ANN Control of DSTATCOM for Improving Power Quality and Dynamic Performance

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Abstract: *Distribution power system has poor power quality and dynamic performance due to insufficient reactive power support during disturbances. Distribution Static Compensator (DSTATCOM) can improve the power quality and dynamic performance of distribution power system. Proportional and Integral (PI) controllers are often used to control the operation of the DSTATCOM for the distribution power system. However, since the power system is highly nonlinear and subject to various disturbances, the PI controlled DSTATCOM cannot provide optimal performance for different operating points. More robust controllers such as the one based on fuzzy logic approach are required for the DSTATCOM to provide adequate dynamic voltage control and to improve power quality and stability of the distribution power system. This thesis presents the design of a fuzzy logic based controller of a 3MVA DSTATCOM for improving the power quality and stability of a distribution power system. Grey Wolf Optimization (GWO) algorithm has been used to tune the scaling factors of the fuzzy logic controllers. Comparison study of PI controlled, fuzzy logic and ANN controlled DSTATCOM for improving the power quality and dynamic performance of a distribution power system is simulated using Sim Power System in MATLAB/Simulink environment. The performances of the DSTATCOM controllers are evaluated during grid side voltage sag and load variation. The simulation results in MATLAB/Sim Power Systems show that the ANN controlled DSTATCOM controller provides better system dynamic response and hence improves power quality and stability for the distribution power system.*

Keywords: Distribution power system, ANN control in DSTATCOM, Grey Wolf Optimization (GWO) algorithm, MATLAB/Sim Power Systems

1. INTRODUCTION

As of late the development in the utilization of sensitive loads in all enterprises has caused numerous unsettling influences, for example, voltage sags, swells, transient and unbalance. These sorts of unsettling influences which caused glitch or close down and watch out for income misfortunes. A few strategies are accessible to avert hardware mal activity because of voltage swells and sags. One of commonly utilized techniques is the utilization of DSTATCOM so as to alleviate voltage swells and voltage sags. The shunt controller, likewise known under the name, Distribution static compensator" or DSTATCOM. DSTATCOM is a vital instrument to alleviate unsettling influences identified with power quality issues in the distribution network. One of the pivotal aggravations in the electrical network is voltage swells. The current DSTATCOM as appeared in Figure 1.1, comprises of a Voltage Source Inverter (VSI), shunt infusion transformer, separating plan and a vitality stockpiling gadget may that be associated with the dc-link. Voltage sags/swells can happen more as often as possible than other power quality wonder. These sags/swells are the most essential power quality issues in the power distribution framework. The principle goal of this theory is to examine and propose a setup of DSTATCOM so as to grow such gadget for voltage swells, sags relief and for reactive power compensation in the network.

The limit of the created gadget is about 25KVA. This model is assessed and tried in the research center and later it will be tried in the business.

