Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 14 Issue 8 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

# Optimal Power Flow in the Presence of Practical Constraints and with TCSC using Imperialistic Competitive Algorithm

By G. Nageswara Reddy, S. S. Dash, S. Sivangaraju & Ch. V. Suresh
*Yogi Vemana University, India*

*Abstract-* At present, power system operation, control, Management becomes very complex due to continuously increasing demand. Flexible AC Transmission System (FACTS) controllers are used to increase power transfer capability of the transmission lines closer to their limits. This paper proposed a methodology to solve Optimal Power Flow (OPF) problem in the presence of Thyristor Controlled Series Capacitor (TCSC) while satisfying system operating and practical constraints. A novel cost objective function is formulated by combining investment cost of the TCSC with the conventional fuel cost function. The proposed methodology is tested on standard IEEE-14 bus test system with supporting results.

*Keywords: economic dispatch, ramp-rate limit, prohibited operating zones, TCSC, investment cost.*

*GJRE-F Classification : FOR Code: 090607*

# Optimal Power Flow in the Presence of Practical Constraints and with TCSC using Imperialistic Competitive Algorithm

G. Nageswara Reddy [α], S. S. Dash [σ], S. Sivangaraju [ρ] & Ch. V. Suresh [ω]

*Abstract-* At present, power system operation, control, Management becomes very complex due to continuously increasing demand. Flexible AC Transmission System (FACTS) controllers are used to increase power transfer capability of the transmission lines closer to their limits. This paper proposed a methodology to solve Optimal Power Flow (OPF) problem in the presence of Thyristor Controlled Series Capacitor (TCSC) while satisfying system operating and practical constraints. A novel cost objective function is formulated by combining investment cost of the TCSC with the conventional fuel cost function. The proposed methodology is tested on standard IEEE-14 bus test system with supporting results.

*Keywords: economic dispatch, ramp-rate limit, prohibited operating zones, TCSC, investment cost.*

## I. Introduction

Most important problem in power systemoperation and control is Economic Load(ED). This problem should be optimized tomaximize the lowest cost of fuel to meet the load. The main objective of OPF problem is to optimize the chosen objectives such as classical quadratic fuel cost function and non-convex fuel cost functions in the presence of operating as well as practical constraints. In general, OPF problem is described as a highly constrained, large-scale, non-linear, non-convex optimization problem.

In the last three decades eminent population based optimization techniques have been developed. They are: Grenade Explosion Method (GEM) [1], Ant Colony Optimization (ACO) [2], Shuffled Frog Leaping (SFL) [3], Artificial Immune Algorithms (AIA) [4], Harmony Search (HS) [5], Genetic Algorithm (GA) [6], Artificial Bee Colony (ABC) [7], Particle Swarm Optimization (PSO) [8], Bacteria Foraging Optimization (BFO) [9], Gravitational Search Algorithm (GSA) [10], Biogeography-Based Optimization (BBO) [11] and Differential Evolution (DE) [12] these algorithms have been applied to solve OPF problems effectively for specific type of problems.

All of these algorithms are population based optimization methods, but they have some limitations in some aspects. To overcome this limitations research is continued, to improve the performance of the above methods. Improvement of the existing methods is reported in GA [13], PSO [14, 15], ACO [16, 17], ABC [18, 19]. Combining merits in the different optimization techniques known as hybridization of the optimization techniques. Some hybrid algorithms can found in [20, 21], etc.

The performance comparison of optimization techniques such as DE, PSO and GA for power loss minimization using FACTS devices is presented [22]. Optimal location and best setting of TCSC is proposed. Best location is performed using sensitivity analysis [23]. In [24], the improvement of the power system security against contingencies with TCSC approach is proposed. In this GA and PSO algorithms are used to find the optimal location and parameter settings of TCSC under contingency. Mathematical modeling of varies series FACTS devices are presented in economic dispatch problems [25]. Here selection of optimal location of FACTS devices is based on the improvement of the economic dispatch.

In [26], OPF problem formulation has been presented along with considering effects of FACTS devices and power flow constraints. To solve OPF problem a two stage problem formulation has been proposed. This reference [27], Presents the performance comparison of PSO and GA optimization techniques for FACTS based controller design. In [28], the main aim is the optimal allocation of TCSC device in the power system so the power loss become minimized and also increase power transfer capacity of the transmission line that ultimately yields minimum operating cost with different load conditions. In this, first the locations of the TCSC device is identified by calculating line flows. TCSC is placed in line where reactive power flows are very high. To solve OPF problem Hybrid GA incorporating TCSC is proposed. To select best control variables, to minimize the generation cost and maintain the power flow within the control

*Author α: Assistant Professor, Electrical and Electronics Engineering Department, YSR College of engineering of Yogi Vemana University, Proddatur, A.P., India. e-mail: gnageswarareddy@gmail.com*

*Author σ: Professor, Electrical and Electronics Engineering Department, SRM University, Chennai, India. e-mail: munu_dash2k@yahoo.com*

*Author ρ: Professor, Electrical and Electronics Engineering Department, University College of Engineering, JNTUK, Kakinada, A.P., India.*

*Author ω: Regular Research Scholar, University College of Engineering, JNTUK, Kakinada, A.P., India. e-mail: venkaatsuresh3@gmail.com*

range, hybrid GA is integrated with conventional OPF [29].

