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Application of proportional–integral–derivative controller for unified power flow controller

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ABSTRACT

FACTS devices are new technology that developed in recent years and have been used vastly in modern power electrical networks. These devices can improve the voltage profile and reduce the active power loss in large scale power networks. These devices can inject or absorb variable reactive power. The level of this injected or absorbed reactive power must be controlled to have normal and good conditions in the power network. PID controllers are a very popular and efficient controller that has a simple structure. In this paper application of the UPFC unit in the power network is proposed to enhance the voltage profile and reduce the power loss. In order to have good condition and performance, the manner of UPFC must be controlled. In the proposed method PID controller is proposed to control the UPFC. In the PID controller the free parameters have a vital role in its performance. Therefore in this study bee's algorithm is used to find the optimum value of these parameters. The bee's algorithm is one of the best and rapid nature-based optimization algorithms that its capabilities are proven in many kinds of literature. The proposed system is tested real standard system and the obtained computer simulation results show that the proposed method has excellent performance.

1. Introduction

Electrical power network is the biggest system that made by man. This system have many sections such as big generators, big transformers, breakers, loads, transmission lines, compensators and many other parts and instruments. With increasing the demand of electrical by humans and factories and as sequence increasing the scale of this big network, some difficulties and complicated problems have been emerged. In this large scale power network the level of voltage is low, power factor is weak and the stability margins are very weak. For overcome to these problems numerous techniques and technologies have been proposed by researchers. One of the most efficient and powerful of these technologies is Flexible AC Transmission Systems or FACTS devices (Hingorani, 1988). This new technology first presented in 1980s. In next years and decades some modifications and improvements on FACTS devices have been performed. Also some new devices added to this technology. Some of the FACTS devices are SVC, STATCOM, UPFC (Hingorani, 1988; Gerbex et al., 2001).

Available power networks are very big and have many sections. In one standard power network there are many generators, many power transformers, many breakers and other devices and parts. These big networks have some important problems that must be solved to work on its normal condition. One of the most disadvantages in big power network is the high level of power loss. The second one is weak voltage profile. Therefore specialist must propose new control systems to remove or reduce these problems.

As mentioned FACTS devices can improve the characters of power network significantly. In literature numerous approaches and techniques have been presented for enhance the power quality using this new technology (Venkatesh et al., 2003; Gerbex et al., 2001). In each case, associated to operation and target of system the new and special purposed is determined. Because the FACTS devices can be used for remove generator output voltage oscillation, or can be used for enhance the power factor by injecting reactive power at last terminal.

The FACTS devices can control the power factor, reduce the real power loss, enhance the voltage profile, and improve the level of security in power network. But for these purposes the FACTS devices must located in good location. Also the placed FACTS device must have good value. It must inject or absorb sufficient level of reactive power into or to power network respectively. In last decade usage of nature based optimization algorithms have been vastly used in many fields of science. One of the interesting fields is FACTS device technology. Literature review shows that these optimization algorithms have high application in this issue (Venkatesh et al., 2003). Nature based optimization algorithms mimic the manner of animals in searching of food source. For example the particle swarm optimization algorithm mimics the behavior of flock of birds in searching the food source in the sky.

In this new technology some issues are that must be noticed carefully. In order to act in its best state and led to best output, the FACTS devices must have good controller. In last year many techniques and intelligent methods have been proposed to control the FACTS device manner. The most popular one is PID controller. The PID controller is very simple and cheap. Also this type of controller has very good performance. Another applied controller is fuzzy controller. This type of controller use fuzzy rules to control the studied system. The performance of this controller is better than PID controller. But the complexity and price of this controller is very high compared with PID controller. Furthermore the implementation of fuzzy controller is very complicated and in some cases is not economic. Other control systems are adaptive controller, artificial neural networks and robust controllers.

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Literature review shows that the food optimization algorithm must have some features. The two main of these features are the ability of exploration and the extraction. If the one optimization algorithm can find the vicinity of global solution in short time, that optimization algorithm has very good exploration ability. Also if one optimization algorithm can reach to global solution, this optimization algorithm has very good extraction capability. There numerous optimization algorithms that have been introduced in recent decades, for example PSO, GA, ACO, ABC and other optimization algorithms. For the excellent properties of bee's algorithm in exploration and extraction, in this paper the bee's algorithm is proposed to select the optimum parameters of PID controller. Also UPFC is used to enhance the power system quality. The optimized PID will control the UPFC behavior. The detail of PID controller and optimization algorithm is presented in next sections.

