Step 5: Evaluation of total force
The total force acts on the agent in k[th] dimension are premeditated as follows,

$$f_i^d(kt) = \sum_{i=1 j \neq i}^{N} rand_i f_{ij}^d(k) \tag{21}$$

Where, $rand_j$ is a random number in the interval [0, 1] and the acceleration is designed.

Step 6: Determination of Acceleration
Acceleration of whichever mass is equal to the force represented on the scheme divided with the help of mass of inertia

$$\alpha_i^d(k) = \frac{f_i^d(k)}{M_i(k)} \tag{22}$$

Step 7: Determination of Mass
Novel positions of the agents and gravitational constant & inertia masses are updated with the help of the subsequent equations.

$$m_i(k) = \frac{fit_i(k) - worst(k)}{best(k) - worst(k)} \tag{23}$$

$$M_i(k) = \frac{m_i(k)}{\sum_{j=1}^{N} m_j(k)} \tag{24}$$

Where, $fit_i(k)$ represents the fitness value of the i^{th} agent at iteration k .

Step 8: Updating velocity and position of agent
Velocity of each mass is considered, the novel position of the masses could be measured updating the agent's velocity and position with the help of the succeeding equation,

$$V_i^d(k+1) = rand \times v_i^d(k) + \alpha_i^d(k) \tag{25}$$

If acceleration and velocity of each and every mass are considered then novel positions of the masses could be measured as trails

$$\gamma_i^d(k+1) = \gamma_i^d(k) + v_i^d(k+1) \tag{26}$$

In which, $V_i^d(k)$ and $\gamma_i^d(k)$ are the velocity and position of an agent at the k time and d dimension, $random_i$ is the random number at the interval at [0, 1].

Step 9: Updating velocity and position of agent
The process is terminated otherwise repeat the step 3-7 after reaching the maximum iteration. Here, the minimized power loss values are considered and their consistent inputs are renowned. On the basis of the fitness performance, the controller gets optimal control pulses and the

conforming gain of the controller is considered. The flowchart of the projected GSA is exemplified in figure 4.

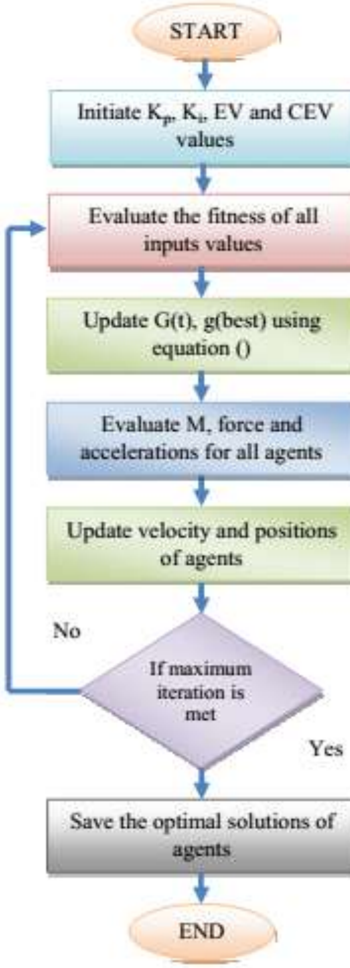


Figure 4. Flowchart of proposed GSA

4. Results and Discussion

A Gravitational search algorithm (GSA) based D-STATCOM is projected for recompensing the PQ in this paper. Primarily, the error voltage ($EV(\delta)$) and the alteration of error voltage ($CEV(\delta)$) are smeared to the input of the GSA and produces the optimal control pulses. For producing the optimal control pulses, the function of the PI controller is enhanced with the help of GSA. The reference current is produced and the minimum power loss is attained in the aspect GSA. Furthermore, the PI controller gain is enhanced by using the projected GSA. An improved PI controller is specified to the optimal control signals to the scheme. The dynamic behavior of the scheme is scrutinized in the name of the parameters like the settling time, rising peak overshoot time and etc. The anticipated GSA method is employed in the Matlab/Simulink platform. The functional investigation of the projected technique is established and compared with the available methods like FLC method and ANN technique. In Figure 5, the Simulink model of the anticipated controller is established. In table 1, the application parameters are investigated and demonstrated.

