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Research Article

A Fuzzy-PSO based PI Controller for DC Link Voltage Improvement in DSTATCOM

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Abstract

This paper presents the DC voltage regulation of DSTATCOM. A non-linear controller is preferred over linear controller due to non-linear operation of DSTATCOM . Previously the system was implemented with a PI controller for better voltage regulation and improvement in the system dynamics. The effectiveness of a Fuzzy controller is shown in this paper. A PSO based algorithm is used to optimize the parameters of the PI controller. It improves the response of the controlled system effectively by searching a high-quality solution. The tracking of the reference value for capacitor voltage is achieved with less ripples and improved transient performance than the conventional. The paper deals with PI, Fuzzy-PI and PSO-PI. Simulation and comparison of results are presented and it has been found that the proposed algorithm gives better results with better control performance.

Keywords: *Particle Swarm Optimization, Nonlinear Controller, Fuzzy, DC Voltage*

1. Introduction

Current trends in power distribution worldwide report a substantial increase in usage of non-linear loads and the proliferation of power electronic based equipment have led to many problems in the power distribution network (H. Suryanarayana *et al*, 2008).An unprecedented increase in domestic loads, large fluctuating industrial loads such as commercial building air conditioning, lighting heating, arc furnace, traction etc. has been observed which affect the power supply of the distribution system. This could lead to low system efficiency and poor power factor. Many power quality problems usually occur in the distribution system (A.Ghosh *et al*, 2002). The nonlinear loads (solid state converters) draw harmonic and reactive power components of current from AC mains in addition to fundamental active power current components. They may also cause unbalance and draw excessive neutral currents in the three phase system and create disturbance by interference in nearby communication networks. The injected harmonics, unbalance and excessive neutral currents, reactive power burden, cause low system efficiency and poor power factor. The increase severity of harmonic pollution in power networks has attracted the attention of power electronics and power engineers to develop dynamic and adjustable solutions to the power quality problems (N G.Hingorani, 1995). The conventional approach to this problem is to use of passive power filters. Though they are a low-cost solution, but there are certain disadvantages. They are bulky and overcompensation can lead to a lower power factor more over risk being that of resonance with the system impedance. Active power filters can overcome these problems. Present generation ofcompensating devices include power electronic based static controllers to enhance the controllability and the power transfer capability. The new and emerging areas of custom power devices have resulted in the development of series shunt and hybrid controllers (A.Ghosh *et al*, 2004). One such shunt connected custom power device is DSTATCOM. It is one of the key compensating devices and operated as a shunt connected static VAR compensator whose inductive and capacitive current can be controlled independent of AC system voltage. Nonlinear loads such as variable speed drives, computers, electronic ballasts, photocopiers and fax machines draw nonlinear load currents which distort the supply voltage and inject harmonics in to the supply system itself. Many standards are used to calculate the harmonic distortion out of which Total Harmonic Distortion (THD) is generally used and its reported that its value should be less than 5% as per IEEE 519 standard (April 9).

2. Design of Distribution Static Compensator

D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through an interfacing inductor(N G.Hingorani, 1995). The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. There are many possible configurations of Voltage Source Inverters (VSI) and consequently many different configurations of DSTATCOM (S. Iyer, *et al*, 2005;N.

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Farokhnia, *et al*, 2009).These voltages are in phase and coupled with the ac system through the reactance of the -

