Power quality enhancement using fully informed particle swarm optimization based DSTATCOM in distribution systems

Moguthala Shankar, R. Senthil Kumar
Department of Electrical and Electronics Engineering, Saveetha Engineering College (Autonomous), Anna University, Chennai, Inda

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ABSTRACT

To compensate for the reactive power, inverter-based conditioners have been utilized in recent years due to their faster response. Distribution static synchronous compensator (DSTATCOM) has been utilized to enhance power quality in power system that is an inverter-based device that is widely utilized. To control this type of equipment, a proportional integrated (PI) controller has been utilized to control most of the equipment with respect to certain parameters. The performance of the controller basically does not meet the expectations because of the dynamics and nonlinearity of a system parameters. In this present paper, a probabilistic neural network has been used in a controller with a fully informed particle swarm optimization (FIPSO) algorithm to generate a suitable weight for controlling the axes of various parameters of DSTATCOMs. Using MATLAB/Simulink software, simulations were performed, and the responses were monitored with particular regard to the reference reactive parameter. The results are compared. DSTATCOM improves power system damping.

Corresponding Author:

Moguthala Shankar
Department of Electrical and Electronics Engineering, Saveetha Engineering College (Autonomous)
Anna University
Chennai, Tamil Nadu, India
Email: nnrgshankar@gmail.com

1. INTRODUCTION

Numerous researchers have looked into power quality concerns such as neutral current compensation, voltage sag, swelling, and voltage instability. These problems lead to a slower response, lower power flow limits, and the system collapse. All these things were a condition for the development of new equipment to improve the quality of electricity, especially on the customer's side. Power electronic device distribution static synchronous compensator (DSTATCOM) attempts to restore power quality on the distribution system's source and load sides [1]. When compared to other devices used methods such as dynamic voltage restorer (DVR), unified power-quality conditioner (UPQC), interline power-flow controller (IPFC), DSTATCOM offers numerous advantages like low cost, low loss, size is compact, and less harmonic generation. One of DSTATCOM's unique benefits is its ability to provide quick, continuous, and uninterrupted inductive or capacitive compensation. Based on the specified load, the DSTATCOM injects a significant amount of the leading along with the lagging compensation current to match the utility connection's total demand [2], [3]. The DSTATCOM began to function dynamically in the radial distribution system as a result of this type of injection. Reactive compensation has been the primary use of this kind of DSTATCOM controller in induction generators in recent years. The control algorithm typically determines DSTATCOM compliance in each given application [4], [5] explained DSTATCOM control using a fixed-parameter proportional integral (PI) controller and offered three different control methods such as P, PI, proportional integral derivative (PID) for producing reference current components [6]. A DSTATCOM connected to a distributed generation distribution network features a nonlinear controller to control the grid voltage used self-tuning filters and instantaneous reactive power theory to construct an algorithm for DSTATCOM. Some researchers used it to dampen the system in addition to controlling the exchange of reactive power [7], [8]. Reference values for DSTATCOM control are often acquired via PI controllers, primarily the ‘d’ and ‘q’ axis currents. Data mining is typically done in a linear controller, which necessitates the use of a mathematical model. In this model, the various parameters have been tuned to produce the optimum outcomes for a certain region under constrained conditions. These controllers, which were created using a linear mathematical model, perform poorly in nonlinear system dynamics, mostly due to load disturbance and parameter changes [9]. Until now, linearized models utilized for DSTATCOM control were also reported. Some authors created a nonlinear controller for basic power system models using an intricate Lyapunov technique, which is not applicable to all situations [10], [11].