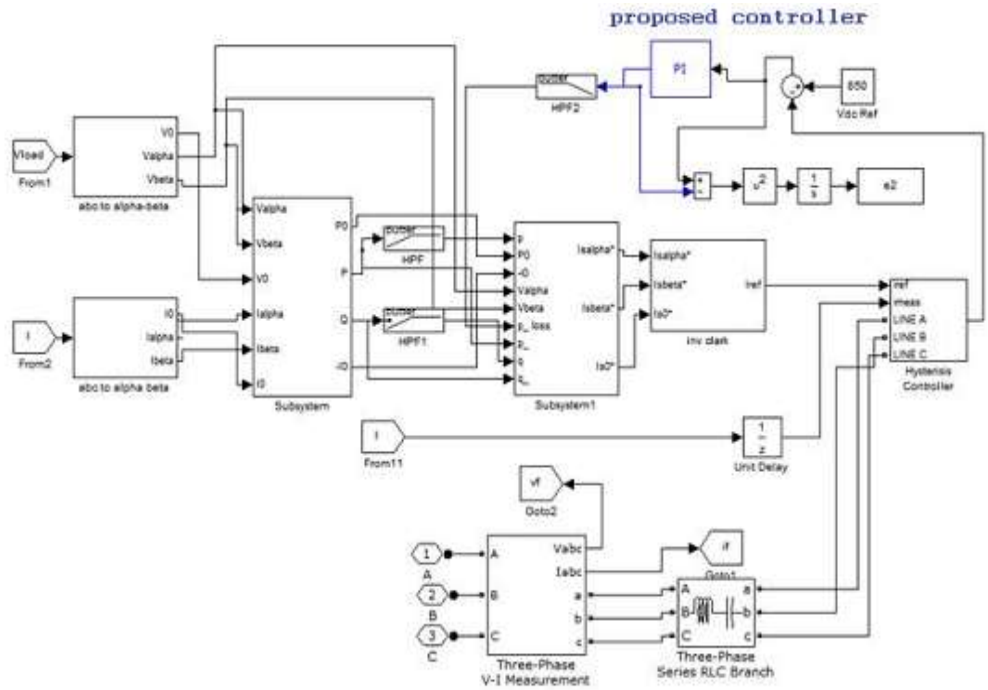


Figure 5. Simulink model of the proposed method based D-STATCOM

Table 1. Implementation parameters of the proposed method

Description of parameters	Values
N	10
Number of solutions	50
Maximum iteration	100
Dimension	1
Alpha	20
Gravitational constant	10

A. Performance analysis

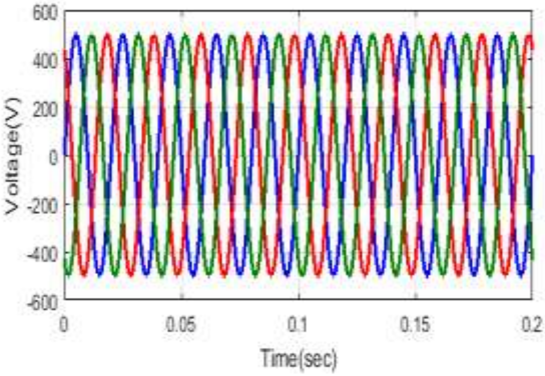
The function of the presented controller is investigated and tested in the sub-segment. The recommended method is used to control the dc link voltage conferring to their control signals. The function of the projected controller is investigated in the sinusoidal supply, trapezoidal and unbalanced circumstances. These investigate of the three settings are fashioned as the various kinds of cases like case 1, case 2 and case 3 correspondingly. The analyzed outputs of the projected technique are associated with FLC technique and ANN methods. The comprehensive analysis of the anticipated method is designated in the succeeding sector.