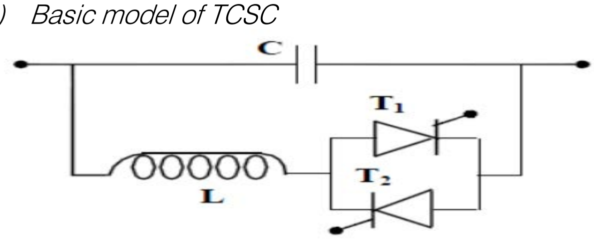
The generation cost is minimized subjected to equality and inequality constrains. The optimal active power flow control strategy with TCSC is proposed. In this method problem is solved in two steps. First step is power flow control and second step is normal OPF problem [30]. In [31], presents solution of OPF with different objective functions such as generation cost and total power loss minimization using GA. In base case OPF solution is obtained with generation cost minimization and optimal setting of the control parameters are determined. In this OPF with TCSC is carried out with generation cost and total power loss as objective functions.

This paper mainly concentrates on certain power system issues such as quadratic fuel cost function and non-convex fuel cost functions are optimized while satisfying operating and practical constraints is analyzed in the presence of TCSC. A methodology to install TCSC in an optimal location is presented. The proposed OPF problem is solved using Imperialistic Competitive Algorithm (ICA) while satisfying equality, in-equality, ramp-rate constraints and prohibited operating zones in the presence of TCSC.

## II. Modeling of TCSC

TCSC is a variable impedance type series compensator which is connected in series with the transmission line to increase the power transfer capability, improve transient stability, reduces transmission losses. The basic configuration of TCSC and its equivalent pi-representation for transmission line modeling is shown in Fig.1.

*a) Basic model of TCSC*




*b) Equivalent pi-representation of TCSC*

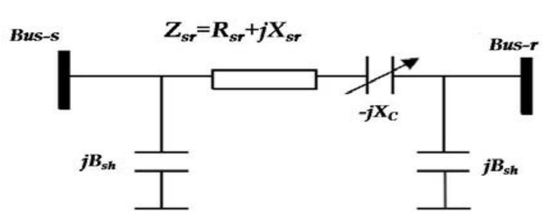



*Fig 1 :* TCSC model

This device is incorporated in a line between buses, 's' and 'r' then, the new line reactance can be expressed as

$$X_{sr\,new} = X_{sr} - X_C \qquad (1)$$

Therefore new line admittance between buses's' and 'r' can be derived as follows

$$Y'_{sr} = \frac{1}{Z'_{sr}} = \frac{1}{R_{sr} + j(X_{sr} - X_C)} \qquad (2)$$

$$Y'_{sr} = G'_{sr} + jB'_{sr} = \frac{R_{sr} - j(X_{sr} - X_C)}{R_{sr}^2 + (X_{sr} - X_C)^2} \qquad (3)$$

$$G'_{sr} = \frac{R_{sr}}{R_{sr}^2 + (X_{sr} - X_C)^2} \;;\; B'_{sr} = -\frac{(X_{sr} - X_C)}{R_{sr}^2 + (X_{sr} - X_C)^2}$$

The modified active and reactive power flows from bus-s to bus-r, and from bus-r to bus-s of a line having series impedance and a series reactance are

$$P_{sr}^{TCSC} = V_s^2 G'_{sr} - V_s V_r \left(G'_{sr} Cos(\delta_{sr}) + B'_{sr} Sin(\delta_{sr})\right)$$

$$Q_{sr}^{TCSC} = -V_s^2 \left(B'_{sr} + B_{sh}\right) - V_s V_r \left(G'_{sr} Sin(\delta_{sr}) - B'_{sr} Cos(\delta_{sr})\right)$$

$$P_{rs}^{TCSC} = V_r^2 G'_{sr} - V_s V_r \left(G'_{sr} Cos(\delta_{sr}) - B'_{sr} Sin(\delta_{sr})\right)$$

$$Q_{sr}^{TCSC} = -V_r^2 \left(B'_{sr} + B_{sh}\right) + V_s V_r \left(G'_{sr} Sin(\delta_{sr}) + B'_{sr} Cos(\delta_{sr})\right)$$

The power loss in the line with TCSC can be written as

$$P_{Loss} = P_{sr}^{TCSC} + P_{rs}^{TCSC} = G'_{sr}\left(V_s^2 + V_r^2\right) - 2 V_s V_r G'_{sr} Cos(\delta_{sr})$$

$$Q_{Loss} = Q_{sr}^{TCSC} + Q_{rs}^{TCSC} = -\left(V_s^2 + V_r^2\right)\left(B'_{sr} + B_{sh}\right) + 2 V_s V_r B'_{sr} Cos(\delta_{sr})$$