Recently, fuzzy logic and an artificial neural network controller were utilized to control DSTATCOM as a substitute for a general controller. The necessity and advantages of fuzzy logic along with the neural network-based controllers in a grid system were covered in. One significant benefit that will demonstrate good response times is the controllers created with the expert system do not need a mathematical model [12], [13]. This kind of controller is different from the traditional linear controller in that it allows for a broad variety of system operating circumstances, regardless of task complexity. Selecting the controller's inputs that are truly important might improve performance even further; this topic is covered in further detail in this article [14]. Considering all these problems, fully informed particle swarm optimization (FIPSO) is suggested along with a probabilistic neural network (PNN)-PI controller to control the DSTATCOM 'd' and q axes. PNNs appear to provide more effective solutions for a range of control issues [15], [16]. The fact that PNNs can solve intricate, nonlinear, and mathematical problems in real-world dynamical systems certainly draws researchers to employ them in controller design. Gaining the right weight and losing weight, however, are difficult tasks. Weight adjustment applications are primarily built by human professionals and rely on many controllers [17]. However, it takes a great deal of expertise, time, and patience, and the tuning and design weight might not be ideal. There has been a lot of research on estimating the appropriate weight needed for controller design fully informed particle swarm optimization (FIPSO) is used to extract the weight, this approach has been utilized to predetermine the weight function on the input properties. Initial settings for these functions are set in order to accommodate changing parameters. When compared to other algorithms FIPSO algorithm give better accuracy and takes less time, which can be applicable for all the networks maintaining unique algorithm. Fully informed PSO requires less terminal parameter data compared to other algorithms. The suggested controller is put into practice, simulated, and found to have superior qualities than the conventional controller [18], [19]. The work addresses PNN-PI, PNN FIPSO controller design, and mathematical modeling of DSTATCOM in order of precedence. The significant initiatives that have fueled and guided particle swarm research, along with some significant new uses and avenues. The two-step PSO and the PSO-support vector machine (PSO-SVM), demonstrate the quick adaptation of PSO [20]. Stunning outcomes have also been produced by the PSO's integration and practical application with the industry-standard method. The inertia weight, mutation operators, and swarm startup [21]. This overview's primary benefit was emphasizing how crucial it is to introduce several mutation operators and the inertia weight parameter in order to enhance PSO performance [22]. The PSO algorithm, as well as doing a theoretical examination of the system. Then, they examined its current use and research in engineering applications, discrete and parallel PSO algorithms, parameter selection, multi-objective optimization, algorithm structure, and topological structure. Despite the successful application of PSO in various domains, there are still challenges that need to be addressed and considered as future research directions [23], [24]. Over the past few years, PSO has garnered significant interest from researchers and has been applied in diverse areas [25]. However, there are still critical problems and issues that persist [26], [27]. Therefore, it is imperative for scholars and researchers to dedicate more research efforts towards overcoming these challenges and issues that could potentially hinder the future application of PSO. The research community should focus on addressing new methodologies for complex problems [28], [29].

2. DSTATCOM MODELLING

A 3 MVAR DSTATCOM had been connected in the parallel with load on B3 to raising a load voltage, as depicted in the given Figure 1. The sources of voltage are directly connected to B1, B2, and B3 through a network of 21 km feeders, while the generated energy travels through B1, B2, and B3. In order to connect B2 and B3, a 2 km feeder is utilized in this. They have been connected in the B3 via a 25/0.6 step-down distribution transformer so that both variable and fixed loads can be studied. Connecting a load especially a variable load is meant to alter the voltage and current flowing through bus B3. The DSTATCOM absorbs or generates reactive power on the B3 bus to regulate voltage. Using the coupling transformer's leaky reactance to create a secondary voltage in the phase having the primary voltage, reactive power will be sent to the grid.

The DSTATCOM's pulse-width modulated (PWM) voltage inverter provides voltage support. When the secondary voltage drops below the system bus voltage, DSATCOM functions as an inductor by absorbing reactive power conversely, when the secondary voltage rises above the bus voltage, it functions as a capacitor by producing reactive power. Table 1 gives the parameters and values used for the study of source voltage, line voltage, and constant and variable load.

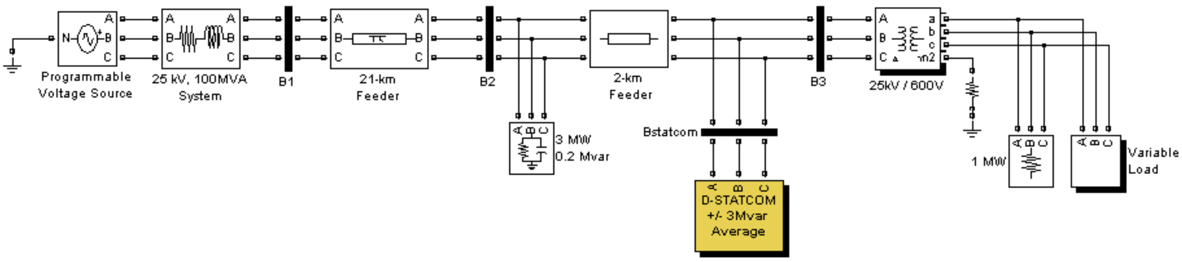

Figure 1. System configuration of a distribution system

Table 1. System parameters

System quantities	Values
Line voltage	25000 V
Source voltage	25000 V
Feeder resistance R	0.1155 Ω/ km
Feeder capacitance C	11.36 nF/km
Feeder inductance L	1.049 mh/km
Frequency	50 hz
Variable load	1.8 MVA, pf=0.9 1.2 MVA having the Mod. freq of 5 Hz
Fixed load at bus 2	3 MVA, pf=0.998
Fixed load	1 MVA, pf=1
The reference voltage of the DC bus	2400 V
Capacitor of DC bus	10000 microfarad

