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Improvement of power quality by optimized SAPF system

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ABSTRACT

The paper presents an optimal fuzzy logic controller – controlled shunt active power filter (SAPF) used to compensate for harmonic distortion in three-phase systems. A optimal fuzzy logic controller based current controller strategy is used to regulate the filter current and hence ensure harmonic free supply current. The optimal adjustment of the membership functions and normalization gains are realized by using Ant Colony Optimization. Simulations results show the best dynamic behavior and performance control compared with traditional Fuzzy controller. as well as effective in reducing harmonic. The validity of the presented approach in harmonic mitigation is verified via simulation results of the proposed test system under different loading conditions.

Introduction

The proliferation of nonlinear loads such as diode/thyristor rectifiers, nonsinusoidal currents degrade power quality in power transmission/distribution systems. Power Quality (PQ) is an important measure of an electrical power system. The term PQ means to maintain purely sinusoidal current wave form in phase with a purely sinusoidal voltage wave form. The power generated at the generating station is purely sinusoidal in nature. The deteriorating quality of electric power is mainly because of current and voltage harmonics due to wide spread application of static power electronics converters, zero and negative sequence components originated by the use of single phase and unbalanced loads, reactive power, voltage sag, voltage swell, flicker, voltage interruption etc. Different theories have been introduced such as the instantaneous power theory (p-q theory), notch algorithm, synchronous reference method and kalman filter method. The proposed optimized shunt active power filter system is a great tool for the compensation not only of current harmonics produced by distorting loads, but also of reactive power of non-linear loads. The DC-link voltage of SAPF can be adjusted to a great extent so as to provide easy control and high performance Fuzzy theory was first proposed and investigated by Prof. Zadeh in 1965.The mamdani fuzzy inference system was presented to control a steam engine and boiler combination by linguistic rules [4]-[5]. Fuzzy logic is expressed by means of if-then rules with the human language. In the design of a fuzzy logic controller, the mathematical model is not necessary.

The ant colony algorithm has been used to find the optimal values and parameters of our fuzzy logic controller .W Ant Colony Algorithm was proposed by Dorigo in the year 1991[3]. After observation people found that between the individual ants there is a material known as the phenomenon for the transmission of information. When ants were in moving, phenomenon was left in the way the Ants passed and ants can feel the concentration of the phenomenon, to lead their actions and tend to choose a higher concentration of pheromone way to move. As a result, the behavior of a group of ants is feedback: the way which the more Ants passed, the greater probability it was chose. The ants find the food by exchange of information between the individual ants. The ACO algorithms are applied to look for globally optimal parameters of fuzzy logic. The best ranges of membership functions, the greatest shapes of membership functions and the best fuzzy inference rules. Moreover, the two different fuzzy logic controllers are compared and then simulations results are offered to show the efficacy of fuzzy logic controller.

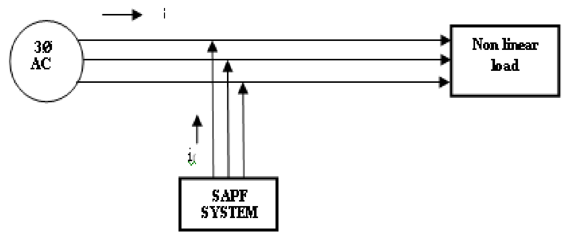

Fig. 1. Principle of Shunt Active Power Filter

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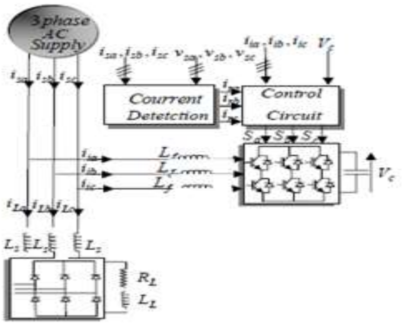
Design of Shunt Active Power Filter Shunt Active Filter

Active power filter is an advanced power electronic device, which can be used for integrated compensating harmonics, reactive currents and negative-sequence currents. Because of the characteristics of real time and accurate Compensation, it is possible to take full advantage of digital signal processing and many other technologies. If so, the performance of active power filters can be improved significantly. The SAPF system exactly to sense the load currents and extracts the harmonic component of the load current to produce a reference current. The reference current consists of the harmonic components of the load current which the active filter must supply. This reference current is fed through a controller and then the switching signal is generated to switch the power switching devices of the active filter such that the active filter will indeed produce the harmonics required by the load. Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.



