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# Optimization of the unified power flow controller based on the Imperialist competitive algorithm method

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ABSTRACT

FACTS devices are a new technology that developed in recent years and has 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 a 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, ICA is used to find the optimum value of these parameters. The imperialist competitive algorithm (ICA) is one of the best and rapid nature-based optimization algorithms that its capabilities are proven in 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

The electrical power network is the biggest system made by man. This system has many sections such as big generators, big transformers, breakers, loads, transmission lines, compensators and many other parts and instruments. With increasing the demand for electrical by humans and factories and as sequence increasing the scale of this big network, some difficulties and complicated problems have emerged. In this large scale power network the level of voltage is low, the 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 (Sreejith et al., 2015). This new technology first presented in the 1980s. In the 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 (Sreejith et al., 2015; Gasperic and Mihalic, 2015).

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 their normal condition. One of the most disadvantages in the big power network is the high level of power loss. The second one is a weak voltage profile. Therefore specialists must propose new control systems to remove or reduce these problems.

As mentioned FACTS devices can improve the characters of power networks significantly. In literature, numerous approaches and techniques have been presented for enhancing the power quality using this new technology (Singh et al., 2015a; 2015b; Ravi and Rajaram, 2013; Bhattacharyya and Gupta, 2014; Wan et al., 2014). In each case, associated with operation and target of the system the new and special purposed is determined. Because the FACTS devices can be used to remove generator output voltage oscillation or can be used to enhance the power factor by injecting reactive power at the 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 the power network. But for these purposes, the FACTS devices must locate in a good location. Also, the placed FACTS device must have good value. It must inject or absorb a sufficient level of reactive power into or to power network respectively. In the last decade usage of nature-based optimization algorithms has 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 (Bhattacharyya and Gupta, 2014; Banaei et al., 2014). Nature-based optimization algorithms mimic the manner of animals in search for the food source. For example, the particle swarm optimization algorithm mimics the behavior of a flock of birds in searching for 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 the best output, the FACTS devices must have a good controller. In last year many techniques and intelligent methods have been proposed to control the FACTS device manner. The most popular one is the PID controller. The PID controller is very simple and cheap. Also, this type of controller has very good performance. Another applied controller is a fuzzy controller. This type of controller use fuzzy rules to control the studied system. The performance of this controller is better than a PID controller. But

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the complexity and price of this controller are very high compared with the PID controller. Furthermore, the implementation of the fuzzy controller is very complicated and in some cases is not economic. Other control systems are adaptive controllers, artificial neural networks and robust controllers.

A literature review shows that the food optimization algorithm must have some features. The two main of these features are the ability of exploration and extraction. If the one optimization algorithm can find the vicinity of a global solution in a short time, that optimization algorithm has very good exploration ability. Also if one optimization algorithm can reach a 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 ICA in exploration and extraction, in this paper, the ICA is proposed to select the optimum parameters of the PID controller. Also, UPFC is used to enhance power system quality. The optimized PID will control the UPFC behavior. The detail of the PID controller and optimization algorithm is presented in the next sections.

## 2. UPFC

FACTS devices made is possible to inject and absorb reactive power. This action can improve the capacity of the available power network. Also, this technology improves the voltage profile of the electrical power network and reduces power loss. One of the most flexible and efficient types 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 a parallel transformer, direct current voltage source, parallel converter and series converter. In UPFC all the section operations must be controlled by an external controller. As mentioned this external controller may be selected from the PID controller, fuzzy controller, neural network or adaptive controller (Banaei et al., 2014; Naderi and Yazdani, 2014).