3. PROBABILISTIC NEURAL NETWORKS (PNNs)

PNNs use a Bayesian decision strategy in a distribution system. A PNN has been guaranteed to converge with enough training data. It does not require learning and initial network weights. This had been one of the supervised learning networks. Figure 2 gives the detailed architecture structure for working out with the different weights (inputs). This network is suitable for any real-time problems because it learns quickly. Input units without much deviation distribute their values to the unit of the next layer, which is the sample unit. In each training unit, there has been one pattern unit for every pattern. In every pattern unit, the weight vectors are duplicates of the corresponding example. During training, the addition of the selected weight vector is performed. In this work, the training example is differentiated based on the probability density function, which has been the basic function of a PNN.

A simple partial differential function is as follows.

$$f_k(X) = \frac{1}{N_k}\sum_{j=1}^{N_k} exp\left(\frac{\|X-X_{kj}\|}{2\sigma^2}\right) \quad (1)$$

By adjusting and applying the above equation to output vector H of the hidden layer in the architecture.

$$H_h = exp\left(\frac{\sum_i (X-X_{kj})^2}{2\sigma^2}\right) \quad (2)$$

$\text{Net}_j = \frac{1}{N_k}\sum_h N_{n\,j}^{h\,y} H_h$ and $N_j = \sum_h W_{n\,j}^{h\,y}$

$\text{Net}_j\ max_k(net_k)$ then $y_i = 1$, else $y_j = 0$

Here i is the number of input layers, h is the number of hidden layers, j is the number of output layers, k is the number of training exemplars, N is the number of classifications, σ is the smoothing parameters, and X is input vector. $\|X - X_{kj}\|$ is the Euclidean distance among the vectors X and X_{kj} i.e., $\|X - X_{kj}\| = \sum_i (X - X_{kj})^2, W_{i\,h}^{x\,h}$ is the connection weight between the input layer X and M and $W_{n\,j}^{h\,y}$ as connection weight among hidden layer and the output layers.

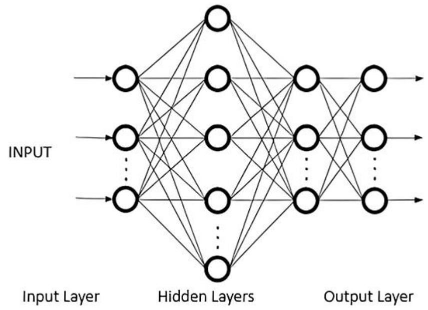

Figure 2. Architecture of PNN

4. FULLY INFORMED PARTICLE SWARM OPTIMIZATION

The global version of the particle swarm optimization is the fully informed particle swarm (FIPS). Like normal PSO, the FIPSO also adapts the best position of every neighbourhood particle as depicted in (3).

$$v_i^{\,t+1} = k\left[v_i^{\,t} + \frac{\varphi_{max}}{|N_i|}\sum_{k=N_i} U \otimes (pb_k^{\,t} - x_i^{\,t})\right]$$

$$x_i^{\,t+1} = x_i^{\,t} + v_i^{\,t+1} \tag{3}$$

Where $x_i^{\,t}$ denoted as the position of the i^{th} particle in iteration 't', $v_i^{\,t}$ denoted as the velocity of the i^{th} particle in iteration 't', $pb_k^{\,t}$ is the best position of k^{th} particle in iteration 't', k is the constriction coefficient, N_i is denoted as the set of the neighborhood particles of the i^{th} particle, $|N_i|$ denoted as the number of the neighborhood particle of the j^{th} particle, φ_{max} is the learning coefficient, U is the random vector in the interval (0,1), and $\otimes$ is the element-by-element vector multiplication. The learning coefficient φ_{max} and constriction coefficient k must be fixed according to requirements respectively. The population size has to be assumed suitably. The initial position of the particles is formed randomly. A greater number of iterations is needed for high-dimensional optimization problems. Here, to solve two locations of the particles were altered to decrease the number of iterations

5. RESULTS AND DISCUSSION

5.1. PNN–PI controller

All that was involved with the well-known classic control system which is frequently employed in place of other controller types was a linear PI controller. Due to the fact that this controller is linear, it is unsuitable for a system that deals with nonlinearity. For the nonlinear system, a PNN controller is utilized as an alternative. Because this PNN controller does not require a mathematical model to control any type of system, it has been broadly utilized in systems having complex structures. To execute the process. The input signals for training are determined randomly. Learning is set to a learning rate of 0.01 and a target error of 0.001. 30 data points from every class are taken for testing and 15 data points from each class are used to train the network. Every time the network repeats, the weights are updated, providing the network with a fresh training input. 30 randomly chosen samples are used to evaluate the PNN.