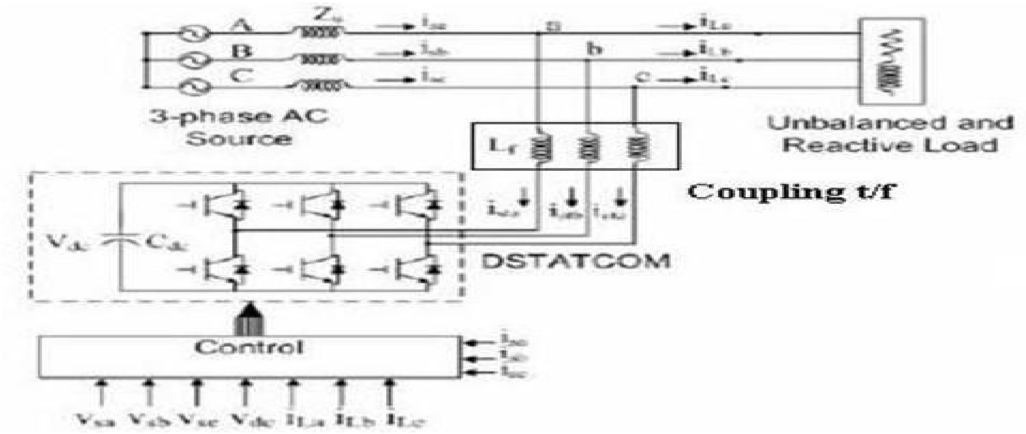


Figure 1.1: Basic circuit diagram of DSTATCOM

1.1. DSTATCOM OPERATING PRINCIPLE

A DSTATCOM is a controlled reactive source which Includes a Voltage Source Converter (VSC) and a DC link capacitor associated in shunt, fit for producing and/or engrossing reactive power. It is comparable to a perfect synchronous machine, which creates a reasonable arrangement of three sinusoidal voltages at the major recurrence with controllable abundancy and stage point. This perfect machine has no dormancy, gives an immediate reaction, does not modify the framework impedances, and can inside create reactive (both capacitive and inductive reactive power) [4]. Fig.2 demonstrates the essential structure of a DSTATCOM. In the event that the output voltage of the VSC is equivalent to the AC terminal voltage; no reactive power is conveyed to the framework. In the event that the output voltage is more prominent than the AC terminal voltage, the DSTATCOM is in the capacitive method of activity and the other way around. The amount of reactive power stream is corresponding to the distinction in the two voltages.

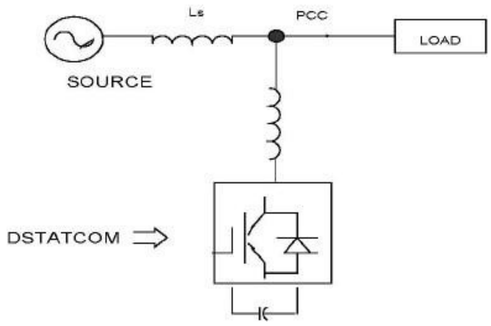


Figure1.2. Basic structure of DSTATCOM

It is to be noticed that voltage control at Point of Common Coupling (PCC) and power factor rectification can't be accomplished at the same time [5]. For a DSTATCOM utilized for voltage control at PCC the compensation ought to be to such an extent that the supply currents should lead the supply voltages and for power factor redress the supply current ought to be in stage with the supply voltages. The control calculations considered in this proposition are connected with a view to ponder the execution of a DSTATCOM for reactive power compensation and power factor redress.

2. PAST WORK

A. Banerji, S. K. Biswas, and B. Singh, et.al[1] Distribution power framework has poor power quality and dynamic execution because of deficient reactive power bolster amid unsettling influences. Distribution Static Compensator (DSTATCOM) can enhance the power quality and dynamic execution of distribution power framework. Corresponding and Integral (PI) controllers are regularly used to control the task of the DSTATCOM for the distribution power framework.

K. Schipman and F. Delince et.al [2] Proportional and Integral (PI) controllers are frequently used to control the activity of the Distribution Static Compensator (DSTATCOM) for the distribution power framework. Be that as it may, since the power framework is exceptionally nonlinear and subject to different aggravations, the PI controlled DSTATCOM can't give ideal execution to various working focuses.

D. Masand, S. Jain, G.et.al[3] Effort for development of power quality in distribution frameworks has been step by step expanded. Customarily, settled, mechanical exchanged reactor/capacitor banks and Static Var Compensator have been utilized for enhancing the power quality issue in distribution frameworks. As of late, utilizations of inverter based power quality conditioner have been developing for reactive power compensation in distribution frameworks, since their reaction is quicker than that of the regular compensators.

Singh, B., Kant, K., Arya, S.et.al,[4] The DC-link voltage of VSC utilized as DSTATCOM is directed by the SMC which smothers undershoots and overshoots in the DC-link voltage. This paper displays an execution of sliding mode controller (SMC) alongside a Fuzzy controller for a DSTATCOM (Distribution Static Compensator) for enhancing current incited power quality issues and voltage direction of three-stage self-energized enlistment generator (SEIG). DSTATCOM is a shunt-associated custom power gadget uniquely intended for power factor redress, current music sifting and load adjusting. It can likewise be utilized for voltage direction at a distribution transport.

Times New Roman et.al [5] Accumulation of power request due to raise the industrialization and populace, vitality age is veritably a testing in now a days. Enhancement of power quality is the more noteworthy worry in cutting edge power framework component, it is fundamental to assemble the need of vitality by utilize the sustainable power source producing sources like pv, energy component, biomass, wind, and so on and using a lot more applications like matrix interconnected frameworks, power quality enhancement.

Tarak Salmi, et al.[6] The Power quality has turned out to be a standout amongst the most indispensable issue to both electric utilities and end level clients of electric power • Automation has totally changed the heap nature because of across the board utilization of power electronic based drives, for example, movable speed drives, Energy proficient lighting, PC's, office extras and so on.

Cirstea, M., Dinu, A., Khor, J., et.al.,[7] In assembling forms it is perpetually required to control certain procedure parameters to keep up a stipulated dimension of value. Process control truly implies that every one of the parameters of the procedure are kept at their separate set qualities subject to reasonable deviation from the set or reference esteem (i.e. inside passable resilience).