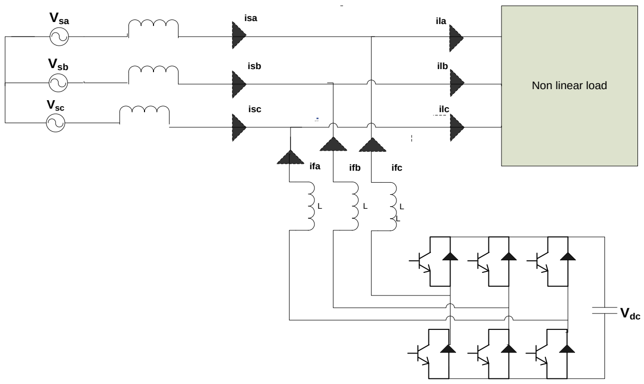


Fig.1 Block Diagram of DSTATCOM

coupling transformer. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes

3. Mythology

3.1 Design Mythology of Fuzzy System

PID controllers are extensively used in industry for a wide range of control processes and provide satisfactory performance once tuned when the process parameters are well known and there is not much variation (Alka Singh, 2010; T. Srikanth, 2013).However, if operating conditions vary, further tuning may be necessary for good performance. Since many processes are comp-licated and nonlinear, For such type of processes fuzzy control seems to be a good choice. Some of the main aspects of fuzzy controller design are choosing the right inputs and outputs and designing each of the four components of the fuzzy logic controller. Also, the fuzzy controller is activated only during the transient period and once the value of the dc-link voltage settles down, the controller gains are kept constant at the steady state value. The inputs of the fuzzy supervisor have been chosen as the error in dc link voltage and the change in error in dc link voltage.The outputs of the fuzzy supervisor are chosen as the change in Kp value and the change in Ki valueare the steady state values determined by the method specified in and ΔKp and ΔKi are the outputs of the fuzzy logic supervisor.

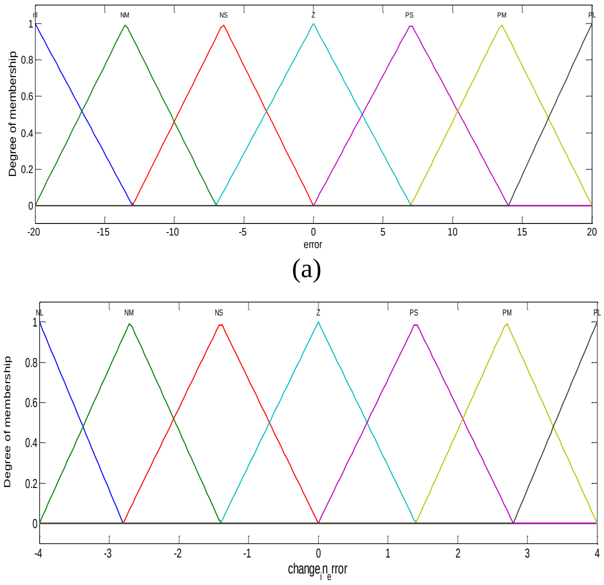
$$e = V_{dc}^{ref} - V_{dc}$$
$$ce_i = e(i) - e(i-1)$$

Fuzzification: It takes in the crisp input signals and assigns a membership value to the membership function under whose range falls in the input signal. Seven triangular membership functions have been chosen for both error (e) and change in error (ce). The input membership functions are shown in Fig.2.The tuning of each membership function is done based on the requirement of the process. Each membership function has a membership value belonging to (0 1).

Inference Mechanism: The two main functions of the inference mechanism are:

a) Based on the active membership functions in error and the change in error inputs, the rules which apply for the current situation are determined.

b) Once the rules which are on are determined, the certainty of the control action is ascertained from the membership values. This is known as premise quantification (H.Suryanarayana *et al*, 2008). Designing the rule base is a vital part in designing the controller. It is important to understand how the rule base has been designed. The membership function shows a typical dc link voltage waveform after an increase in the load without the inherent ripple due to compensation. Thus, using information from the rule base, the rule and its certainty is determined by the inference mechanism.



(a)

(b)

Fig.2(a) Membership functions for error input,
(b) Membership functions for change in error input

Table1shows the rule base matrix for change in Kp for DC link voltage. The method to convert the fuzzy result to crisp control action is called defuzzification.

Table1: Rule Base Matrix for Change in Ki

e/ce	**NL**	**NM**	**NS**	**Z**	**PS**	**PM**	**PL**
NL	SK	LK	LK	SK	SK	SK	Z
NM	SK	LK	SK	SK	SK	Z	SK
NS	LK	LK	SK	SK	Z	Z	Z
Z	Z	Z	Z	Z	Z	Z	LK
PS	Z	Z	Z	SK	SK	LK	LK
PM	SK	Z	SK	SK	SK	LK	LK
PL	Z	SK	SK	SK	LK	LK	LK

This mechanism considers these rules and their respective *μpremise* values, combines their effect and comes up with a crisp, numerical output. Thus, the fuzzy control action is transformed to a non-fuzzy control action. The 'center of gravity' method has been used in this work.