5.2. PNN controller by fully informed particle swarm optimization

This method is carried out using a set of error-free, two-dimensional inputs, and outputs that are produced by the model operation. Sampling of the input character, which is an error, and changes in the errors were performed periodically on the basis of output. This method created the weights automatically when the data was generated. The number of retrieved weights for input and output is constrained to predetermined criteria in this case by means of FIPSO. With this information, PNN analysis was performed as usual by creating input and output weights using the MATLAB toolkit. The 'd' and 'q' axes' current is regulated by a PI controller, which takes the role of the outputs that this controller estimated. Figures 3 and 4 display the effects of the PI-controller, and PNN- FIPSO controller simulation results for the change of Iq and Iq_{ref}.

According to the data, the PNN controller constructed with FIPSO has a reduced overshoot between Iq and Iq_{ref} than the PI controller. With the improved PNN with FIPSO controller time processing is achieved better output than the conventional controllers. The well-known conventional classic control system can be used only for linear systems but by using the PNN controller constructed with FIPSO which can be used for both the linear and non-linear systems. So, by considering all the features of the PSO algorithm FIPSO can be applied to a power system to improve the performance for many problems related to power quality improvement. Figures 5 and 6 show the differences in the average DC voltage that have been depicted in, for a given parameter, the peak time & rise time of FIPSO were greater in comparison to other approaches.

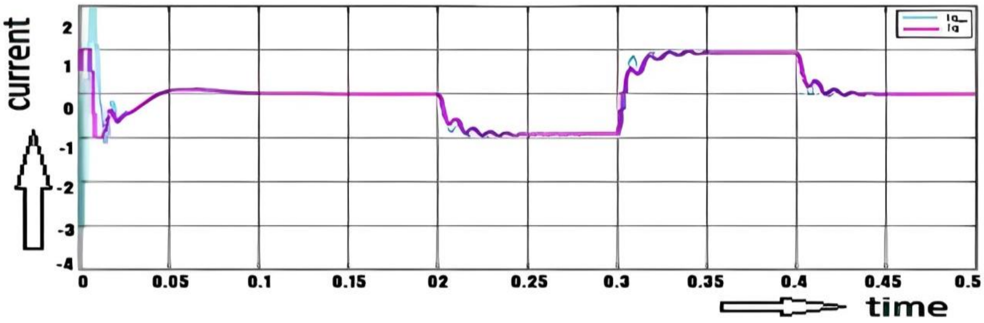

Figure 3. Simulation outcomes of PI controller of Iq and Iq_{ref}

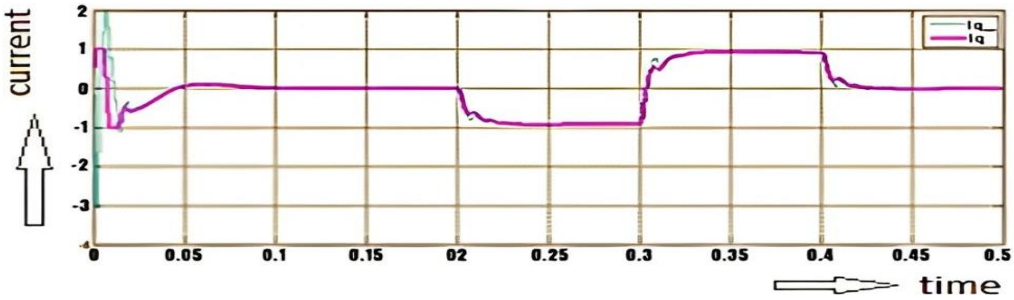

Figure 4. Simulation result of PNN-FIPSO controller for variation of Iq and Iq_{ref}