S. Pande, R. Kansal, et.al.,[8] Essentially, it is noteworthy to supply the buyer with solid and adequate power. Since, power quality is estimated by the consistency in recurrence and power stream between control territories. Along these lines, in a power framework task and control, Automatic Generation Control (AGC) assumes a vital job.

3. CONTROL TECHNIQUES FOR DSTATCOM

PI controller:

The general block diagram of the PI speed controller is shown in Figure 3.1

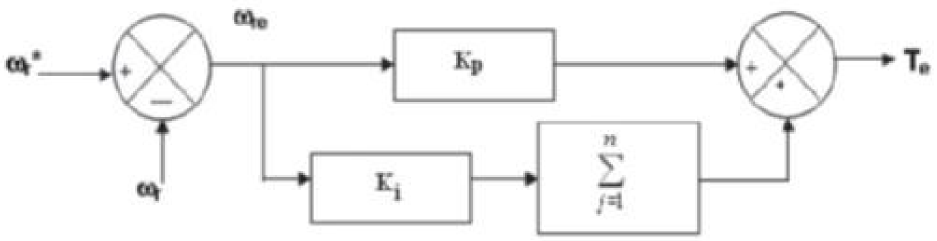


Figure 3.1. Block Diagram of Pi Speed Controller

The output of the speed controller (torque command) at *n*-th instant is expressed as follows:

$$Te\ (n)=Te(n-1)+Kp\_\omega re(n)+Ki\omega re(n)$$

Where *Te* (*n*) is the torque output of the controller at the *n*-th instant, and *Kp* and K*i* the Proportional and integral gain constants,respectively.
A limit of the torque command is imposed as

$$T_{e(n+1)}=\begin{cases} T_{e\max} & \text{for} \quad T_{e(n+1)}\geq T_{e\max} \\ -T_{e\max} & \text{for} \quad T_{e(n+1)}\leq -T_{e\max} \end{cases}$$

The gains of PI controller shown in (10) can be selected by many methods such as trial and error method, Ziegler–Nichols method and evolutionary techniques-based searching. The Numerical values of these controller gains depend on the ratings of the motor.

Advantages and Disadvantages

- The integral term in a PI controller causes the steady-state error to reduce to zero, which is not the case for proportional-only control in general.
- The lack of derivative action may make the system more steady in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs.
- Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach setpoint and slower to respond to perturbations than a well-tuned PID system may be.

Integral Action and PI Control

- Like the P-Only controller, the Proportional-Integral (PI) algorithm computes and transmits a controller output (CO) signal every sample time, T, to the final control element (e.g., valve, variable speed pump). The computed CO from the PI algorithm is influenced by the controller tuning parameters and the controller error, e(t).
- PI controllers have two tuning parameters to adjust. While this makes them more challenging to tune than a P-Only controller, they are not as complex as the three parameter PID controller.

- Integral action enables PI controllers to eliminate offset, a major weakness of a P-only controller. Thus, PI controllers provide a balance of complexity and capability that makes them by far the most widely used algorithm in process control applications.

The PI Algorithm

While different vendors cast what is essentially the same algorithm in different forms, here we explore what is variously described as the dependent, ideal, continuous, position form:

$$CO = CO_{bias} + Kc \cdot e(t) + \frac{Kc}{Ti}\int e(t)dt$$

CO=Controlled Output Signal CO_{bias}=Controlled bias e(t)=Current Controlled Error pv=Measured Process Variable kc=Controlled Gain, T_1=Rest time

The first two terms to the right of the equal sign are identical to the P-Only controller referenced at the top of this article.

The integral mode of the controller is the last term of the equation. Its function is to integrate or continually sum the controller error, e(t), over time.

- It provides a separate weight to the integral term so the influence of integral action can be independently adjusted.
- It is in the denominator so smaller values provide a larger weight to (i.e. increase the influence of) the integral term.
- It has units of time so it is always positive.

Function of the Proportional Term

As with the P-Only controller, the proportional term of the PI controller, Kc·e(t), adds or subtracts from CO_{bias} based on the size of controller error e(t) at each time t.As e(t) grows or shrinks, the amount added to CO_{bias} grows or shrinks immediately and proportionately. The past history and current trajectory of the controller error have no influence on the proportional term computation.