Case 1: Analysis of Sinusoidal supply

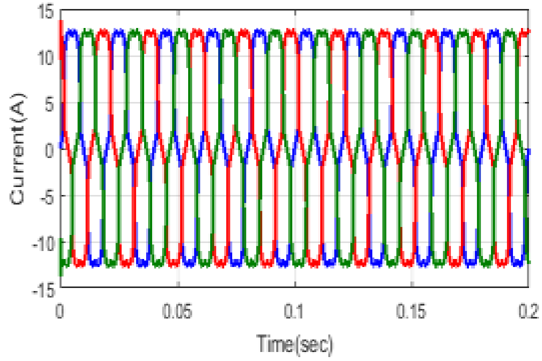
Case 2: Analysis of unbalanced condition

Analysis of Case 1

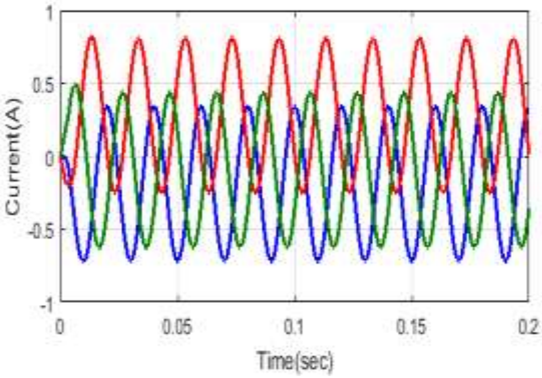
Primarily, the execution of source voltages and currents are studied in the normal condition and delineated in figures 6 (an) and (b). For examining the adequacy of D-STATCOM, the injected current is determined using the projected method. The harmonic levels are measured with the help of projected method based p-q hypothesis and the THD norms similarly reviewed. Here, the deliberate quality comprises unsettling influences and the D-STATCOM fascinates the powers. The implementation of D-STATCOM current signals is delineated in figure 7.



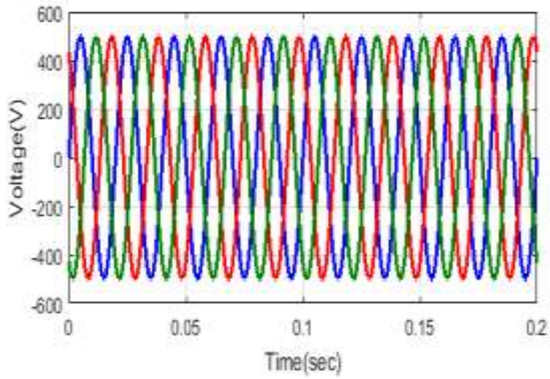
(a)



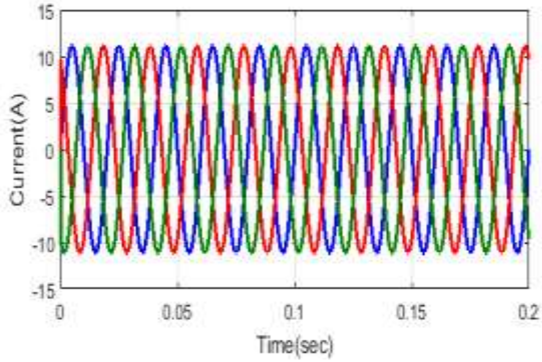
(b)



(c)



(d)



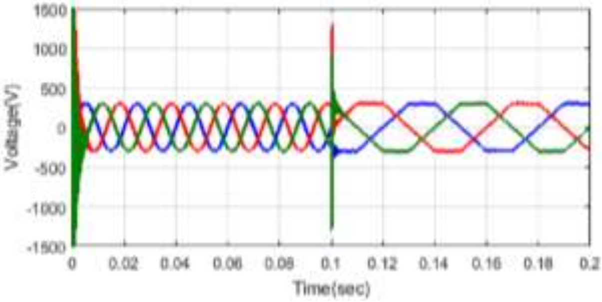
(e)