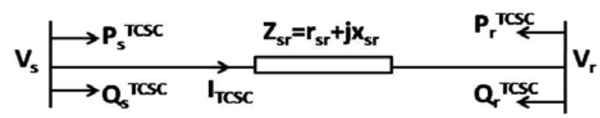



*Fig 2 :* Power injection model of TCSC

Due to TCSC, the change in line flow can be represented as a line without TCSC plus with power injected at the sending and receiving ends of the line with device as shown in Fig.2. The active and reactive power injections at bus-s and bus-r can be written as

$$P_s^{TCSC} = V_s^2 \Delta G_{sr} - V_s V_r \left[\Delta G_{sr} Cos(\delta_{sr}) + \Delta B_{sr} Sin(\delta_{sr})\right] \qquad (4)$$

$$P_r^{TCSC} = V_s^2 \Delta G_{sr} - V_s V_r \left[\Delta G_{sr} Cos(\delta_{sr}) - \Delta B_{sr} Sin(\delta_{sr})\right] \qquad (5)$$

$$Q_s^{TCSC} = -V_s^2 \Delta B_{sr} - V_s V_r \left[\Delta G_{sr} Sin(\delta_{sr}) - \Delta B_{sr} Cos(\delta_{sr})\right] \qquad (6)$$

$$Q_r^{TCSC} = -V_r^2 \Delta B_{sr} + V_s V_r \left[\Delta G_{sr} Sin(\delta_{sr}) + \Delta B_{sr} Cos(\delta_{sr})\right] \qquad (7)$$

Where

$$\Delta G_{sr} = \frac{X_C R_{sr}(X_C - 2X_{sr})}{\left(R_{sr}^2 + X_{sr}^2\right)\left(R_{sr}^2 + (X_{sr} - X_C)^2\right)}$$

$$\Delta B_{sr} = \frac{-X_C\left(R_{sr}^2 - X_{sr}^2 + X_C X_{sr}\right)}{\left(R_{sr}^2 + X_{sr}^2\right)\left(R_{sr}^2 + (X_{sr} - X_C)^2\right)}$$

TCSC device is modeled with power injection model so far by using the TCSC control variable. It is possible to calculate the complex power injected $S_s^{TCSC}$ and $S_r^{TCSC}$ at bus-s and bus-r respectively.

$$S_s^{TCSC} = P_s^{TCSC} + j\,Q_s^{TCSC}$$
$$S_r^{TCSC} = P_r^{TCSC} + j\,Q_r^{TCSC}$$

i. *Installation cost*

In this paper, device life time is considered for 15 years during the analysis. The Installation Cost (IC) of

$$IC_{TCSC} = \frac{C_{TCSC} \times S_{TCSC} \times 1000}{n \times 8760} \quad \$/h \qquad (8)$$

Where, $C_{TCSC}$=[0.0015S$^2$-0.713S+153.75] $/KVAr, and $S_{TCSC}$=|Q2|-|Q1| MVAr. Here, $C_{TCSC}$ and $S_{TCSC}$ are the cost and operating range of TCSC, $Q_1$ and $Q_2$ are the reactive power flows in the line without and with TCSC; 'n' is the device life time in years (15 years).

ii. *Optimal location*

In order to select appropriate branch for placement of FACTS devices, contingency analysis and sensitivity index method is used. Sensitivity index is introduced for ranking the optimal location. Sensitiveness of each branch towards the change in power transfer capability, voltage profile with respect to change in line reactance, reactive power injection at various branches, buses are identified. The sensitivity indexes at different branches have been evaluated to select appropriate branch for device location by using load flow program suitable to transmission networks. These sensitivity indexes reflect how the load ability of branch change with respect to line reactance, how the voltage profile can be change with respect to reactive power injection at a particular bus. Sensitivity indices are evaluated for the base case and arrange in descending order. The branch which corresponds to highest sensitivity index is highest severe contingency.

The power flows of highest severe contingency are considered as base case. From these flows, the branch with least power flow can be considered as the best location for the TCSC device. Because the transmission line has inductive reactance where as the TCSC is a series controlled device which can provide a capacitive reactance so that the total reactance of the branch which leads to the increase of load ability of the line where the device was located. The objective is, to increase the power transfer capability of the transmission line. The power transfer capability of the transmission line depends on the line reactance as well as bus voltages. Hence the load ability of the line can be increased either by reducing line reactance or increasing voltage profile. In order to reduce the reactance of the transmission line TCSC can be used. The voltage profile can be improved by injecting the reactive power at a particular bus where the voltage is minimum. The optimal location of the device is that where it gives maximum benefit for optimal size of FACTS devices placed at selected location. The contingency analysis and severity index based ranking procedures are explained as follows:

a. *Contingency analysis*

Usually, outage of one of the transmission lines can be considered as the contingency condition. This happens due to many reasons; it may be because of maintenance of the transmission lines, environmental conditions, etc. Because of this situation, the transmission lines get overloaded. This contingency analysis analyzes the system security and gives future directions for the proper planning and designing. Because of this analysis, the preventive and corrective measures under contingency conditions can be predicted. Usually, the contingency condition may be due to a transmission line or a generator failure or a transformer failure. Out of which, transmission line failure plays an important role to assess the power system security.

b. *Performance Index and Ranking*

It is not required to consider each and every line outage to assess power system security. Because, for a particular line outage, there are few lines and buses do not have line flow and voltage variations beyond the limits. If there are any line overloads and bus voltage variations then the outage line is considered as critical line. The critical lines or credible contingencies are identified by contingency analysis and only these critical lines need to be taken to assess the power system security. A parameter which is known as performance index used for security analysis. It indicates how much a particular outage might affect the security of power system. In general the performance index (PI) or severity index (SI) is defined as

$$Severity\ Index = \sum_{l=1}^{N_{line}} \left( \frac{S_l}{S_l^{\max}} \right)^{2m} \qquad (9)$$

Where, $S_l$ and $S_l^{\max}$ are the MVA flow in line 'l' and MVA rating of the line 'l' respectively. 'm' is an integer exponent taken as 1.