The plot below (click for a large view) illustrates this idea for a set point response. The error used in the proportional calculation is shown on the plot:

- At time t = 25 min, e(25) = 60–56 = 4
- At time t = 40 min, e(40) = 60–62 = –2 The plot below (click for a large view) illustrates this idea for a set point response. The error used in the proportional.

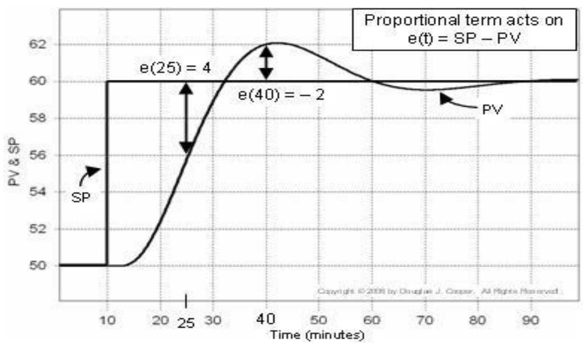
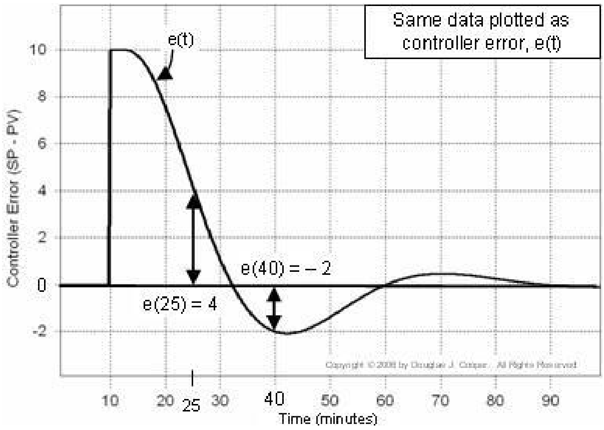


Figure 3.2. Proportional Integral

Recalling that controller error e(t) = SP – PV, rather than viewing PV and SP as separate traces as we do above, we can compute and plot e(t) at each point in time t.

Below click for a large view is the identical data to that above only it is recast as a plot of e(t) itself. Notice that in the plot above, PV = SP = 50 for the first 10 min, while in the error plot below, e(t) = 0 for the same time period.



This plot is useful as it helps us visualize how controller error continually changes size and sign as time passes.

GREY WOLF OPTIMIZATION ALGORITHM

Grey wolf optimization is a swarm intelligent technique developed by Mirjalili et al., 2014, which mimics the leadership hierarchy of wolves are well known for their group hunting. Grey wolf belongs to Canidae family and mostly prefer to live in a pack. They have a strict social dominant hierarchy; the leader is a male or female, called Alpha (α). The alpha is mostly responsible for decision making. The orders of the dominant wolf should be followed by the pack. The Betas (β) are subordinate wolves which help the alpha in decision making. The beta is an advisor to alpha and discipliner for the pack. The lower ranking grey wolf is Omega (ω) which has to submit all other dominant wolves. If a wolf is neither an alpha or beta nor omega, is called delta. Delta (δ) wolves dominate omega and reports to alpha and beta. The GWO mimics the hunting behavior and the social hierarchy of grey wolves. In addition to the social hierarchy of grey wolves, pack hunting is another appealing societal action of grey wolves. The main segments of GWO are encircling, hunting and attacking the prey. The algorithmic steps of GWO are presented in this section.

Algorithmic steps and Pseudo code

The GWO algorithm is described briefly with the following steps:

Step 1: Initialize the GWO parameters such as search agents (Gs), design variable size (Gd), vectors a, A, C and maximum number of iteration ($iter_{max}$).

$$\vec{A}. = 2\vec{a}.rand_1 - \vec{a}$$

$$\vec{C}. = 2.rand_2$$

The values of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations.
Step 2: Generate wolves randomly based on size of the pack. Mathematically, these wolves can be expressed as,

$$Wolves = \begin{bmatrix} G_1^1 & G_2^1 & G_3^1 & \cdots & G_{Gd-1}^1 & G_{Gd}^1 \\ G_1^2 & G_2^2 & G_3^2 & \cdots & G_{Gd-1}^2 & G_{Gd}^2 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ G_1^{Gs} & G_2^{Gs} & G_3^{Gs} & \cdots & G_{Gd-1}^{Gs} & G_{Gd}^{Gs} \end{bmatrix}$$

Where, G^i is the initial value of the j^{th} pack of the i^{th} wolves.