P-q Theory Description

Control strategy is based on the p-q theory introduced by *Akagi et al.* [2] and expanded to three-phase four-wire systems by *Aredes et al*. [3]. It applies an algebraic transformation (Clarke transform) of the three-phase system voltages and load currents in the *a-b-c* coordinates to the *α-β-0* coordinates. After the transformation, the p-q theory components are achieved by the expressions (1-3), where *p* is the instantaneous real power, *q* is the instantaneous imaginary power (by definition) and *p0* is the instantaneous zero-sequence power. In this paper deals with instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms.

p – Average value of the instantaneous real power *p*.
Corresponds to the energy per time unit transferred from the source to the load, in a balanced way through the 3 phases.

$\tilde{p}$– Oscillating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the 3 phases.

q – The instantaneous imaginary power, q corresponds to the power that is exchanged between the phases of the load. This component does not imply any transference or exchange of energy between the power supply and the load, but is responsible for the existence of undesirable currents imply any transference or exchange of energy between the power source and the load.

p − Mean value of the instantaneous zero-sequence power. It corresponds to the energy per time unity that is transferred from the power source to the load through the zero-sequence components of voltage and current;

~*p* − Oscillating value of the instantaneous zero sequence power. It means the energy per time unity that is exchanged between the power source and the load through the zero-sequence components of voltage and current.

$$P_x = P_{res} - P_{reg} + \tilde{P} \quad (1)$$

$$Q_x = \tilde{Q} + Q \quad (2)$$

$$p = v + i + v$$

The PQ theory consists of an algebraic transformation (Clarke transformation) of the three phase voltages and current in the abc coordinates to the αβ coordinates. Finally, it is possible to calculate the reference currents, in the *α-β-0* coordinates, by applying the expressions (5) and (6).

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{v\alpha^2 + v\beta^2} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} . \begin{bmatrix} p_x \\ q_x \end{bmatrix} \quad (3)$$

Finally, we get

$$i = i_0 = \frac{1}{\sqrt{3}} . (i_a + i_b + i_c) \quad (4)$$

Fuzzy Logic Controller

The desired switching signals for the filter inverter circuit are determined according to the error in the filter current using Fuzzy logic controller [8]-[9]. The parameters for the fuzzy logic current controller used in this paper are as follows. The design uses centrifugal defuzzification method. There are two inputs; error and its derivative and one output, which is the command signal to the PWM of the filer inverter. The two input uses Gaussian membership functions while the output use triangle membership function. In this work, the type of fuzzy inference engine used is Mamdani. The linguistic variables are defined as (NB, NS, Z, PS, PB) which mean big, negative small, zero, positive small and positive big respectively. The membership functions of the fuzzy logic controller are shown in Fig. 3 the fuzzy inference mechanism used in this work is presented as following. The fuzzy rules are summarized in Table 1.

Fuzzy output *u*(*t*) can be calculated by the center of Gravity defuzzification as: $\mu_p(u(t)) =$

$$\mu_p(u(t)) = \max_{j=1}^{m} [\mu_{A1j}(e(t)), \mu_{A2j}(\Delta e(t)), \mu_{Bj}(u(t))] \quad (8)$$

Fuzzy output u(t) can be calculated by the center of Gravity defuzzification as:

$$u(t) = \frac{\sum_{i=1}^{m} \mu_B(\mu_i(t)) u_i}{\sum_{i=1}^{m} \mu_B(\mu_i(t))} \quad (9)$$

Where i is the output rule after inferring

u(t)		e(t)				
		NB	NS	Z	PS	PB
de(t)	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