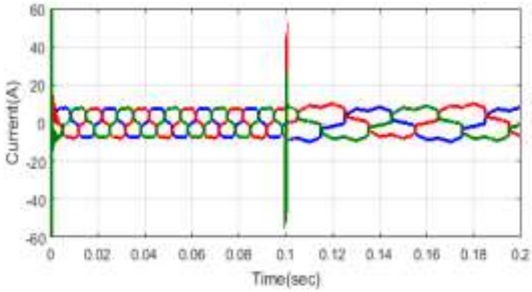
Figure 76. Analysis of (a) source voltage (b) source current (c) injected current (d) load voltage and (e) load current

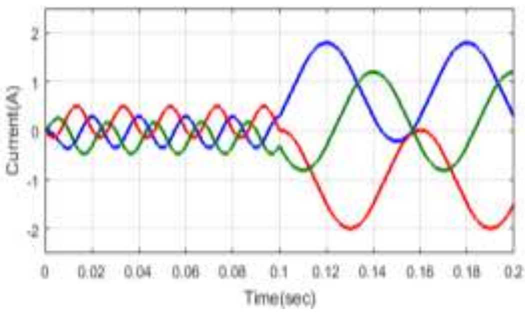
From the complete investigation, the projected technique is efficiently decreasing the current harmonics of the load current. The reference current extraction and the voltage regulation are proficient while using the projected controller. Furthermore, the settling time, rising time and overshoot times are inspected and evaluated the K_p and K_i gain parameters. These are represented in area 4.2. After that, the case 2 exhibitions are dismembered under the accompanying.

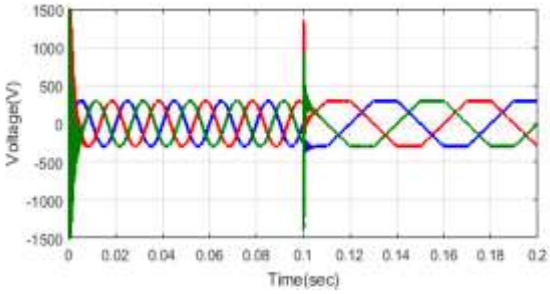
Analysis of Case 2

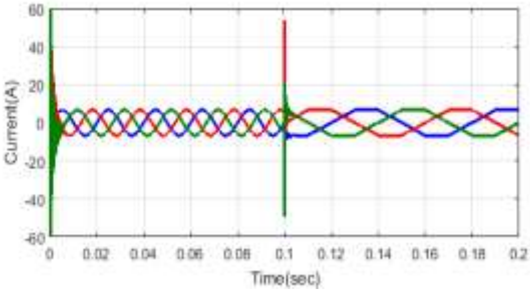
The functions are investigated in the unbalanced condition in the subsection. Here, the sinusoidal and trapezoidal circumstances are concurrently familiarized in the waveform. Consequently, it is completed as the unbalanced condition. Amongst the unbalanced condition, the voltages, currents and injected currents are separated concerning the projected controller, which is characterized in the accompanying figure.


Voltage(V)
1500
1000
500
0
-500
-1000
-1500
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time(sec)
(a)


Current(A)
60
40
20
0
-20
-40
-60
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time(sec)
(b)


Current(A)
2
1
0
-1
-2
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time(sec)
(c)


Voltage(V)
1500
1000
500
0
-500
-1000
-1500
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time(sec)
(d)



(e)

Figure 8. Analysis of (a) source voltage (b) source current (c) load voltage (d)injected current and (e) load current

To achieve study under the unbalanced condition, a harmonic constituent is combined into the supply voltage. For unbalanced supply, a voltage in one of the phases is measured the harmonic remuneration capability of D-STATCOM. An assessment is done among the convergence characteristics of V_{dc} for conventionally tuned and GSA based PI controllers. The simulation waveforms for V_{dc} are investigated in the assessment portions. In the unbalanced supplies have been presented in the Fig. 9.The nature of source current without compensation is specifically same as load current. It is observed that, the nature of current drawn with the help of the same burdens is diverse under different supply conditions. Amongst the season of unbalance in burden current occurs. All the control systems are competent in recompensing the PQ performances, thus harmful consequences because of the harmonics can be evaded.