Step 3: Estimate the fitness value of each hunt agent using Equations (3.4)-(3.5)

$$\vec{D} = \left| \vec{C} . \vec{G}_P (t) - \vec{G}(t) \right| \tag{3.4}$$

$$\vec{G}(t+1) = \vec{G}_P (t) - \vec{A} . \vec{D} \tag{3.5}$$

Step 4: Identify the best hunt agent (G), the second best hunt agent (G and the third best hunt agent (G) using Equations (3.6)-(3.11).

$$\vec{D}_\alpha = \left| \vec{C}_1 . \vec{G}_\alpha - \vec{G} \right| \tag{3.6}$$

$$\vec{D}_\beta = \left| \vec{C}_2 . \vec{G}_\beta - \vec{G} \right| \tag{3.7}$$

$$\vec{D}_\delta = \left| \vec{C}_3 . \vec{G}_\delta - \vec{G} \right| \tag{3.8}$$

$$\vec{G}_1 = \vec{G}_\alpha - \vec{A}_1 .(\vec{D}_\alpha) \tag{3.9}$$

$$\vec{G}_2 = \vec{G}_\beta - \vec{A}_2 .(\vec{D}_\beta) \tag{3.10}$$

$$\vec{G}_3 = \vec{G}_\delta - \vec{A}_3 .(\vec{D}_\delta) \tag{3.11}$$

Step 5: Renew the location of the current hunt agent using Equation (3.12).
Step 6: Estimate the fitness value of all hunts.
Step 7: Update the value of G_α ,G_β and G_δ

$$\vec{G}(t+1) = \frac{\vec{G}_1 + \vec{G}_2 + \vec{G}_3}{3} \tag{3.12}$$

Step 8: Check for stopping condition i.e., whether the Iterreaches Itermax , if yes, print the best value of solution otherwise go to step 5.

FUZZY LOGIC CONTROLLER DESIGN FOR THE DSTATCOM

A fuzzy logic controller (FLC) consists of four elements. These are a fuzzification interface, a rule base, an inference mechanism, and a defuzzification interface. A FLC has to be designed for the DC voltage regulator, AC voltage regulator, and the current regulator. The design of the FLC for DC voltage regulator is described in detail first. The design of the fuzzy controllers for the AC and current regulators follows similar procedure. The PI-like FLC designed for DC voltage regulator has two inputs and one output. The error e(t)(e = Vdcref − Vdc) and the rate of change of error (˙ e(t)) are the inputs and the output of the FLC is ΔId. In fact, ΔId is integrated to produce .

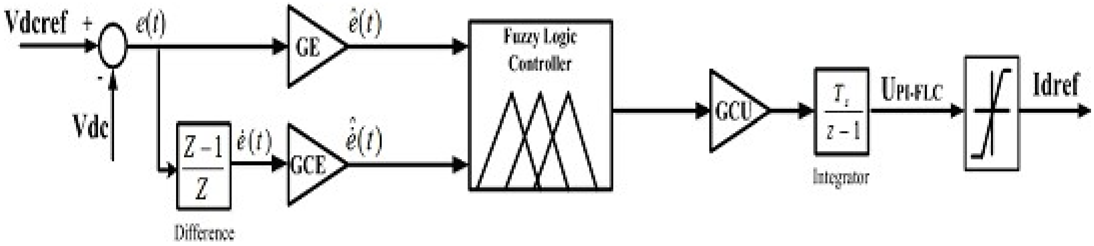


Figure 3.3. DSTATCOM control system block diagram

NL = Negative Large NM = Negative Medium NS = Negative Small ZO = Zero PS = Positive Small PM= Positive Medium PL = Positive Large. The above linguistic quantification has been used in this thesis to specify a set of rules or a rule-base. The rules are formulated from practical experience. For the FLC with two inputs and seven linguistic values for each input, there are 72 = 49 possible rules with all combination for the inputs. The tabular representation of the FLC rule base (with 49 rules) of the fuzzy control based DC voltage regulator is shown in Table I.