The line flows are obtained by using power flow solution method. In Eqn. (9), the performance index is defined only based on over loaded lines.

## III. Opf Problem Formulation

A novel cost objective function is formulated by combining TCSC investment cost (ICTCSC) along with the conventional fuel cost function. Because of the combining ICTCSC with fuel cost function, the system and the FACTs controller control variables are readjusted to optimize the combined fuel cost function. This objective function is optimized while satisfying system operating, practical and the device limits. The modified fuel cost function with TCSC investment cost can be expressed as follows:

$$Minimize\ \ FC = \sum_{i=1}^{N_G} C_i(P_{Gi}) + IC_{TCSC} \qquad (10)$$

Where, 'FC' is the total generation cost, '$C_i(P_{Gi})$' is the fuel cost function of the i[th] unit, '$P_{Gi}$' is the power generated by the i[th] unit and '$N_G$' is the total number of generating units.

*a) Quadratic Fuel cost function*

The conventional quadratic fuel cost function can be expressed as follows:

$$C_i(P_{Gi}) = a_i P_i^2 + b_i P_i + c_i \quad (11)$$

Where, $a_i$, $b_i$, and $c_i$ are the fuel-cost coefficients of the i[th] unit.

*b) Non-Convex Fuel cost function*

The conventional quadratic fuel cost function with valve-point effects can be considered as non-convex /non-smooth fuel cost function and this can be expressed as follows:

$$C_i(P_{Gi}) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin\left(f_i \times \left(P_i^{\min} - P_i\right)\right)\right| \quad (12)$$

Where $e_i$ and $f_i$ are the fuel cost-coefficients of the i[th] unit reflecting valve-point loading effects.

The above problem is solved while satisfying equality, in-equality constraints explained in earlier chapters and the following device limits.

*c) Constraints*

The objective functions are subjected to the following equality, inequality and practical constraints.

i. *Equality constraints*

These constraints are usually load flow equations described as

$$P_{Gk} - P_{Dm} - \sum_{m=1}^{NB} |V_k||V_m||Y_{km}| \cos(\theta_{km} - \delta_k + \delta_m) = 0$$

$$Q_{Gk} - Q_{Dm} + \sum_{m=1}^{NB} |V_k||V_m||Y_{km}| \sin(\theta_{km} - \delta_k + \delta_m) = 0$$

where, '$P_{Gk}$, $Q_{Gk}$' are the active and reactive power generations at k[th] bus, '$P_{Dm}$, $Q_{Dm}$' are the active and reactive power demands at m[th] bus, 'NB' is number of buses, $|V_k|$, $|V_m|$ are the voltage magnitudes at k[th] and m[th] buses, '$\delta_k$, $\delta_m$' are the phase angles of voltages at k[th] and m[th] buses, $|Y_{km}|$, $\theta_{km}$ are the bus admittance magnitude and its angle between k[th] and m[th] buses.

ii. *In-equality constraints*

Generator bus voltage limits

$$V_{G_i}^{\min} \le V_{G_i} \le V_{G_i}^{\max}; \quad \forall i \in N_G$$

Active Power Generation limits

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}; \quad \forall i \in N_G$$

Transformers tap setting limits

$$T_i^{\min} \le T_i \le T_i^{\max}; \quad i = 1,2,\ldots,n_t$$

Capacitor reactive power generation limits

$$Q_{Sh_i}^{\min} \le Q_{Sh_i} \le Q_{Sh_i}^{\max}; \quad i = 1,2,\ldots..,n_C$$

Transmission line flow limit

$$S_{l_i} \le S_{l_i}^{\max}; \quad i = 1,2,\ldots.,N_{line}$$

Reactive Power Generation limits

$$Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max}; \quad \forall i \in N_G$$

Load bus voltage magnitude limits

$$V_i^{\min} \le V_i \le V_i^{\max} \quad i = 1,2,\ldots\ldots N_{load}$$

TCSC limits $\quad -0.8X_{line} \le X_{TCSC} \le 0.2X_{line}$

where '$n_t$' is the total number of taps, '$n_c$' is the total number of VAr sources, '$N_{load}$' is the total number load buses.