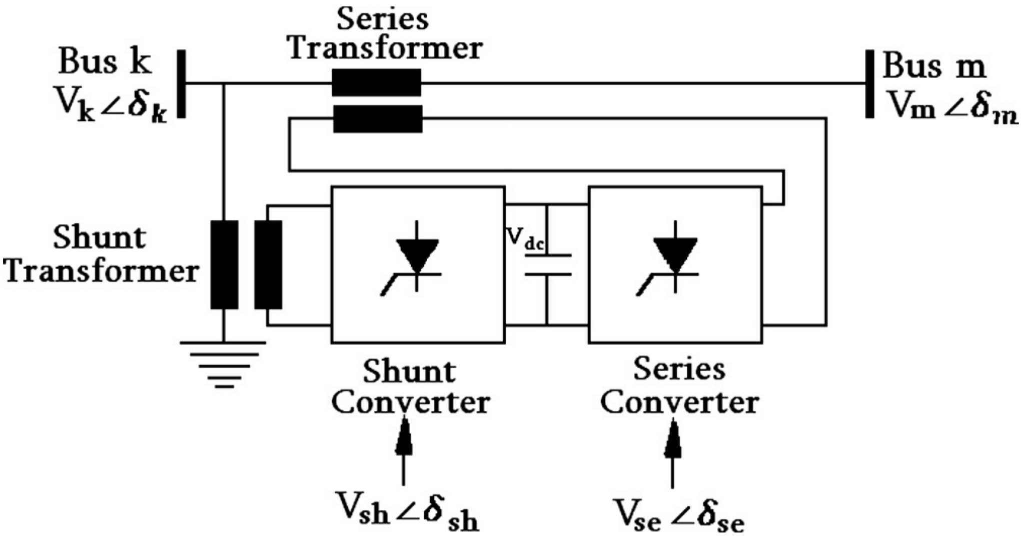


**Fig. 1.** UPFC structure.

In Fig. 2, the electrical schematic of this device is depicted. It can be seen from Fig. 2 that UPFC in its electrical circuit has a 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 sources have constraints. The magnitude of these two voltage sources 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 a vital role in UPFC performance. The more details regarding the UPFC structure and operation of these two voltage sources can be found in other references.

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

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

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

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

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

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

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

In the above equations, the $N_G$ indicates the number of generator terminals and n determines the all terminal numbers, $P_D$ shows the power system load-requirement, $P_L$ indicate the system's 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 $t$th power line; $\delta_{k_t}, \delta_{m_t}$ are voltage angles of forwarder end and recipient end terminals as sequence jointed with $t$th transmission line; $yline_t$ is the admittance of the $t$th transmission line. $a_i, b_i, c_i$ 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:

$$P_{G_i}^{\min} \leq P_{G_i} \leq P_{G_i}^{\max} \quad (7)$$

$$Q_{G_i}^{\min} \leq Q_{G_i} \leq Q_{G_i}^{\max} \quad (8)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (9)$$

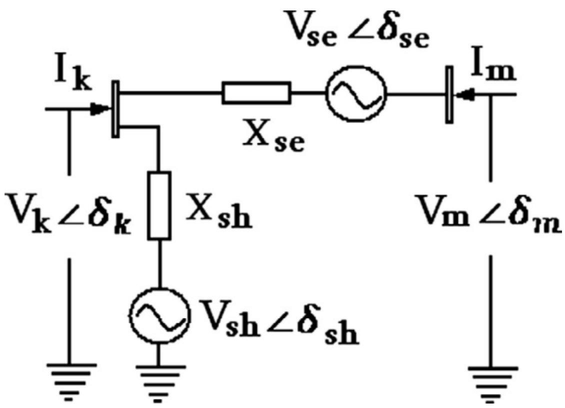

**Fig. 2.** UPFC circuit.

## 3. ICA

In the last decade, several nature-based optimization algorithms have emerged. These algorithms mimic the animals and human manner in searching for 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 (Wan et al., 2014; Naderi and Yazdani, 2014). 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 a good optimization algorithm. Many of the proposed methods that have 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.

In the science of swarm intelligence, the imperialist competitive algorithm is an iterative optimization technique inspired by the human manner in social issues. Similar to other nature-based optimization algorithms, imperialist competitive algorithm don't need to gradient information of fitness function. This feature gives this ability to these algorithms to don't trap in local minima. The imperialist competitive algorithm is more similar to a genetic algorithm. In both optimization algorithms, human enhancement is modeled. In the genetic algorithm, the human improvement from a genetic view is studied, but in the imperialist competitive algorithm, the human enhancement in social and political issues is studied. In other nature-based optimization algorithms, the manner of animals for food searching in nature is modeled. In Fig. 3, the main structure of the imperialist competitive algorithm is illustrated.