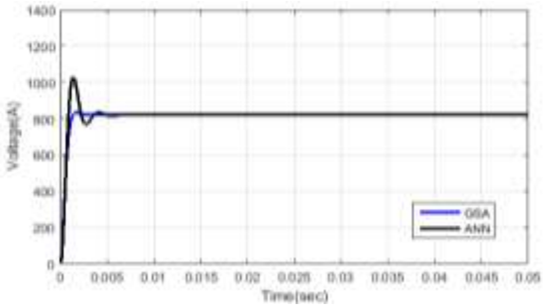
B. Comparison analysis

In the comparison examination, the three cases are investigated and achieved the dc link voltage regulations. At that time, the settling time, overshoot time and rising times are investigated. From the above circumstance, the settling time, rise time and overshoot time are investigated. In the assessment graphs, the rise time is the projected, FLC and ANN approaches are t=0.0932sec, t= 0.4327sec and t=0.9521sec correspondingly. Likewise, the settling time is investigated that is 0.038, 0.0536, 0.814correspondingly. Formerly the overshoot time is 0.0072 sec, 0.0094 and 0.173 sec of the projected and prevailing approaches correspondingly. This valuation displays that the projected technique is the finest technique to disbelieving the nonlinearity in this scheme with great reliability, more robust and good performance than the other methods as can be elucidated in the figure. The THD study of the projected and prevailing approaches are prescribed in table 2.

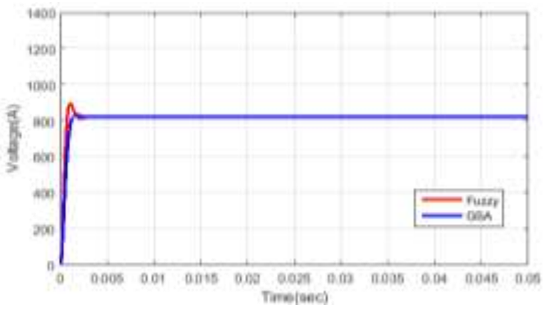
Table 2. THD analysis of the proposed method

Methods	Sinusoidal Supply THD in percentage			Unbalanced Supply THD in percentage		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Without	33.47	33.98	34.36	7.52	7.13	7.25
Conventional p-q	4.47	3.98	4.03	5.74	5.55	5.31
Modified p-q	3.69	3.81	3.84	2.78	2.11	2.16
Id-iq method	3.45	2.97	3.07	8.64	8.03	8.38
ANN-PI	18.36	19.27	18.75	5.51	5.38	5.24
FLC-PI	9.47	9.61	8.34	2.05	1.95	1.91
Proposed controller	4.08	4.02	4.64	7.52	7.13	7.25

The THD comparison of phase A, B, and C of projected and prevailing controller like, Conventional p-q method, modified p-q technique, ANN-PI controller, FLC-PI controller, and proposed controller are accessible and the values are prepared in table 3. The THD investigation of conventional p-q approaches and modified p-q approaches are unwavering from [34]. It displays, the projected controller have very less percentage of harmonics to other control approaches. The minimum THD of projected controller in phase A is 3.02%. Trailed by that, the PI controller gains are enhanced using various tuning algorithm and the values are provided in table 3. The power factor of the scheme is varied before and after recompensing the harmonics issue.