*d) Practical constraints*

The following practical constraints are considered to analyze the effect on the considered objectives.

i. *Ramp-rate limits*

The constraints of the ramp-rate limits, the operating limits of the generators are restricted to operate always between two adjacent periods forcibly. The ramp-rate constraints are

$\max\left(P_{G_i}^{\min}, P_i^0 - DR_i\right) \le P_{G_i} \le \min\left(P_{G_i}^{\max}, P_i^0 + UR_i\right)$ where, $P_i^0$ is i[th] unit power generation at previous hour. $DR_i$ and $UR_i$ are the respective down and up ramp-rate limits of i[th] unit.

ii. *Prohibited Operating Zone (POZ) limits*

To improve the efficiency of the thermal power plant generators are avoid to operate in the prohibited operating zones. This can be represented as

$$P_i = \begin{cases} P_i^{\min} \le P_i \le P_{i,1}^L \\ P_{i,k-1}^U \le P_i \le P_{i,k}^L \quad ; k = 2,3,\ldots,n_i \\ P_{i,n_i}^U \le P_i \le P_i^{\max} \end{cases}$$

where $n_i$ is the number of POZ's and k-index of POZ of unit-i. $P_{i,k}^L$ and $P_{i,k}^U$ are the respective lower and upper limit of k[th] POZ of i[th] generator.

Finally the above proposed problem is more generalized to solve in-equality constraints can be given as

$$FC_{aug} = FC + R_1\left(P_{g,slack} - P_{g,slack}^{\lim}\right)^2 + R_2 \sum_{i=1}^{N_{Load}} \left(V_i - V_i^{\lim}\right)^2 + R_3 \sum_{i=1}^{NG} \left(Q_{G_i} - Q_{G_i}^{\lim}\right)^2 + R_4 \sum_{i=1}^{N_{line}} \left(S_{l_i} - S_{l_i}^{\max}\right)^2$$

Where, R1, R2, R3 and R4 are the penalty quotients having large positive value. The limit values are defined as

Global Journal of Researches in Engineering ( F ) Volume XIV Issue VIII Version I Year 2014

$$x^{\lim} = \begin{cases} x^{\max}, & x > x^{\max} \\ x^{\min}, & x < x^{\min} \end{cases}$$

Here '$x$' is the value of $P_{g,slack}$, $V_i$, $Q_{Gi}$.

## IV. Imperialistic Competitive Algorithm

Imperialistic competitive algorithm [33] is inspired by the imperialistic competition in geo-political interactions between countries. Initially, countries for the considered control variables are generated. Out of which, some of them are best countries (lowest cost) treated as "imperialist" and the remaining are treated as "colonies". All colonies are moved towards their imperialists based on their powers. Here the power of each country is inversely proportional to its cost value. Finally, the "empires" are formulated by combining imperialists with the corresponding colonies.

After this, the assimilation policy is applied to move the empires towards their imperialist. Then power of each empire is calculated as the sum of the power of the imperialist and percentage of mean of power of its colonies. Then, all these empires participate in imperialistic competition and finally, the empire which has least power is eliminated from the system. The colonies will move towards their relevant imperialist and cause all the countries to converge to a state with single empire in the process.

The important steps in this algorithm are briefly discussed below:

### *a) Generating initial empires*

Initially population is generated for all control variables as countries (Ncountry). For N-dimensional problem, the position of ith country is defined as follows:

$$Country_i = \left[P_{G_1},...P_{GNG}, V_{G_1},...V_{GNG}, T_1,...T_{nt}, Q_{sh_1},.....Q_{sh_{nc}}\right]$$

The control variables corresponds to each population are updated in bus and line data then perform load flow and finally calculate the cost $(C_i)$ of each country. Initialize the total number of imperialists $(N_{imp})$ and there by calculate the number of colonies $(N_{Col}=N_{Country}-N_{imp})$. To divide the colonies among imperialists proportionally, the normalized cost of all imperialists is calculated and based on this normalized powers are calculated. From this the number of colonies for nth empire is evaluated. As the imperialists force to move the colonies towards them by applying attraction policy.

### *b) Moving colonies towards their imperialists*

If a colony has best cost value than that of the imperialist, then exchange these colony and imperialist to continue this process in new location.

### *c) Calculation total power of an empire*

The total power of an empire is the sum of the power of the imperialist and powers of the colonies.

### *d) Imperialistic competition*

All these empires try to take the possession of colonies of other empires and try to control them. In this process, the power of the powerful empire increases where as the weak empire decreases. This competition is modeled by choosing some of the weakest colonies of the weakest empires and competition among all empires to possess these colonies. Then, total power of each empire is calculated.

### *e) Eliminating powerless empires*

The powerless empires will collapse in the imperialistic competition. Different criteria can be defined for collapse mechanism. In this paper, an empire is assumed collapsed when it loses all of its colonies. Weak empires gradually decline in imperialistic competition and strong empires take the possession of their colonies. There are different conditions for declining an empire.

### *f) Stopping criteria*

After some imperialistic competitions, all the empires except the most powerful one will collapse all of the countries under their possession become colonies of this empire. All the colonies have the same positions and the same costs and there is no difference between the colonies and their imperialist. In such a case, the algorithm stops.

## V. Results and Analysis

An IEEE 14 bus system has been considered as first example to find the efficacy of the proposed method without and with TCSC. In 14 bus test system, bus 1 is slack bus, while buses 2, 3, 6 and 8 are generator buses and other buses are load buses. The input parameters of the proposed ICA method are given in Table.1.