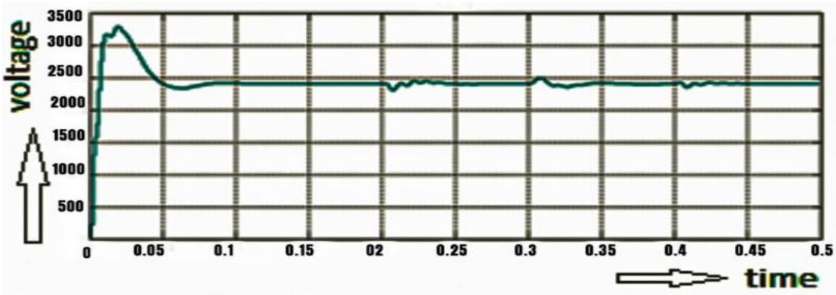

Figure 5. Variation of the average DC voltage with PI controller

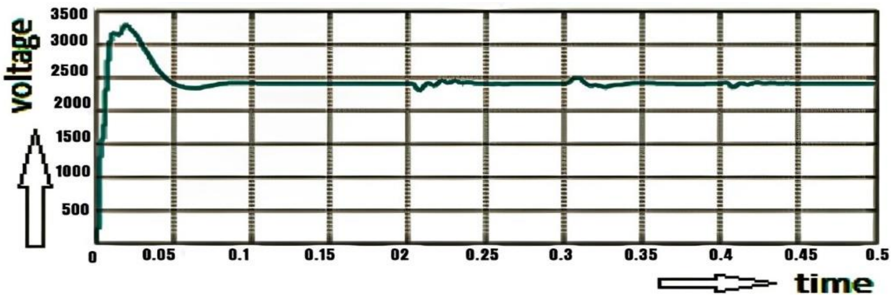

Figure 6. Variation of average DC voltage with PNN-FIPSO controller

6. CONCLUSION

This paper represented a PNN controller design by FIPSO for DSTATCOM to increase the power quality of the distribution system. The MATLAB/Simulink platform has been utilized to test the complete system. The PNN-FIPSO controller and the conventional PI controller are used to compare and show better outcomes. In contrast to other conventional approaches, the comparison results demonstrate that the PNN controller constructed using FIPSO delivers better reactions to the change in reference reactive current. With the suggested controller, Q34, the parameters rise and peak times are longer. From this, the FIPSO approach proves to be the best substitute for another traditional method for solving complex tasks such as complex mathematical modeling tasks. This method can be applied to a power system to increase performance for any problems related to power quality improvement. This paper presents a novel information-sharing-oriented PSO algorithm named FIPSO. Unlike the conventional PSO algorithm, enhancements have been implemented in two key aspects. Firstly, a new information-sharing mechanism has been introduced where the worst location of each particle and the worst location of the entire swarm are both tracked. This innovative approach directs the particles to move away from the worst particle and swarm locations, thereby expanding the global search space and minimizing the risk of particles getting trapped in local optima. Additionally, it presents a particle competitive strategy that encourages the worst information to challenge the best. This approach not only lowers the chances of getting stuck in a suboptimal solution but also enhances the likelihood of reaching the best solution.

Moreover, the time complexity is only twice that of the conventional PSO algorithm. To summarize, this paper initially examined the effectiveness of PSO in comparison to GA and concluded that PSO outperforms GA. Subsequently, the limitations of the standard PSO were analyzed. Based on this analysis, a novel PSO algorithm called FIPSO was introduced. The experimental findings demonstrated that FIPSO surpasses both the traditional PSO and the GA algorithm when applied to benchmark functions. Notably, FIPSO exhibits remarkable enhancements in successfully identifying optimal solutions, particularly for challenging functions.

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BIOGRAPHIES OF AUTHORS

Moguthala Shankar has received a B.Tech. and M.Tech. from JNTU Hyderabad, India, in 2012 and 2015 respectively, and pursuing a Ph.D. at Anna University, Chennai, Tamil Nadu, India. He has presented technical papers in various national and international journals and conferences. His areas of interest include power electronics, power quality, multi-level inverters neural networks, and fuzzy logic. He can be contacted at email: nnrgshankar@gmail.com.

Dr. R. Senthil Kumar currently is working as a professor in the Electrical and Electronics Engineering Department of Saveetha Engineering College (Autonomous), Chennai, and Tamil Nadu. He has done B.E. in electrical engineering from the University College of Engineering (guindy) and an M.E. and Ph.D. from Anna University, Chennai, Tamil Nadu, India. His main research directions include artificial intelligence (neural networks, fuzzy logic, genetic algorithm, particle swarm optimization, and imperialist competitive algorithm) gravitational search algorithm, power quality, and proportional-integral controller. He has published 25 international journal papers, 15 international conference papers, and 2 National Conference papers and also published a book named Special Electrical Machines in the year 2009. Reviewer of the book - Basic Electrical and Electronics Engineering – Charulatha Publications and reviewer of the Journal in International Journal of Electrical Engineering and Technology and the Journal of IET in Power Electronics. His areas of research interest are renewable and non-renewable energy sources, power converters, and electrical machines. He is a professional member of IEI, IEEE, ISTE, and UACEE. He is one of the members of the advisory committee for one of the leading engineering colleges. He can be contacted at email: senthilkumar@saveetha.ac.in.