Tab.1. Fuzzy inference rules

Ant Colony Optimization

The main idea of ACO is to model the problem as the search for a minimum cost path in a graph that base the evolutionary meta-heuristic algorithm. The behavior of artificial ants is inspired from real ants. They lay pheromone trails and choose their path using transition probability. Ants prefer to move to nodes which are connected by short edges with a high among of pheromone. The algorithm has solved traveling salesman problem (TSP), quadratic assignment problem (QAP) and job-shop scheduling problem (JSSP) and so on. The problem must be mapped into a weighted graph, so the ants can cover the problem to find a solution. The ants are driven by a probability rule to choose their solution to the problem (called a tour) [12]. The probability rule (called Pseudo-Random-Proportional Action Choice Rule) between two nodes i and j.

$$P_{ij} = \frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{k\in s}[\tau_{ij}]^{\alpha}[\eta_{ik}]^{\beta}} \qquad (10)$$

The heuristic factor or visibility is related to the specific problem as the inverse of the cost function. This factor does not change during algorithm execution; instead the meta heuristic factor (related to pheromone which has an initial value) is updated after each iteration. The parameters α and β enable the user to direct the algorithm search in favor of the heuristic or the pheromone factor. These two factors are dedicated to every edge between two nodes and weight the solution graph.

The pheromones are updated after a tour is built, in two ways: firstly, the pheromones are subject to an evaporation factor , which allows the ants to forget their past and avoid being trapped in a local minimum (equation 2). Secondly, they are updated in relation to the quality of their tour (equations 12 and 13), where the quality is linked to the cost function.

$$\tau_{ij} \rightarrow (1-\rho)\tau_{ij} \qquad \forall (i,j)\in L \qquad (11)$$

$$\tau_{ij} \rightarrow \tau_{ij} + \sum_{k=1}^{m}\Delta\tau_{ij}^{k} \qquad \forall (i,j)\in L \qquad (12)$$

$$\Delta\tau_{ij} = \begin{cases}\frac{1}{c^{k}} \text{ if } & \text{arc } (i,j) \text{ beong to } T^{k} \\ 0 & \text{othrwise}\end{cases} \qquad (13)$$

Where m is the number of ants, L represents the edges of the solution graph, and Ck is the cost function of tour Tk,uilt by the kth ant.

Aco Applied To Optimize FLC Parameters of Dc Link Capacitor

In this paper, The SAPF as controlled plant, the SAPF diagram is shown in Fig.4.

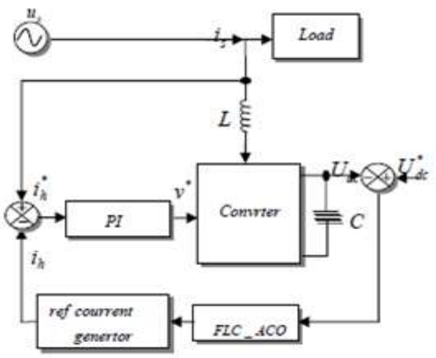


Fig.4 Control diagram of APF system

The estimation of the reference currents from the measured DC bus voltage is the basic idea behind the PI controller based operation of the SAF. The capacitor voltage is compared with its reference value in order to maintain the energy stored in the capacitor constant. The DC link voltage discretely at the positive zero-crossing point of respective phase source voltage, computes the variation of power according to difference of DC link voltage between two sampling points. The regulation of the error between the capacitor voltage and its reference is assured by The FLC controller which its output is multiplied by the mains voltage waveform Vs1, Vs2, Vs3 in order to obtain the supply reference currents found. In this paper, all parameters of FLC controller such as, the range of the membership functions Ke and Kde , the shape of the membership functions (e1-e5, de1-de5 and u1-u5) are hinted by 150 nodes respectively and there is resolution 0.0001among each node. The more accuracy trails are updated after having constructed a complete path and the solution. In this study, there are 2552 nodes including the start node and the end node to form a graph representation Fig.5. Each path defines the performance indexes on the load disturbance response and transient response for a set of Ke , Kde , e1…..e5, de1….de5 and u1……u5.