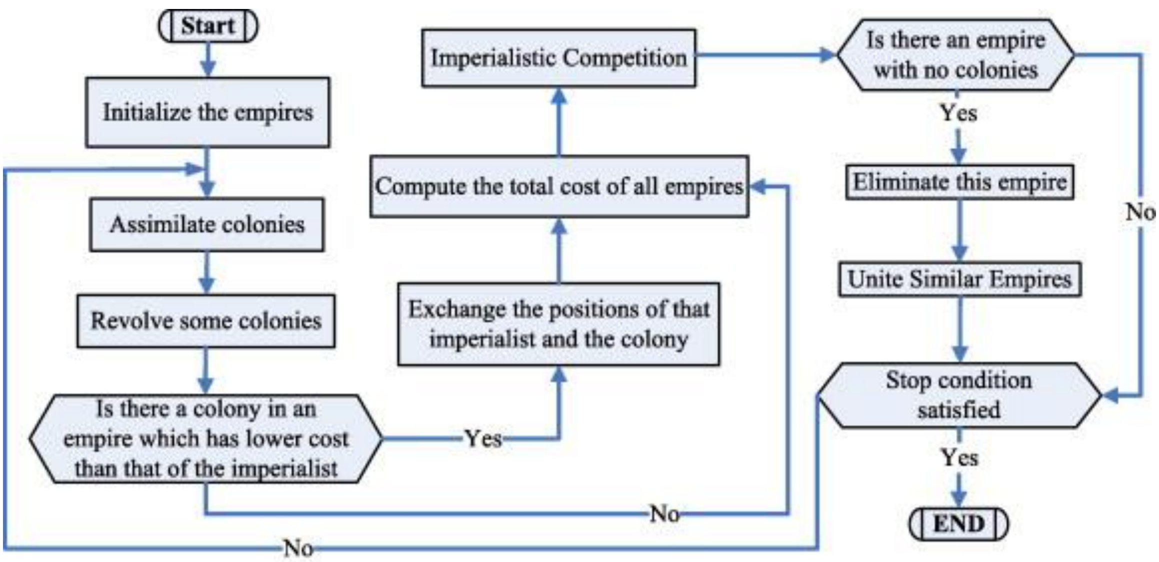

**Fig. 3.** The main structure of the imperialist competitive algorithm.

The imperialist competitive algorithm is a swarm intelligence algorithm that firstly presented by Iranian researchers (Naderi and Yazdani, 2014). Since emerges of this optimization algorithm, it is applied in many optimization problems (Banaei et al., 2014). ICA is based on the imperialist contest. These algorithm efforts to model the human policy and imperialist countries in attain and govern high nations and countries. The imperialist countries use different resources of occupied countries. These resources may be mine, underground source of energy and many other source of energy. Also, the imperialist countries attempt to change the culture and language of weak countries. Also in this algorithm, the imperialist countries contest with them to increase their power. The imperialist competitive algorithm starts with a chancily primary population in search space. In this algorithm, countries have chromosomes roles in genetic algorithms or particles in a particle swarm optimization algorithm. In the first iteration, the fitness function is calculated for these initial countries and the most powerful countries are selected as imperialist countries. The remaining countries are colonies and must divide among the imperialist countries. In this step, a competition starts among the imperialist countries to attain more colonies. The more powerful imperialist has a high chance to attain more colonies. After finishing the competition among the imperialist countries, the empires composed. This procedure is depicted in Fig. 4. The most powerful imperialist country has more colonies and therefore has more power in the world.

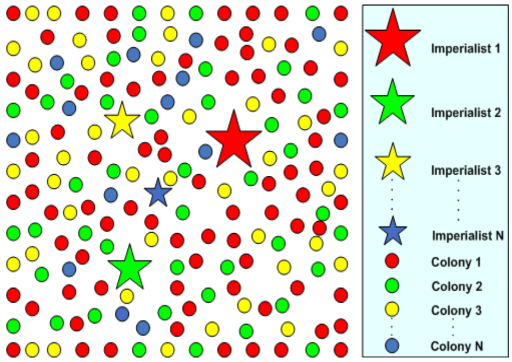

**Fig. 4.** Composition of empires in ICA.

When the completion stopped and the empires took place, the weak countries or colonies attempt to approach their associated imperialist country. This procedure is illustrated in Fig. 5. In this movement, the colony doesn't completely arrive at its imperialist. The mathematical modeling of this movement is as follows:

$$\alpha \approx U(0, \beta \times S) \tag{10}$$

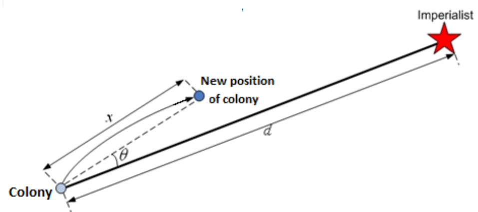

**Fig. 5.** Moving colonies toward their relevant imperialist.

In the final step of this algorithm, the most powerful empire will take all the colonies and empires. In this state, only one empire will be in the world and the optimization will stop. The main steps of ICA are as follows:

1: Generate initial population (countries) in search space.
2: Evaluate the fitness function for each country.
3: Select the empires and colonies.
4: Do the movement of colonies to the imperialist country as shown in Fig. 3.
5: Evaluate each empire's power.
6: Eliminate the weakest empire and divide it among other empires.
7: Check the empires' number. If there is only one empire, then stop the algorithm. Else go to step 4.

## 4. PID controller

A proportional- Integral- Derivative controller or PID controller is the closed-loop control system. This type of controller has numerous applications in industry. The PID controller has a simple structure and therefore can be applied in most industries. This controller has three free parameters that determine the behavior of the controller. If these parameters set by accuracy, the PID controller will have a good output. The basic strategy of PID is based on fault magnitude between the output of the system and the 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 the 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 an economical selection to apply fuzzy controllers and adaptive controllers. Based on the mentioned reasons, the selection of the PID controller is an economic and smart selection. In this controller the input signal to the controller called control signal and defined as follows:

$$u(t) = K_p e(t) + K_i \int_0^\infty e(t)dt + K_d e(t) \tag{11}$$

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 the simulations are presented in the next lines. For this purpose, a power network system in two different situations is chosen. The first situation is a normal load situation and the second situation is a heavy load situation. In these tests, the proposed PID controller and the PI controller is used. PI controller is used to proving the effectiveness and powerfulness of our introduced intelligent method. The output of the test is indices such as voltage profile and reduction of real power loss in the network. The parameters of power networks are mentioned in Table 1 and Table 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 conditions. Also in the optimization algorithm, the ITAE index is selected as the target function. In the ICA algorithm, the control parameters have a very vital role in its speed and convergence. For this purpose, we must select these parameters by accuracy. In ICA the number of countries (n) indicates the number of all the countries that spread in search space in the first step. 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 ICA parameters.

**Table 3**
ICA parameters.

| Parameter | Value |
|---|---|
| Number of colonies | 40 |
| Number of Imperialists | 7 |
| $\beta$ | 0.05 |
| $\theta$ | 50 |
| Number of iterations | 100 |

As mentioned, the ICA is applied to select the optimum parameters of the PI and PID controller. The obtained optimum values of these parameters are listed in Table 4 and Table 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 the PI controller. During the simulation both in a normal situation and heavy load situation, the proposed method has a better result.

**Table 4**
Optimum values of PI controller gains selected by ICA.

| | |
|---|---|
| $K_p$ | 4.48 |
| $K_I$ | 25.31 |

**Table 5**
Optimum values of PID controller gains selected by ICA.

| | |
|---|---|
| $K_p$ | 4.34 |
| $K_I$ | 18.76 |
| $K_D$ | 0.232 |

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

| | ITAE | |
|---|---|---|
| | PI | PID |
| Normal load | 4.4219×10e-4 | 2.0543×10e-4 |
| Heavy load | 4.865×10e-4 | 2.5434×10e-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 the best performance in UPFC, a good and powerful controller is needed. In this paper, an optimized PID controller is proposed to control the UPFC. In the proposed system, ICA is used to find the optimum values of PID free gains. After optimizing the controller, this controller is applied to the real standard system and the obtained results show that the proposed method has good performance.

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