(a)



(b)

Figure 9. Analysis of dc voltages (a) ANN method and (c) FLC method

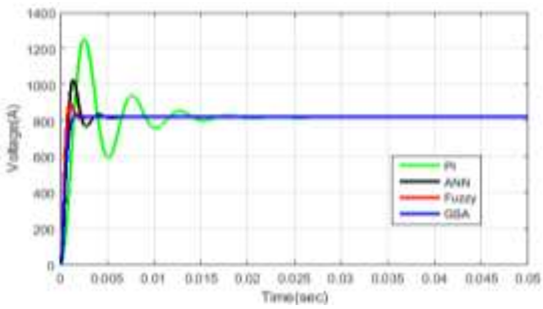


Figure 10. Comparison analysis of (a) dc voltages

The dc link voltage is investigated in different time moments at this point; the dc link voltage can be coordinated with the help of the projected controller and the conventional controller from the above illustrations. The dc link voltage of D-STATCOM is incompletely sustained to the reference value under all influences. The expected method gives closest voltage value to optimal value and moves repetitively. But for the prevailing technique, the voltage values are very far from the optimal one and that cannot be feasible for proposing better voltage. Besides, the gain parameters of the projected and prevailing strategies are investigated and tabularized in the following table.

Table 3. Gain parameters of PI controller using various algorithms

Methods	Controller gain	
	K_P	K_I
Without tuning algorithm	0.921	0.646
ANN-PI controller	1.4893	4.9435
FLC-PI controller	3.7286	3.9683
Proposed PI controller	3.9987	3.9836

Table 4. Tabulation of power factor analysis

Phase	With distortion and no DSTATCOM	ANN based DSTATCOM	FLC based DSTATCOM	Proposed method with DSTATCOM
A	0.9213	0.9465	0.9535	0.9789
B	0.9426	0.9556	0.9743	0.9835
C	0.9568	0.9735	0.9768	0.9931

The current harmonics of the load current is decreased with the help of projected controller due to the reason of good voltage parameter from the above investigation. The THD contrast of phase A, B and C of ANN controller, FLC controller and projected controller are tabularized in table 3. Additionally, the projected controller has the respectable power factor value as 0.9931. The power factor of ANN controller is 0.9768 and FLC controller is 0.9768. Although distinguished with various approaches, the projected controller skilled excellent power factor.

5. Conclusion

The projected GSA process based D-STATCOM is anticipated for reimbursing the PQ problems in this article. For analyzing the PQ problems, three cases are deliberated that are the sinusoidal supply, trapezoidal power supply, and unbalanced supply. The projected controller is executed in the MATLAB/Simulink platform. For recompensing PQ functions the D-STATCOM performances are improved while using the GSA technique. At first, the reference current is extracted with a utilization of the projected technique for mitigating the PQ problems. The dc link voltage regulation is attained by the projected technique. Furthermore, the gain parameters of PI controller are tuned for refining the performance of D-STATCOM. In the projected controller, the load currents are investigated with different time instants and their performances are demonstrated. Formerly the FFT investigation is engaged in the projected technique, ANN controller, and FLC controller. The THD and power factor values are investigated in the projected controller and the available controller. The proportional solutions display that the projected controller can attain a better performance of D-STATCOM and enhance the problems when associated with the available controllers.

6. References

[1]. L.V.Suresh Kumar, G.V.Nagesh Kumar and P.S.Prasanna, "Differential Evolution Based Tuning of Proportional Integral Controller for Modular Multilevel Converter STATCOM", pp.439-446, 2016

[2]. Om Prakash Mahela and Abdul GafoorShaik, "Topological aspects of power quality improvement techniques: A comprehensive overview", *International Journal of Renewable and Sustainable Energy Reviews*, Vol.58, pp.1129–1142, 2016

[3]. M.SahithullahamdA.Senthil Kumar, "A hybrid control strategy to control active filter and improve the PQ of non-linear load", *Australian Journal of Electrical and Electronics Engineering*, pp.1-13, 2016