As a preliminary computation the contingency analysis and ranking is performed on the test system for one branch outage at a time. The over loaded line flows and ranking during contingency analysis are tabulated in Tables 2 and 3 respectively. In this paper, Rank 1 contingency is considered to investigate the effectiveness of the proposed method without and with TCSC device to eliminate the over loaded lines.

As the TCSC is a series controlled FACTS device a line in which least power will flow is required for the best location of TCSC. The required best location for the TCSC is determined from the rank 1 contingency by using severity index. The SI values for the test system are given in Table3. From this table it can be seen that the line outage 4-5 is the most severe which is represented as rank 1 contingency. From rank 1 contingency result in order of priority of the line for the location of TCSC is 3-4 based on the power flows intransmission lines under rank 1 contingency.

*Table 1 :* Input parameters for test example

| Parameters | Quantity |
|---|---|
| Number of initial countries | 1000 |
| Number of initial imperialists | 8 |
| Number of decades | 200 |
| Revolution rate | 0.05 |
| Assimilation coefficient | 0.2 |
| Zeta (ζ) | 0.02 |
| Damp ratio | 0.99 |
| Uniting threshold limit | 0.02 |

*Table 2 :* Overloaded lines of IEEE-14 bus system during contingency analysis

| S. No | Outage line | Over loaded lines | Line Flow (MVA) | Line limit (MVA) | PI |
|---|---|---|---|---|---|
| 1 | 4-5 | 1-2 | 179.4369 | 150 | 1.1962 |
| | | 2-3 | 89.1447 | 85 | 1.0488 |
| | | 2-4 | 89.2352 | 85 | 1.0498 |
| | | 5-6 | 62.1180 | 45 | 1.3804 |
| | | 6-11 | 17.4159 | 14 | 1.244 |
| | | 6-13 | 23.7676 | 22 | 1.0803 |
| | | 10-11 | 13.4437 | 12 | 1.1203 |
| 2 | 7-9 | 1-2 | 157.5373 | 150 | 1.0502 |
| | | 5-6 | 60.7119 | 45 | 1.3492 |
| | | 6-11 | 17.6322 | 14 | 1.2594 |
| | | 6-13 | 24.1568 | 22 | 1.098 |
| | | 10-11 | 13.0879 | 12 | 1.0907 |

*Table 3 :* Contingency ranking of IEEE-14 bus system

| S. No | Outage line | Severity Index | Rank |
|---|---|---|---|
| 1 | 4-5 | 8.1198 | 1 |
| 2 | 7-9 | 5.8475 | 2 |

The results of optimized values for all control variables for minimization of quadratic and nonconvex fuel cost objective using proposed ICA method with considering effect of practical constraints for without and with TCSC are tabulated in Table.4. The convergence characteristics of the proposed algorithm for all the cases are shown in Figs 3 and 4.

From Table.4, it is observed that, with TCSC, the quadratic fuel cost is decreased by 0.6855 $/h and the non-convex cost is decreased by 0.3291 $/h when compared to without device. It is also observed that, the total real power generation is increased with TCSC and consequently the system power losses also increased.

The ramp-rate and POZ limits followed by the generators are tabulated in Table.5. From this table, it is observed that, while minimizing quadratic fuel cost objective the 2nd generator is following up ramprate and operative above the POZ upper limit whereas while minimizing non-convex fuel cist objective 2nd generator is following down ramp-rate and operating below the POZ lower limit.

From figures 3 and 4, it is observed that proposed method with TCSC starts the iterative process with good initial value and reaches final best value in less number of iterations when compared to without device.

*Table 4 :* OPF results of IEEE-14 bus system for convex and non-convex costs

| S.No | Parameter | | Quadratic cost ($/h) | | Non-convex cost ($/h) | |
|---|---|---|---|---|---|---|
| | | | Without | With TCSC | Without | With TCSC |
| 1 | Real power generation (MW) | PG1 | 168.7799 | 173.1421 | 213.2493 | 213.563 |
| | | PG2 | 50.3254 | 47.0367 | 23.2421 | 25.5652 |
| | | PG3 | 21.1789 | 20 | 20 | 20 |
| | | PG6 | 18.1432 | 16.3694 | 7.7983 | 5.3562 |
| | | PG8 | 8.6787 | 10.6415 | 5 | 5 |
| 2 | Generator voltages (p.u.) | VG1 | 1.0886 | 1.1 | 1.0883 | 1.1 |
| | | VG2 | 1.0565 | 0.9164 | 1.0599 | 0.9 |
| | | VG3 | 0.9419 | 1.0264 | 1.007 | 0.9912 |
| | | VG6 | 1.0505 | 0.9628 | 0.9836 | 0.9739 |
| | | VG8 | 1.015 | 1.0307 | 1.0507 | 0.9224 |
| 3 | Transformer tap setting (p.u.) | TAP4-7 | 1.0508 | 1.0321 | 1.1 | 0.9631 |
| | | TAP4-9 | 0.9362 | 0.9962 | 0.9579 | 0.9692 |
| | | TAP5-6 | 1.0188 | 0.9226 | 1.0773 | 0.9598 |
| 4 | Shunt compensator (MVAr) | QC9 | 19.4419 | 25.5866 | 9.3157 | 17.9661 |