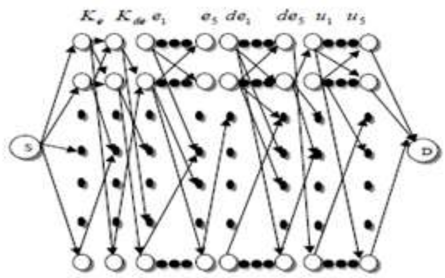


Fig.5 ACO graph representation for parameters

Design of Optimizing Algorithm

In this work, we have used the following parameters values for the ant colony optimization which is step in the table.2.

Initial values parameters of ACO

Ant Number	30
Maximum Cycle Time	200
Initial Value of Nodes Trail Intensity	0.05
Coefficient	0.4
Relative Important Parameter of Trail Intensity	1.5
Relative Important Parameter of Visibility	2

Simulation Result

The optimal fuzzy controller design by ACO of DC link capacitor has been set in Matlab Simulink environment to predict performance of the proposed approach. The SAPF model parameters are shown in the following.

Table.2 SAPF parameters

Supply phase voltage U 220 V
Supply frequency fs 50 HZ
Filter inductor Lf 1mH
Dc link capacitor Cf 5.3 mF
Smoothing inductor 0.12 mH
Sample time Ts 4 µs

Two different fuzzy controllers are implanted for the computer simulation. Firstly, conventional fuzzy logic controller is based on the expert experience has been used on the system SAPF which is connected in parallel with nonlinear load. Secondly, the proposed optimized fuzzy logic controller with

ACO has been examined to see its effect for damping harmonics current and reducing total harmonic (THD).
The main objective is to minimize the fitness function that is defined by the following equation.

$$F = f_{os} + f_{rt} + f_{ias} + f_{st} \qquad (14)$$

In this paper, we have based on the minimizing integral absolute error, so it has been multiplied by coefficient . The objective function is returned by the following equation:

$$F = f_{os} + f_{rt} + \alpha * f_{ias} + f_{st} \qquad (15)$$

In this case, we have fixed value: and that to give an importance for the integral error in formulation function.
The maximum overshoot is defined as:

$$f_{os} = y_{max} - y_{ss} \qquad (16)$$

characterize the maximum value of y and denote the steady-state value of y

For represent the function of the rise time is defined as the time required for the step response. In the other hand, the integral of the absolute magnitude of control error is written as:

$$f_{ias} = \int_0^\infty |e(t)|dt \qquad (17)$$

Simulation studies are carried out to predict performance of the proposed method. The Fig. 8 shows the DC link voltage response curves of system used conventional fuzzy logic and optimized fuzzy logic controller, and the value of system indexes are compared in Tab. 3.

The source voltage, current, load current, harmonic order and Dc link voltage waveforms are shown in the following figures after adopted the optimized system.

Table 3 comparisons of SAPF indexes between used and unused ant colony algorithm

Parameter and indexes	Conventional FLC controller	Optimized FLC controller with ACO
Gain K_e	0.1	0.998
Gain K_{de}	$1/6e^{-7}$	$1/5.88e^{-7}$
Gain K_u	$35e^{-4}$	$33e^{-4}$
Overshoot (%)	11.0247	3.7920
Rise time (sec)	0.0068	0.006798
Setting time	0.0048	0.0046
Integral absolute error	$4.4629e^{+000}$	$4.0341e^{+000}$

The source voltage, current, load current, harmonic order and Dc link voltage waveforms are shown in the following figures after adopted.

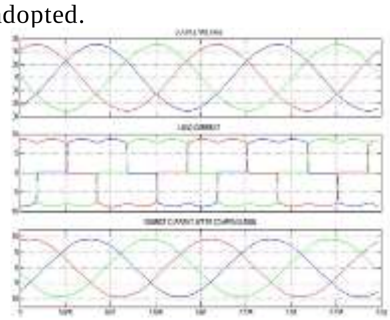


Figure 4. Three phase voltage and load current

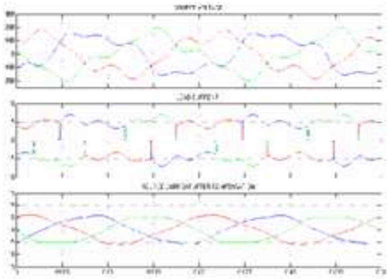


Figure 5. Simulation results for Unbalanced distorted source voltages and load current

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