[4]. Chandan Kumar and Mahesh K.Mishra, "An Improved Hybrid DSTATCOM Topology to Compensate Reactive and Nonlinear Loads", I*EEE transactions on Industrial Electronics*, Vol.61, No.12, pp.6517-6527, 2014

[5]. Law Kah Haw, Mohamed S.A.Dahidah and HaiderA.F.Almurib, "A New Reactive Current Reference Algorithm for STATCOM System Based on Cascaded Multilevel Inverters", *IEEE Transactions on Power Electronics*, Vol.30, No.7, pp.3577-3588, 2015

[6]. Mario Gonzalez, Victor Cardenas and Gerardo Espinosa, "Advantages of the passivity based control in dynamic voltage restorers for power quality improvement", *Simulation Modelling Practice and Theory*, Vol.47, pp.221–235, 2014

[7]. N.N.V.SurendraBabu and B.G.Fernandes, "Cascaded Two-Level Inverter-Based Multilevel STATCOM for High-Power Applications", *IEEE Transactions on Power Delivery*, Vol.29, No.3, pp.993-1001, 2014

[8]. SharadW.Mohod and Mohan V.Aware, "A STATCOM-Control Scheme for Grid Connected Wind Energy System for Power Quality Improvement", *IEEE Systems Journal*, Vol.4, No.3, pp.346-352, 2010

[9]. P.K.Dhal, "Improvement of Stability by Optimal Location with Tuning STATCOM Using Particle Swarm Optimization Algorithm", *International Journal of Applications, Advances in Intelligent Systems and Computing*, Vol.434, pp.583-593, 2016

[10]. M.R.Qader, "A novel strategic-control-based Distribution Static Synchronous Series Compensator (DSSSC) for power quality improvement", *International Journal of Electrical Power and Energy Systems*, Vol.64, pp.1106–1118, 2015

[11]. S.M.Abd-Elazim and E.S.Ali, "Imperialist competitive algorithm for optimal STATCOM design in a multimachine power system", *International Journal of Electrical Power and Energy Systems*, Vol.76, pp.136–146, 2016

[12]. DigvijayB.Kanase, A.R.Thorat and H.T.ladhav, "Distribution Static compensator for Power Quality Improvement using PV Array", *IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, pp.1-5, 2015

[13]. Keyou Wang and MariesaL.Crow, "Power System Voltage Regulation via STATCOM Internal Nonlinear Control", *IEEE Transactions on Power Systems*, Vol.26, No.3, pp.1252-1262, 2011

[14]. G.Farivar, B.HredzakV.G.Agelidis, "Decoupled Control System for Cascaded HBridge Multilevel Converter Based STATCOM", *IEEE Transactions on Industrial Electronics*, Vol.63, No.1, pp.322-331, 2015

[15]. Ilango.K, Bhargav.A, Trivikram.A, Kavya.P.S, Mounika.G and ManjulaG.Nair, "Power Quality Improvement using STATCOM with Renewable Energy Sources", *IEEE 5th India International Conference on Power Electronics (IICPE)*, pp.1-6, 2012

[16]. Xiaofeng Yang, Jianghong Li, Wenbao Fan, Xiaopeng Wang and Trillion Q.Zheng, "Research on Modular Multilevel Converter Based STATCOM", *6th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, pp.2569-2574, 2011

[17]. Sixing Du, Jinjun Liu, Jiliang Lin and Yingjie He, "A Novel DC Voltage Control Method for STATCOM Based on Hybrid Multilevel H-Bridge Converter", *IEEE Transactions on Power Electronics*, Vol.28, No.1, pp.101-111, 2013

[18]. Mohamed S.El-Moursi, BirgitteBak-Jensen and Mansour H.Abdel-Rahman, "Novel STATCOM Controller for Mitigating SSR and Damping Power System Oscillations in a Series Compensated Wind Park", *IEEE Transactions on Power Electronics*, Vol.25, No.2, pp.429-441, 2010