$e(t)$ \ $\dot{e}(t)$	NL	NM	NS	ZO	PS	PM	PL
PL	ZO	PS	PM	PL	PL	PL	PL
PM	NS	ZO	PS	PM	PL	PL	PL
PS	NM	NS	ZO	PS	PM	PL	PL
ZO	NL	NM	NS	ZO	PS	PM	PL
NS	NL	NL	NM	NS	ZO	PS	PM
NM	NL	NL	NL	NM	NS	ZO	PS
NL	NL	NL	NL	NL	NM	NS	ZO

Table 3.1:7*7 FLC Rule-Base in Tabular Form

4. RESULT ANALYSIS

Artificial Neural Network (ANN)

The concept of ANN is basically introduced from the subject of biology where neural network plays an important and key role in human body. In human body work is done with the help of neural network. Neural Network is just a web of inter connected neurons which are millions and millions in number. With the help of these interconnected neurons all the parallel processing is done in human body and the human body is the best example of Parallel Processing. Artificial Neural Network “ANN” has been applied successfully to a wide range of control system applications in recent years. Artificial neural networks have high learning and nonlinear mapping essences and its parallel and distributed structure can provide a nonlinear mapping between inputs and outputs of an electric drive system, without the knowledge of any predetermined model. This makes ANN a good choice to be used in the adaptation mechanism of a MRAC system. In the proposed work, a speed control strategy for BLDC motor is proposed using a model reference adaptive controller based on Artificial Neural Networks. The performances of the proposed ANN drive system and the conventional PID control are designed and implemented using TMS320LF2407A digital signal processor and evaluated under different operating conditions, such as sudden load impact, parameter variations, etc.

Main Technology and Implementation

BP Network and Its Learning Algorithm;

The output signal of multilayer feed forward neural network is the complete responses to the network input layer excitation pattern on source nodes, that is, the input signal imports from the input layer, passes through the hidden layer reaching output layer. The output signal is obtained from the output layer as Fig.4.1 shown. Be noted that the hidden layer can be single or multi-layer; signal can be transmitted between nodes only through transfer function. Here the transfer function is selected as the S-type, Work signal is being transmitted forward, in which the connecting weight doesn't change. If the output value is less than expected value, then an error signal turns to transferred back propagation. Process of back propagation of error signal is called learning, during which weights are adjusted by the error feedback

ANN _ MS System

The identification of BP / RBF neural networks is reflected in the nonlinear I / O modeling, and the corresponding algorithm is more perfect; so it is time for them to be out of the theoretical research, and to enter applied research. This is just the significance of developing an Artificial Neural Networks Management System (ANN MS), further more, the profound significance is finding the limitations of ANN network, developing a more anthropomorphic "brain" through applied research. ANN MS system is structured artificial neural network model from the view of bionics, and its application is based on the model, therefore, its main functions are to establish and simulate BP network, to establish and simulate RBF networks, to research the application model basically, and so on. The system is a management system based on BP / RBF artificial neural network theory and application research.

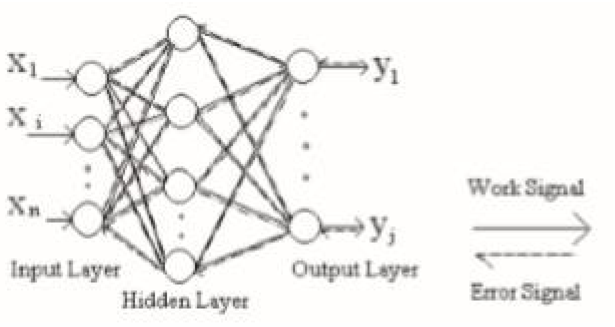


Figure 4.1. Schema of Feed Forward Neural Network Mode

ANN_MS System Solution

The identification of BP / RBF neural networks is reflected in the nonlinear I / O modeling, and the corresponding algorithm is more perfect; so it is time for them to be out of the theoretical research, and to enter applied research. This is just the significance of developing an Artificial Neural Networks Management System (ANN MS), further more, the profound significance is finding the limitations of ANN network, developing a more anthropomorphic "brain" through applied research. ANN MS system is structured artificial neural network model from the view of bionics, and its application is based on the model, therefore, its main functions are to establish and simulate BP network, to establish and simulate RBF networks, to research the application model basically, and so on. The system is a management system based on BP / RBF artificial neural network theory and application research.. is an ANN MS system function block diagram. It shows that the total function of the artificial neural network

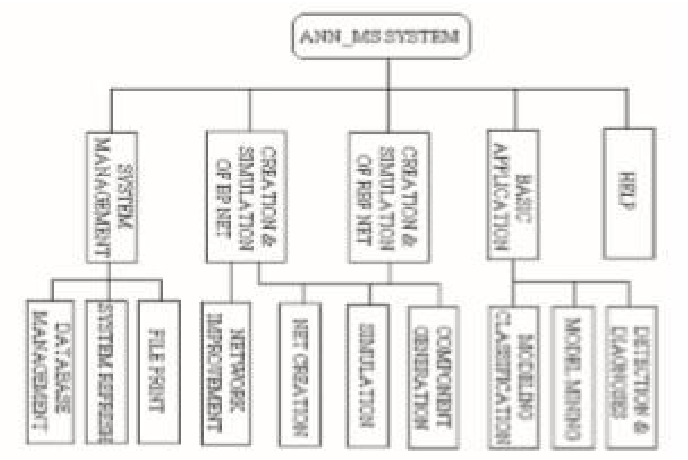


Figure 4.2. ANN_MS system function model

Results and Implemented Model on ANN:

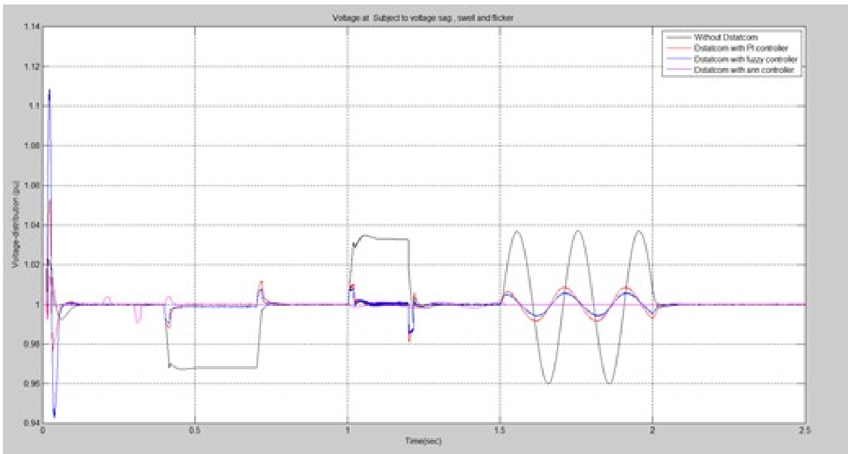


Figure4.3: Comparison of DSTATCOM WITH PI, FUZZY AND ANN Controller

Attempts are being made to enhance the drive performance by intelligent control using fuzzy logic (FL) and neural network techniques. One of the frequently discussed applications of artificial intelligence in control is the replacement of a standard proportional plus integral (PI) speed controller with an FL or artificial neural network (ANN) speed controller. Regardless of all the work, it appears that a thorough comparison of the drive behaviour under PI, FL, and ANN speed control is necessary. This article attempts to compare PI, fuzzy, and ANN controllers that are implemented in an embedded system for closed-loop speed control of DC drive fed by a buck-type DC–DC power converter. The PI controller is designed based on the small signal modelling of the system. The PI-like fuzzy controller structure is considered for comparison. Two ANN controllers are designed. One controller uses training data obtained from the simulation of a fuzzy controller and the other uses training data from the simulation of a PI controller. The performance of the controllers is studied for a variety of operating conditions, such as step change in speed command and step change in load torque. The parameters selected for the comparison are the steady-state error and the rise time of the response. It is shown that ANN speed controllers provide a superior speed response in terms of rise time and the steady-state error compared to PI and FL controllers. This advantage arises from the fact that the neural network has the property of generalization and the control surface of the neural controller is smooth. The designed neural network controller is simple, with three neurons only, and so it is best suited for embedded system implementation. It is also found that the ANN controller trained with the training data from a PI controller has a better response compared to the ANN controller trained with data from a fuzzy controller.

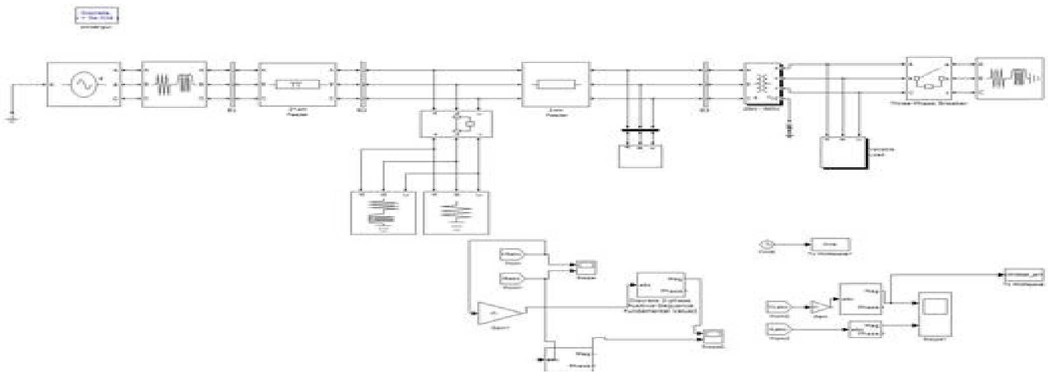


Figure 4.4. DSTATCOM Mode ANN

The DSTATCOM is commonly used for voltage sags mitigation and harmonic elimination at the point of connection. The DSTATCOM employs the same blocks as the DVR, but in this application the coupling transformer is connected in shunt with the ac system, as illustrated in Fig. 4.7. The VSC generates a three-phase ac output current which is controllable in phase and magnitude. These currents are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. Active and reactive power exchanges between the VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power;
- Correction of power factor
- Elimination of current harmonics