3.2Particle Swarm Optimization

Several new intelligent optimization techniques havebeen evolved in the past two decades like: Genetic Algorithm (GA),Ant Colony Optimization (ACO), Simulated Annealing (SA), and Particle Swarm Optimization (PSO). A swarm is considered to be a collection of particles, where each particle represents a potential solution to the problem. The particle changes its position within the swarm based on the experience and knowledge of its neighbors. Basically it 'flies' over the search space to find out the optimal solution (P.Valle *et al*, 2008;P.Mitra*et al*, 2008)PSO is one of the modern Heuristics algorithms, and has been found to be robust in solving continuous non-linear optimization problems. It can stable convergence characteristic and can generate a high-quality solution within less time and than other stochastic methods. PSO is characterized as a simple concept, computationally efficient and easy to implement, as it is been motivated by the behavior of organisms, such as fish schooling and bird flocking. Here social sharing of information takes place and individuals can profit from the discoveries and previous experience of all the other companions during the search for food (Anil Kumar *et al*, 2013;Zhao*et al*, 2005). The population, is known as swarm, and each companion is called particle. Each particle's movement is influenced by its local best known position and it is also guided towards the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions. The particle is assumed to fly in many directions over the search space in order to meet the demand of the prescribed fitness function.

4. Implementation of a PSO-PI controller

In this work, a PI controller using the PSO algorithm was developed to improve the step transient response of DC link voltage of a DSTATCOM. It was also called the PSO-PI controller. The PSO algorithm was mainly utilized to determine three optimal controller parameters Kp, Ki and Kd, such that the controlled system could obtain a good step response output. The following procedure can be used for implementing the PSO algorithm. For n-variables optimization problem a flock of particles are put into the n-dimensional search space with randomly chosen velocities and positions knowing their best values, so far (*Pbest*) and the position in the n-dimensional space . The velocity of each particle, adjusted accordingly to its own experience and the other particles flying experience. For example, the ith particle is represented, as:, Xi = (xi1, xi2, xi3,..................xid) in the d-dimensional space, the best previous positions of the ith particle is represented as: Pbest = (Pbesti,1 , Pbesti,2 ,Pbesti,3..........Pbesti,d). The index of the best particle among the group is gbest. Velocity of the ith particle is represented as:

Vi = (Vi,1 Vi,2 Vi,3.......... Vi,d)

The updated velocity and the distance from Pbesti,d to gbesti,d is given as ;

$$v_{i+1}=v_i+c_1R_1(p_{i,best}-p_i)+c_2R_2(g_{i,best}-p_i) \quad (2)$$

and

$$X_{i,m}^{(t+1)}= X_{i,m}^{(t)}+V_{i,m}^{(t+1)} \quad (3)$$

where

pi and Vi – are the position and velocity of particle i, respectively;

pi - position of particle i

vi –velocity of particle i

pi, best - the position with the best' objective value found sofar by particle i

gi, best - is the position with the best' objective value found sofar by entire population

w - is a parameter controlling the dynamics of flying;

R1 and R2 - are random variables in the range [0, 1]; **c1 and c2** - are factors controlling the related weighting of corresponding terms. The random variables help the PSO with the ability of stochastic searching

The working procedure of the proposed PSO-PI controller is shown below.

i. Specify the lower and upper bounds of the three controller parameters and initialize randomly the individuals of the population including searching points, velocities, Pbests, and gbest.
ii. For each initial individual of the population, employ the Routh-Hurwitz criterion to test the closed-loop system stability and calculate the values of the four performance criteria in the time domain, namely Mp, Ess, tr, and ts.
iii. Calculate the evaluation value of each individual in the population using the evaluation function.
iv. Compare each individual's evaluation value with its Pbest. The best evaluation value among the Pbest is denoted as gbest.
v. Modify the member velocity v of each individual K according to

$$V_{i,m}^{(t+1)}= W.V_{i,m}^{(t)}+C_1 * rand\ (\ \ ) * \left(Pbest_{i,m} - X_{i,m}^{(t)}\right) + C_2\ rand\ (\ \ ) * \left(gbest_m - X_{i,m}^{(t)}\right) \quad (4)$$

For i = 1, 2, 3. . . . . . . n.
m=1,2,3.....d.
where wi - weighting factor. When g is 1,vj1 represents the change in velocity of kp controller parameter. When g is 2, vj2 represents the change in velocity of ki controller parameter.