2. UPFC

FACTS devices made is possible to inject and absorb reactive power. This action can improve the capacity of available power network. Also this technology improves the voltage profile of electrical power network and reduces the power loss. One of the most flexible and efficient type of FACTS devices is UPFC. In Fig. 1, the main structure of UPFC is shown. It can be seen from Fig. 1 that UPFC has parallel transformer, direct current voltage source, parallel converter and series converter. In UPFC all the section operation must be controlled by external controller. As mentioned this external controller may be selected from PID controller, fuzzy controller, neural network or adaptive controller (Fuerte-Esquivel and Acha, 1997).

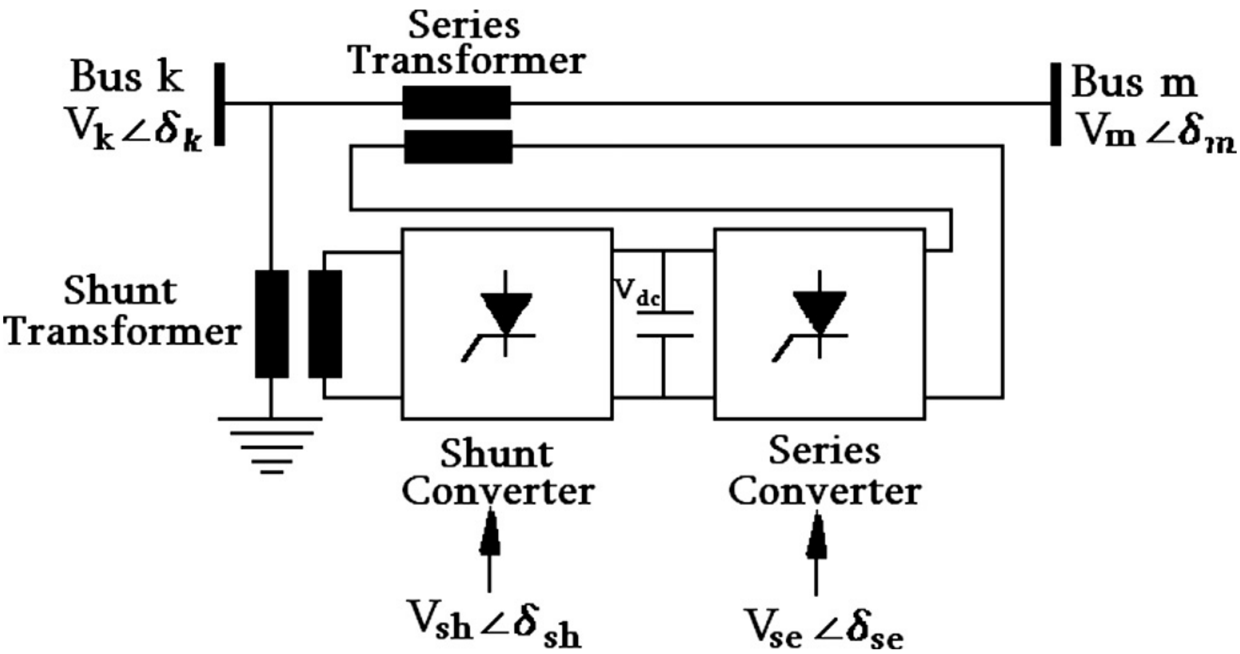

Fig. 1. UPFC structure.

In Fig. 2, the electrical schematic of this device is depicted. It can be seen from this Fig. 2 that UPFC in its electrical circuit has double voltage source that shown by V_{sh} and $\mathrm{V_{se}}$ indices. The detail definition of each of these two voltage sources is: $V_{sh} = V_{sh}\angle\theta_{sh}$, $V_{se} = V_{se}\angle\theta_{se}$. These indices show the shunt voltage source and its relative angle, and series voltage source and its associated angle. These two voltage source have constraints. The magnitude of these two voltage source must obey from the condition: $(V_{sh,\min} \le V_{sh} \le V_{sh,\max})$ and $(V_{se,\min} \le V_{se} \le V_{se,\max})$. These two voltage sources are controllable and have vital role in UPFC performance. The more details regarding the UPFC structure and operation of these two voltage source can be found in other references.