[19]. Susanta Dutta, Provas Kumar Roy and Debashis Nandi, "Optimal location of STATCOM using chemical reaction optimization for reactive power dispatch problem", *International Journal of Ain Shams Engineering*, 2015
[20]. T.Bharath Kumar and M.VenuGopala Rao, "Mitigation of Harmonics and Power Quality Enhancement for SEIG based Wind Farm using ANFIS based STATCOM", *International Conference on Smart Electric Grid (ISEG)*, pp.1-7, 2014
[21]. Soumya Mishra and Pravat Kumar Ray, "Nonlinear modeling and control of a photovoltaic fed improved hybrid D-STATCOM for power quality improvement", *International Journal of Electrical Power and Energy Systems*, Vol.75, pp.245–254, 2016
[22]. M.R.Qader, "Design and simulation of a different innovation controller-based UPFC (unified power flow controller) for the enhancement of power quality", *International Journal of Energy*, Vol.89, pp.576–592, 2015
[23]. S.M.Abd-Elazim and E.S.Ali, "Optimal location of STATCOM in multi-machine power system for increasing loadability by Cuckoo Search algorithm", *International Journal of Electrical Power and Energy Systems*, Vol.80, pp.240–251, 2016
[24]. Abdul Balikci and EyupAkpinar, "A multilevel converter with reduced number of switches in STATCOM for load balancing", *International Journal of Electric Power Systems Research*, Vol.123, pp.164–173, 2015
[25]. Bhim Singh, Sunil Kumar Dube and Sabha Raj Arya, "An improved control algorithm of DSTATCOM for power quality improvement", *International Journal of Electrical Power and Energy Systems*, Vol.64, pp.493–504, 2015
[26]. Esmail YM, Elsayed SK, Mehanna MA., "Mitigation of Voltage Fluctuation in Power Distribution System Using D-STATCOM", *Indonesian Journal of Electrical Engineering and Computer Science*, Vol. 2, No. 3, 2016
[27]. Dawood Amoozegar, "DSTATCOM modelling for voltage stability with fuzzy logic PI current controller", *Electrical Power and Energy Systems*, Vol. 76, pp. 129–135, 2016
[28]. Suresh Mikkili andd Anup Kumar Panda, "Instantaneous Active and Reactive Power and Current Strategies for Current Harmonics Cancellation in 3-ph 4-Wire SHAF with Both PI and Fuzzy Controllers", *Energy and Power Engineering*, Vol.3, pp.285-298, 2011
[29]. M. Sahithullah and A. Senthil Kumar, "A hybrid control strategy to control active filter and improve the PQ of non-linear load and improve the PQ of non-linear load", *Australian Journal of Electrical and Electronics Engineering*, 2016
[30]. Wei Lu, Chunwen Li and Changbo Xu, "Sliding mode control of a shunt hybrid active power filter based on the inverse system method", *Electrical Power and Energy Systems*, Vol. 57, pp. 39–48, 2014
[31]. Soheil Derafshi Beigvand, Hamdi Abdi and Massimo La Scala, "Combined heat and power economic dispatch problem using gravitational search algorithm", *Electric Power Systems Research*, Vol. 133, pp. 160–172, 2016
[32]. S.M. Abd Elazim and E.S. Ali, "Optimal SSSC design for damping power systems oscillations via Gravitational Search Algorithm", *Electrical Power and Energy Systems*, Vol. 82, pp. 161–168, 2016
[33]. Gouthamkumar N, Sharma V, Naresh R., "Disruption based gravitational search algorithm for short term hydrothermal scheduling", *Expert Systems with Applications*, Vol. 42, No. 20, pp. 7000-7011, 2015
[34]. Sushree Sangita Patnaik and Anup Kumar Panda, "Real-time performance analysis and comparison of various control schemes for particle swarm optimization-based shunt active power filters", *Electrical Power and Energy Systems*, Vol. 52, pp. 185–197, 2013