vi. If $V_{i,m}^{(t+1)}>V_m^{max}$,then$v_{j,m}^{(t+1)}=V_m^{max}$ (5)
If $V_{i,g}^{(t+1)}<V_g^{min}$ then $v_{j,g}^{(t+1)}=V_g^{min}$. (6)
vii. Modify the member position of each individual K according to
$K_{j,g}^{(k+1)}=K_{j,g}^{t}+v_{j,g}^{(t+1)}$ (7)
$K_g^{min} <K_{j,g}^{(t+1)} < K_g^{max}$ (8)
represent the lower and upper bounds, respectively, of member g of the individual K.
viii. If the number of iterations reaches the maximum, then go to **ix**. Otherwise, go to **ii.**
ix. The individual that generates the latest gbest is an optimal controller parameter (R.C.Eberhart *et al*, 2008).

5. Objective Function

For best response, the essential function of a feedback control system is to reduce the error '*e(t)*' between any variable and its demand ed value to zero as quickly as possible. There are four basic criteria which are commonly used. .

Integral of absolute error (IAE) = $\int_0^\infty |e(t)|\ dt$

Integral of squared error (ISE) = $\int_0^\infty |e(t)|^2\ dt$

Integral of time multiplied by absolute error (ITAE) = $\int_0^\infty t|e(t)|\ dt$

Integral of time multiplied by squared error (ISE) = $\int_0^\infty t|e(t)|^2\ dt$

For any of the above possible criteria, the best response corresponds to the minimum value of the chosen criterion. In all cases, it is either the absolute error orthe square error involved. Straight forward integration ofthe error would produce zero result even if the system response is a constant amplitude oscillation. IAE is often used where digital simulation of a system is being employed, but it is not applicable for analytical work, because the absolute value of an error function is not generally analytic in form. The ITAE and ITSE have an additional time multiplier of the error function, which emphasises long-duration errors, and therefore these criteria are most often applied in systems requiring a fast settling time. The ITAE performance index has the advantage of producing smaller overshoots and oscillations than the IAE or ISE performance index. It is most sensitive among all. So ITAE performance index is identified as most suitable (Dr.R.Kumar*et al*, 2013).

For the DSTATCOM, the adopted objective function is:

$Q_f(Z) = \sum_i m_i\, f_i(Z)$

where

$$f_i(z) = \sum_j w_j \int_0^T t\left|e_j(t)\right|\ dt \qquad (8)$$

f_i is a performance index. m_i is a weighted factor corresponding to the objective, ej(t) is the error between the real value of the *No. j* controlled variable and its desired value. w_i is the weighted factor corresponding to the *No. j* controlled variable. Vector Z = [Z_1, Z_2................ . Z_n] is the control system parameters, i. e. PI parameters.

For the DSTATCOM, the objective function deduced is expressed as:

$$f(z) = 1000\int_0^T t\left[V_{dc} - V_{dref}\right] dt \qquad (9)$$

where

Z = $\left[K_p \quad K_i\right]$

6. Result and Discussion

The case study parameters for 25KV, 100MVA, DSTATCOM are as follows.

C=10000(μF), f=60 Hz, Rs= 0.625 Ω, L= 0.0165H, Vdc=2400.Fig.3 shows the graph of DC link voltage for DSTATCOM with all the controllers mentioned below beenThe graph of PI controller results in the rise time of 0.006s whereas the settling time is 0.1s, also there are some ripples at 0.2s, 0.3s and 0.4s. The graph with Fuzzy-PI controller shows the rise time is at 0.06s and the settling time isreduced from 0. 1s to 0. 06s. Also the ripples at 0.2s, 0.3s and 0.4s are eliminated. The graph with PI-PSO