From Fig. 2, it can be found that the following equations are exist in UPFC circuit:

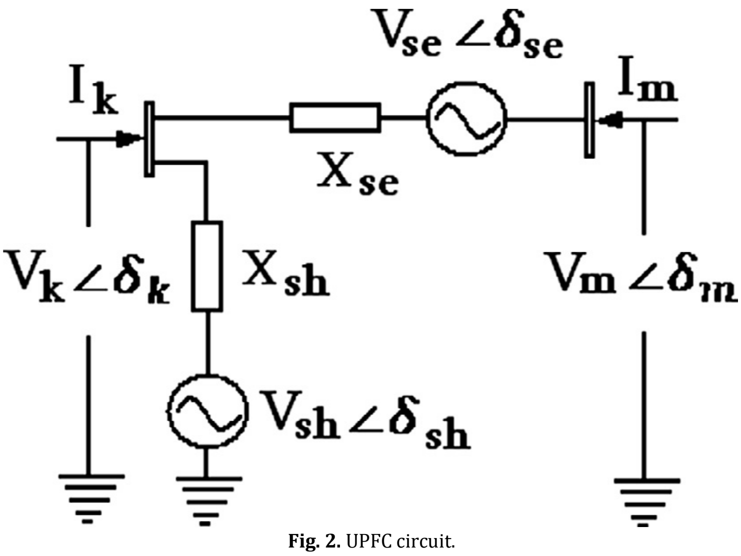

Fig. 2. UPFC circuit.

$$P_{se} = V_{se}^2 G_{mm} + V_{se} V_k (G_{km}\cos(\theta_{se} - \theta_k) + B_{km}\sin(\theta_{se} - \theta_k)) + V_{se} V_m (G_{mm}\cos(\theta_{se} - \theta_m) + B_{mm}\sin(\theta_{se} - \theta_m)) \quad (1)$$

$$Q_{se} = V_{se}^2 B_{mm} + V_{se} V_k (G_{km}\sin(\theta_{se} - \theta_k) + B_{km}\sin(\theta_{se} - \theta_k)) + V_{se} V_m (G_{mm}\sin(\theta_{se} - \theta_m) + B_{mm}\cos(\theta_{se} - \theta_m)) \quad (2)$$

$$P_{sh} = -V_{sh}^2 G_{sh} + V_{sh} V_k (G_{sh}\cos(\theta_{sh} - \theta_k) + B_{sh}\sin(\theta_{sh} - \theta_k)) \quad (3)$$

$$Q_{se} = V_{sh}^2 B_{sh} + V_{sh} V_k (G_{sh}\sin(\theta_{sh} - \theta_k) + B_{sh}\cos(\theta_{sh} - \theta_k)) \quad (4)$$

$$\sum_{i=1}^{N_G} C_i(P_{G_i}) = \sum_{i=1}^{N_G} (a_i + b_i P_{G_i} + c_i P_{G_i}^2) \quad (5)$$

$$\mathrm{P_L} = \sum_t \left(real(yline_t)(V_{k_t}^2 + V_{m_t}^2)\right) - \left(V_{k_t} V_{m_t} abs(yline_t)\cos\left(\delta_{k_t} - \delta_{m_t} - \delta(yline_t)\right)\right) - \left(V_{m_t} V_{k_t} abs(yline_t)\cos\left(\delta_{m_t} - \delta_{k_t} - \delta(yline_t)\right)\right) \quad (6)$$

In the above equations, the N_G indicates the number of generator terminals and n determines the all terminal numbers, $\mathrm{P_D}$ shows the power system load-requirement, $\mathrm{P_L}$ indicate the system active power loss. Also t represents the transmission line count; as well as V_{k_t}, V_{m_t} is voltage amplitudes of sending end and receiving end terminals as sequence jointed with tth power line; $\delta_{k_t}, \delta_{m_t}$ are voltage angles of forwarder end and recipient end terminals as sequence jointed with tth transmission line; $yline_t$ is the admittance of the tth transmission line. $a_i, b_i, and\ c_i$ are respective price-coefficients of the generators. Also there are some terms and conditions on the value of real power and reactive power that listed below:

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max} \quad (7)$$
$$Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max} \quad (8)$$
$$V_i^{\min} \le V_i \le V_i^{\max} \quad (9)$$

3. Bee's algorithm

In last decade several nature based optimization algorithm have been emerged. These algorithms mimic the animals and human manner in searching the best food source or location. Some of these algorithms are: Genetic algorithm (GA), particle swarm optimization (PSO) algorithm, ant colony optimization (ACO) algorithm, imperialist competitive algorithm (ICA), Cuckoo search (CS), Cuckoo optimization algorithm (COA), Bees algorithm (BA), Honey bee mating optimization (HBMO) algorithm, Artificial bee colony (ABC) and many other nature based algorithms or their modified versions (Karaboga and Basturk, 2007; Karaboga and Basturk, 2008; Rao et al., 2008). In each optimization algorithm, two main criteria are important: The finding of global solution vicinity or exploration and the main global solution finding exactly or extraction. Each optimization algorithm that has these two main standards will be good optimization algorithm. Many of the proposed method that has been introduced are week in one of the mentioned standards. For example the PSO algorithm has well exploration capability but doesn't have well extraction capability. In contrast, GA has very well extraction capability and week exploration capability. Also many of these optimization techniques have very operators and computational efforts.

Bees Algorithm optimization technique is an optimization algorithm that mimic the honey bee manner in food resource searching in nature. In Fig. 3, the main steps of bee's algorithm is described by details.

In bees algorithm there are several parameters and operators: (n) that indicates the number of scout bees, (m) that indicates the number of sites selected out of n visited sites, (e) that indicates the number of best sites out of m selected sites, (nep) that indicates the number of bees recruited for best e sites, (m-e) selected sites (nsp) that indicates the number of bees recruited for the other, and the primary value of patches (ngh) that involves site and its vicinity and stopping term. As it depicted in Fig. 3, the optimization procedure start with n bees that located randomly in defined boundaries. Before the starting the optimization method, the minimum and maximum boundaries must be determined. After the starting of the optimization procedure and placement of n bees in search space accidently, we must compute the fitness of these bees. In each optimization problem, the fitness function or target function must be defined by details and accuracy.

1. Generate the initial population of bees in search space
2. evaluate the fitness function for each bee
3. Repeat these actions to reach stop criteria
4. Sort the bee, and select the elite bees
5. Send some bees in elite bees patches to search with more accuracy
6. Remove remaining bees and generate new bees randomly in search space
7. Check the stop conditions.
8. End

Fig. 3. Pseudo code.

In next step, the bee that have high performance and fitness value, selected as elite bees. These bees placed at best locations and their vicinity may have better solutions. Thus the new bees from hive transmitted to that determined location and placed randomly near that elite bee. This strategy helps the bee's algorithm to extract the global optimum solution from all search space. The number of transmitted bees must be determined in starting of algorithm.

In next step, the non-elite bees or remaining bees eliminated and the new bees are generated. These new bees placed randomly in search space. This strategy of bee's algorithm is very good for exploration of global solution vicinity. Also this strategy avoids the bee's algorithm in stacking in local minima traps. The number of the elite bees and these new randomly generated bees must be predetermined in the starting of algorithm.

This procedure is keeping on until the stop criteria are reached. In different problems, different stop criteria can be defined. In our case the maximum iteration of algorithm is determined as stop criterion.

4. PID controller

A proportional- Integral- Derivative controller or PID controller is the close loop control system. This type of controller has numerous applications in industry. The PID controller has simple structure and therefore can be applied in most industries. This controller has three free parameters that determine the behavior of controller. If these parameters set by accuracy, the PID controller will has good output. The basic strategy of PID is based on fault magnitude between the output of the system and desired input. The PID controller changes its parameters to reduce this difference between the real output and desired input.