Global Journal of Researches in Engineering (F) Volume XIV Issue VIII Version I Year 2014

| | | | | | |
|---|---|---|---|---|---|
| 5 | $X_{TCSC}$, p.u. | - | -0.0227 | - | 0.0201 |
| 6 | Total generation (MW) | 267.1061 | 267.1897 | 269.2897 | 269.4844 |
| 7 | Total power loss (MW) | 8.1061 | 8.1897 | 10.2897 | 10.4844 |
| 8 | Total generation cost ($/h) | 715.6184 | 714.9329 | 824.7462 | 824.4171 |

*Table 5 :* Ramp rates and POZ limits followed by the generators of quadratic cost with TCSC for IEEE-14 bus system

| Gen. No | Quadratic cost ($/h) | | Non-convex cost ($/h) | |
|---|---|---|---|---|
| | Without | With TCSC | Without | With TCSC |
| 1 | Up, 2 | Up, 2 | Up, 2 | Up, 2 |
| 2 | Up, 2 | Up, 2 | Down, 1 | Down, 1 |
| 3 | Down, 1 | Down, 1 | Down, 1 | Down, 1 |
| 6 | - | - | - | - |
| 8 | - | - | - | - |

1-Below POZ lower limit
2-Above POZ upper limit
3-Equal to POZ lower limit
4-Equal to POZ upper limit
UP-following up-ramp rate
Down-following down-ramp rate

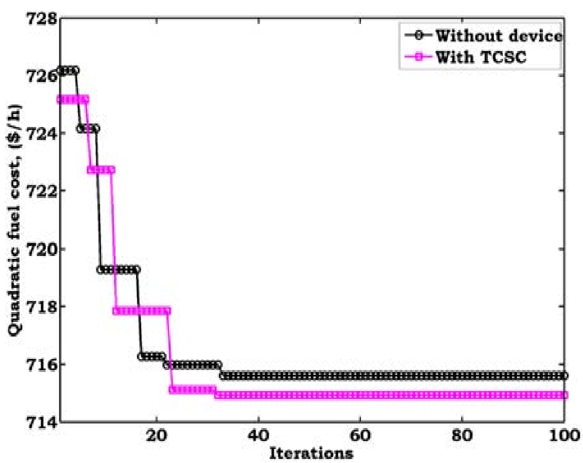



*Fig 3 :* Convergence characteristics of quadratic cost with TCSC for IEEE-14 bus system

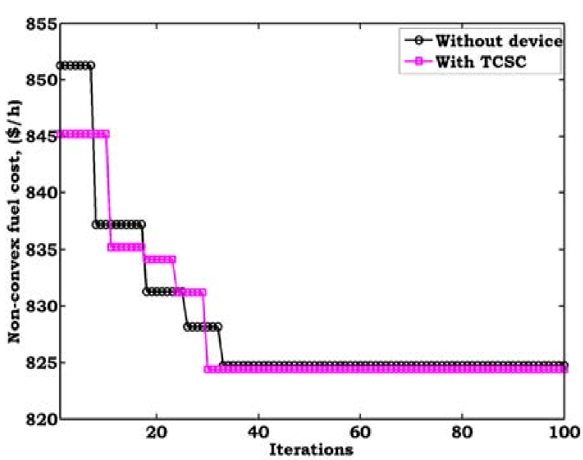



*Fig 4 :* Convergence characteristics of non convex cost with TCSC for IEEE-14 bus system

## VI. Conclusion

The ICA method has been successfully employed to solve the optimal power problem with generator constraints and valve point loading effect. Using this proposed method, the power system objectives such as quadratic and non-convex fuel cost objectives are optimized while satisfying system operating and practical constraints. The power injection modeling of TCSC has been presented with its incorporation procedure in conventional NR load flow. An optimal location identification methodology of TCSC has been identified to enhance the system security in terms of transmission line loadings. Obtained numerical results for IEEE-14 bus test system confirms that, the proposed methodology can handle any type of the objectives and can be applied to solve any size of the system.

## References Références Referencias

1. Ahrari A, Atai A, "Grenade Explosion Method-A novel tool for optimization of multimodal functions", Appl Soft Comput, 2010, Vol.10, No.4, pp: 1132–1140.
2. Dorigo M "Optimization, learning and natural algorithms", PhD Dissertation, 1992, Politecnico di Milano, Italy.
3. Eusuff M, Lansey E "Optimization of water distribution network design using the shuffled frog leaping algorithm", J Water Resour Plan Manag, ASCE 129, 2003, pp: 210–225.
4. Farmer JD, Packard N, Perelson A, "The immune system, adaptation and machine learning", Physica 22, 1986, pp: 187–204.
5. Geem ZW, Kim JH, Loganathan GV, "A new heuristic optimization algorithm: Harmony Search",

Simul, the Soc for Model and Simul Int, Vol.76, No. 2, 2001, pp: 60–68.