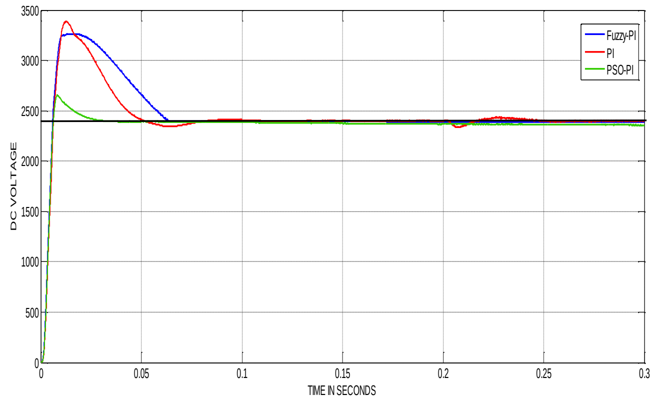


Fig.3 Plot of DC voltage for PI,Fuzzy-PIand PSO-PI

controller tuned for the gain value of Kp = 2. 8855 and Ki = 1. 9412Results show that the overshoot at 0. 02s is reduced from 3400V to 2600V and the settling time is reduced from 0.06s to 0.03s as well as the ripples at 0.2s, 0.3s and 0.4s are eliminated.THD (Total Harmonic Distortion) for load voltage under nonlinear load with PI controller for 5 cycles is shown in fig.4 which is 5.26% whereas THD for load voltage with Fuzzy-PI for 5 cycles is shown in fig.5 which is 0.35%.Thus from the given results it can be seen that the Fuzzy -PI gives much more improved results as compared to conventional controller.

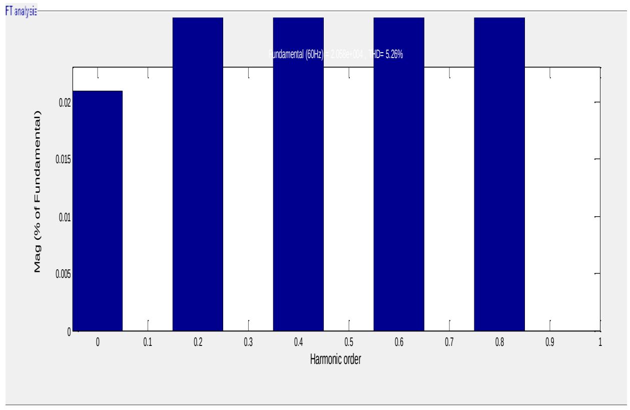


Fig.4 THD for load voltage with PI controller

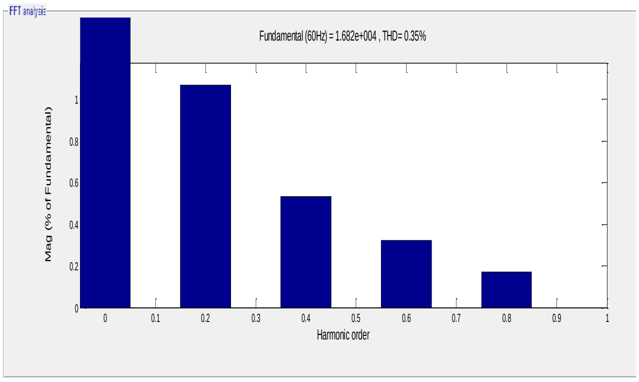


Fig.5 THD for load voltage with PI controller

Table2: Comparison of different parameters for DCLinkVoltage

Controller	t_s	% M_p	t_r	% THD
PI	0.1	41.04	0. 0065	5.26
Fuzzy-PI	0. 06	35.8	0. 006	0.35
PSO-PI	0.03	8. 33	0. 0061	0.30

The above table shows the comparative analysis of PI controller with Fuzzy-PI it is found that in terms of settling time and ripples the performance of Fuzzy-PI is superior to PI. When compared with PSO-PI it is observed that PSO-PI eliminates the overshoot from 41.04 to 8.33 and exhibits considerable improvement in rise time and settling time.

Conclusion

A systematic approach of achieving good voltage regulation of DSTATCOM by means of PI, Fuzzy- PI, PSO-PI controllers and comparison between each of them have been discussed. The results in the form of characteristic curve of voltage with respect to time were obtained. For better voltage regulation Fuzzy –PI control technique showed better performance than the conventional controller. PSO-PI controller optimizes the coefficients of the PI controller and produces better response curves than PI and Fuzzy-PI in terms of rise time, overshoot, settling time and steady state value.The total harmonic distortion (T.H.D) in load voltage has decreased a lot with the help of Fuzzy-PI controller The controllers discussed above are computationally efficient and work with linear as well as complex systems.With PSO-PI it has been observed that the gain co-efficient of the controller can be tuned quickly and better optimization can be provided.

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