In control science, the three free parameters of PID controller called control gains and indexed P, I, and D. PID controller is very simple and inexpensive. In contrast other controllers such as fuzzy controllers and adaptive controllers are very complicated and costly. Therefore it is not economical selection to apply fuzzy controllers and adaptive controllers. Based on the mentioned reasons, selection of PID controller is economic and smart selection. In this controller the input signal to controller called control signal and defined as follow:

$$u(t) = K_p e(t) + K_i \int_0^{\infty} e(t)dt + K_d e(t) \quad (10)$$

Here K_p indicates the proportional gain, K_i indicates the integral gain, K_d indicates the derivative gain, e shows the error signal and finally t represents the time or instantaneous time.

5. Simulation results

This section presents the obtained results from computer simulations. In order to evaluate the performance of the suggested approach some examines are performed. The details of simulations are presented in next lines. For this purpose a power network system in two different situations are chosen. First situation is normal load situation and second situation is heavy load situation. In these tests, the proposed PID controller and PI controller is used. PI controller is used to prove the effectiveness and powerfulness of our introduced intelligent method. The output of test is indices such as voltage profile and reduction of real power loss in network. The parameters of power networks are mentioned in Tables 1 and 2 respectively.

Table 1
Power system information.

Generator parameters	$T'_{do} = 5.044s, X'_d = 0.3, X_q = 0.6p.u, M = 8MVA$
Excitation system values	$K_a = 10p.u, T_a = 0.05s$
Transformers	$X_{te} = 0.1p.u, X_{SDT} = 0.1p.u$
Lines	$X_{t1} = 1p.u, X_{T2} = 1.125p.u$
DC link values	$V_{DC} = 2p.u, C_{DC} = 3p.u$
UPFC values	$m_E = 1.0307, m_B = 0.1347, \delta_E = 32.57^{\circ}, \delta_B = -8.0173^{\circ}$

Table 2
Different conditions case studies.

Normal load	P = 1 p.u. Q = 0.2 p.u.
Heavy load	P = 1.1 p.u. Q = 0.25 p.u.

In the investigation systems, the PID and PI controllers are designed and tuned for normal load condition. Also in optimization algorithm, ITAE index is selected as target function. In the bees algorithm the control parameters have very vital role in its speed and convergence. For this purpose we must select these parameters by accuracy. In bees algorithm the number of bees (n) is indicates the number of all the bees that spread in search space in first step. Then the soldier bees are transmitted to near the elite bee's patches. If the value of n will be high, then the simulation time will be high. Also if the value of n is low, then the probability the convergence of optimization algorithm will be low. Thus we will select the n by accuracy. Table 3 shows the bees algorithm parameters.

Table 3
Parameters of BA.

Number of scout bees, *n*	50
Number of sites selected for neighborhood search, *m*	12
Number of best "elite" sites out of *m* selected sites, *e*	8
Number of bees recruited for best *e* sites, *nep*	4
Number of bees recruited for the other (*m*-*e*) selected sites, *nsp*	4
Number of iterations, *R*	100

As mentioned, the BA is applied to select the optimum parameters of PI and PID controller. The obtained optimum values of these parameters are listed in Tables 4 and 5. These values are obtained after 50 independent and different runs. In all runs, approximately similar results have been gained. The output results after controlling the UPFC by optimized controllers are listed in Table 6. It can be seen from Table 6 that the proposed method has better performance rather than PI controller. In during the simulation both in normal situation and heavy load situation, the proposed method has better result.

Table 4
Optimum values of PI controller gains selected by BA.

K_p	4.13
K_I	25.73

Table 5
Optimum values of PID controller gains selected by BA.

K_p	4.84
K_I	18.29
K_D	0.2059

Table 6
10% step increase in the original power of second line.

	ITAE	
	PI	PID
Normal load	4.4789×10e-4	2.5563×10e-4
Heavy load	4.8698×10e-4	2.7744×10e-4

6. Conclusion

UPFC Controller is one of the FACTS devices that provide secure and reliable reactive power compensation in electrical power networks. In order to have best performance in UPFC, a good and powerful controller is needed. In this paper a optimized PID controller is proposed to control the UPFC. In the proposed system, bee's algorithm is used to find the optimum values of PID free gains. After optimizing the controller, this controller is applied on real standard system and the obtained results show that the proposed method has good performance.

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