6. Holland J, "Adaptation in natural and artificial systems", University of Michigan Press, Ann Arbor, 1975.
7. Karaboga D, "An idea based on honey bee swarm for numerical optimization", Technical Report- TR06, Erciyes University, Engineering Faculty, Computer Engineering Department, Turkey, 2005.
8. Kennedy J, Eberhart RC, "Particle swarm optimization", Proceedings IEEE International Conference on Neural Networks, Piscataway, 1995, pp: 1942–1948.
9. Passino KM, "Biomimicry of bacterial foraging for distributed optimization and control", IEEE Control Syst Mag 22, 2002, pp: 52–67.
10. Rashedi E, Nezamabadi-pour H, Saryazdi S, "GSA: a gravitational search algorithm", Inf Sci 179, 2009, pp: 2232–2248.
11. Simon D, "Biogeography-based optimization", IEEE Trans Evol Comput 12, 2008, pp: 702–713.
12. Storn R, Price K, "Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces", J Glob Optim 11, 1997, pp:341–359.
13. Preechakul C, Kheawhom S, "Modified genetic algorithm with sampling techniques for chemicalengineering optimization", J Ind and Eng Chem 2009, pp: 101–107.
14. Cui H, Turan O, "Application of a new multiagent hybrid co-evolution based particle swarm optimisation methodology in ship design", Comput-Aided Des 2, 2010, pp: 1013–1027.
15. Montalvo I, Izquierdo J, Perez-Garcia R, Herrera M, "Improved performance of PSO with selfadaptive parameters for computing the optimal design of water supply systems", Eng Appl Artif Intell 23, 2010, pp: 727–735.
16. Ying PC, "An ant direction hybrid differential evolution algorithm in determining the tilt angle for photovoltaic modules", Expert Sys Appl 37, 2010, pp: 5415–5422.
17. Yue H, Gu G, Liu H, Shen J, Zhao J, "A modified ant colony optimization algorithm for tumor marker gene selection", Genomics Proteomics Bioinforma 7, 2009, pp:200–208.
18. Karaboga D, Akay B, "A modified artificial bee colony (ABC) algorithm for constrained optimization problems", Appl Soft Comput, 2010.
19. Mouti FSA, Hawary MEE, "Modified artificial bee colony algorithm for optimal distributed generation sizing and allocation in distribution systems", IEEE Electr Power and Energy Conf (EPEC), Montreal, 2009, pp:1–9.
20. Hui L, Zixing C, Yong W, "Hybridizing particle swarm optimization with differential evolution for constrained numerical and engineering optimization", ApplSoftComput10, 2010, pp:629– 640.
21. Wen YL, "A GA–DE hybrid evolutionary algorithm for path synbook of four-bar linkage", Mech Mach Theory 45, 2010, pp: 1096–1107.
22. K. Chandrasekar, N. V. Ramana, "Performance comparison of DE, PSO and GA approaches in Transmission Power Loss minimization using FACTS Devices", International Journal of Computer Applications, Volume 33– No.5, 2011.
23. Abouzar Samimi, Peyman Naderi, "A New Method for Optimal Placement of TCSC based on Sensitivity Analysis for Congestion Management", Smart Grid and Renewable Energy, vol. 3, 2012, pp.10-16.
24. G.I. Rashed, H.I. Shaheen, X.Z. Duan, S.J. Cheng, "Evolutionary optimization techniques for optimal location and parameter setting of TCSC under single line contingency", Applied Mathematics and Computation, 205, 2008, pp:133–147.
25. Tjing T Lie and Wanhong Deng, "Optimal Flexible AC Transmission Systems (FACTS)devices allocation", Electrical Power & Energy Systems, Vol. 19, No. 2, 1997, pp: 125-134.
26. G Shaoyun and T S Chung, "Optimal active power flow incorporating FACTS devices with power flow control constraints", Electrical Power & Energy Systems, Vol. 20, No. 5, 1998, pp: 321-326.
27. Sidhartha Panda, Narayana Prasad Padhy, "Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design", Applied Soft Computing, Vol.8, Issue.4, 2008, pp: 1418–1427.
28. B. Bhattacharyya, Vikash Kumar Gupta, "Application of DE & PSO Algorithm for the Placement of FACTS Devices for Economic Operation of a Power System", wseas transactions on power systems, Issue 4, Volume 7, 2012, pp. 209-216.
29. T.S. Chung, Y.Z. Li, "A Hybrid GA Approach for OPF with Consideration of FACTS Devices", IEEE Power Engineering Review, February 2001.
30. S. Y. Ge, T S Chung, "Optimal active power flow incorporating power flow control needs in flexible ac transmission systems", IEEE Transactions on Power Systems, Vol. 14, No. 2, 1999, pp:738-744.
31. G. Venkata Lakshmi, K. Amaresh, "Optimal Power Flow with TCSC using Genetic Algorithm", 2012 IEEE International Conference on Power Electronics, Drives and Energy Systems, December16-19, 2012, Bangalore, India.
32. AA Alabduljabbar, J V Milanovic, "Assessment of techno-economic contribution of FACTS devices to power system operation", EPSR, 2010, Vol.80, pp: 1247-1255.
33. Atashpaz-Gargari E, Lucas C. Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition. IEEE congress on evolutionary computation; 2007. p. 4661-7.