ANN is a structure comprised closely interconnected neurons which can adapt simple processing elements (named as artificial neurons or nodes) that are capable of performing massively parallel computations for data processing and knowledge representation. Although ANN is the main abstractions of the biological counterparts, the idea of ANN is not to replicate the operation of the biological systems but to make use of what is known as the functionality of the biological networks for solving complex problems.

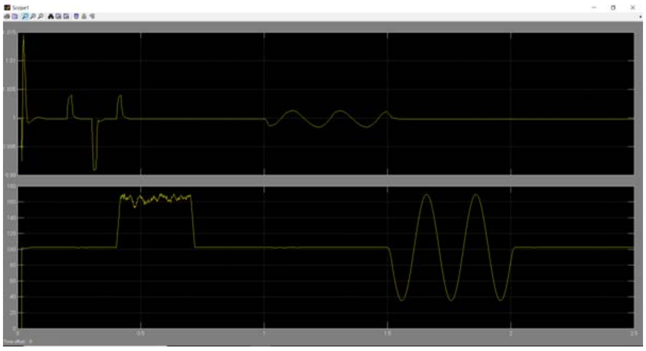


Figure 4.5. Output Voltage and Current

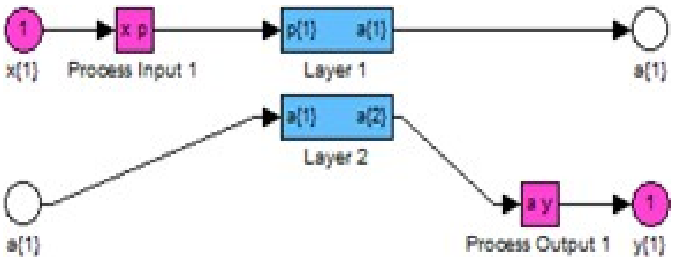


Figure 4.6. ANN Subsystem

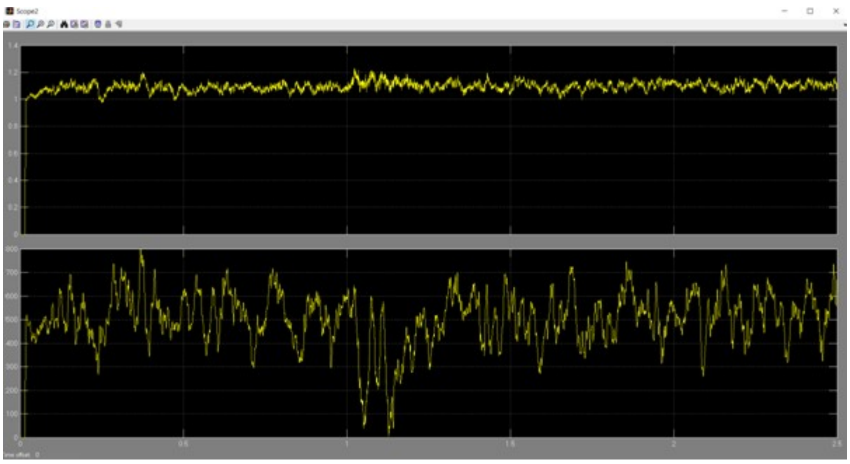


Figure 4.7. Input Voltage and Current

5. CONCLUSIONS

This thesis has presented the design of ANN controller for a DSTATCOM to improve power quality and dynamic performance of a distribution power system. Comparison study of the PI controlled and the optimal fuzzy logic controlled DSTATCOM for improving the power quality and dynamic performance of a distribution power system has been simulated using Sim Power System in MATLAB/Simulink environment. The performances of the DSTATCOM controllers are evaluated during grid side voltage sag and load variations. The simulation results obtained in MATLAB/Sim Power Systems show that the ANN controlled DSTATCOM provides better system dynamic response and hence improves power quality and stability for the distribution power system.

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