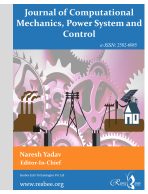
Vol. 2 No.4 Oct 2019

Journal of Computational Mechanics, Power System and Control

Received 28 August, Revised 3 October, Accepted 19 October



An Adaptive Chicken Swarm Algorithm to Solve Optimal Power Flow Problem Considering FACTS Device

Subramanyam T C
JNTU College of Engineering, Hyderabad, Telangana ,India
subramanyam.tc14@gmail.com

Tulasi Ram S S
J.N.T.U.H., Hyderabad, Telangana, India

Subrahmanyam J B V
C.J.I.T.S., Jangaon, Telangana ,India

Abstract: Optimal power flow (OPF) is considered as significant tools in power system operation and control that determines the minimum operating cost and retains the control variables in their secure boundaries. In this paper, various uncontrolled practical constraints in the OPF problem is studied, and three of which is – multi-fuel option, prohibited operating zone, and valve-point effect and aforesaid all, prohibited operating zone are most conspicuous one. Additionally, the Flexible Alternating Current Transmission Systems (FACTS) devices are considered that have various advantages like controlling the power flow, minimizing the active power transmission loss, enhancing the voltage stability/profile, etc. Moreover, in this study Thyristor Controlled Series Capacitor (TCSC), one of the famous and familiar modules of the FACTS equipment's category is exploited. Hence, the OPF problem is incorporated with such practical limitations indicated to above and FACTS devices turn out to be an extremely nonlinear-nonconvex optimization problem and to resolve it; a consistent, and efficient evolutionary algorithm named Adaptive Chicken Swarm Algorithm (ACSA), is proposed. Finally, the proposed algorithm is examined on IEEE 30-bus test system to solve the non-convex and non-smooth versions of the OPF problem.

Keywords: Optimal Power Flow; FACTS; TCSC; Constraints; IEEE Bus System

Nomenclature

Abbreviations	Descriptions
FACTS	Flexible Alternating Current Transmission Systems
GA	Genetic Algorithm
TCSC	Thyristor Controlled Series Capacitor
PSO	Particle Swarm Optimization
OPF	Optimal Power Flow
LP	Linear Programming
PST	Phase Shifting Transformer
DE	Differential Evolution
TS	Transmission switching
PST	Phase Shifting Transformer
DFACTS	Distributed FACTS
VSR	Variable Series Reactor

1. Introduction

Generally, OPF is considered as a non-linear optimization problem. Moreover, it is intended to maintain the variables for a power network, and that is set as their best possible values, which reduces the selected objective models namely cost of fuel or loss of network when gathering a few inequalities and equality constraints. Hence, the solution of OPF has received huge interest in power markets in the past three decades. So, many researchers have focused on this subject matter exploiting various algorithms such as existing mathematical methods or evolutionary algorithms [7].

When fulfilling particular security and transmission constraints, the prospect of the power system operation with the minimum cost is considered as important problems in extending the capacity of transmission by exploiting the controllable FACTS [1] [2]. The existing OPF ought to undertake a few

https://doi.org/10.46253/jcmps.v2i4.a5

changes like the addition of novel control variables which belongs to FACTS devices and the equivalent solutions for load flow solutions in order to pact with the aforementioned problem.

Appropriate operation and planning are essential to provide electrical energy to customers with maximum quality of power supplied with minimum cost. The capacity of power transmission can be maximized by deploying new generating units with new transmission lines in an exact method. The commencement of FACTS technology is proposed to improve the capacity of the power transfer for the transmission lines using enhancement of the power quality without creating power exploiting the new plants [5].

Because of the industrial loads and equipment generators, the reactive power is generated in transmission lines that show the way to power quality problems namely swell, sag, and harmonics, consequently it will be the obligation of FACTS controller to alleviate the power quality problems and improve the capacity of the power transmission[4]. By exploiting the FACTS, the analysis of power flow is currently a necessary method for the economical and secure operation for the contemporary power systems in this present situation as these devices are sensitive to power quality problems. In transmission systems, ahead of deploying compensating devices its suitable position with parameters settings are to be decided.

Conventional optimization algorithms like Gradient Method [17], LP [19], and Newton's method [18], were exploited to resolve the OPF problem for the power system presumptuous differentiable, continuous, and monotonically maximizing cost function. On the other hand, in managing non-linear and non-convex engineering optimization problems aforesaid algorithms have unsuccessful and are inclined to obtain wedged at local optimum solutions. As OPF integrating FACTS devices with valve point discontinuities were extremely non-linear optimization problems with non-differentiable features, stochastic search methods like GA [15] [21], PSO [14] [20], DE [16], etc were exploited to resolve these problems. However, there is a major drawback of aforesaid algorithms are they don't accurately converge the local optimum and need high computational time.

The main contribution of this paper is to propose an Adaptive Chicken Swarm Algorithm to solve the OPF problem taking into consideration of practical constraints like multi-fuel options, valve-point effects, and prohibited operating zones. Lastly, the proposed method is examined on the IEEE 30-bus test system, and the attained results are evaluated with traditional algorithms like GA, PSO, SA, and DE.

2. Literature Review

In 2019, Zora Luburic and Hrvoje Pandzic [1], worked on four different unit commitment algorithms taking into consideration of energy storage and FACTS devices. Here, the energy storage was highly efficient during the minimization of operating cost of the system than the FACTS devices, whereas the wind limitation was efficiently minimization using both the algorithms. On the other hand, the efficiency of energy storage with minimizing operating system costs and wind limitation considerably based upon on the wind profile. Moreover, the FACTS devices had the ability to considerably maximize line loadings, although a huge number of these devices were required to effectively control power flows in the complete system.

In 2019, Yuanrui Sang and Mostafa Sahraei-Ardakani [2], worked on FACTS that were significant providers to smart transmission systems. Moreover, it had the ability to present a few levels of power flow control and improve the transfer capability against the conventional network. This suppleness was exploited for mitigation of congestion and incorporation of renewable energy. D-FACTS were a frivolous version of FACTS that was reinstalled expediently. In recent years, D-FACTS had proposed into a smart power flow control technology, because of its minimal cost and simplicity of installation. Moreover, a computationally efficient stochastic allocation algorithm was presented for D-FACTS and examines their effect on power flows.

In 2019, Samo Gasperic and Rafael Mihalic [3], presented a novel principle for calculating the efficacy of FACTS devices for voltage control. Also, the analysis was appropriate for RESs, which linked to a grid through a converter that can be valid an appropriate control which used as a FACTS device. For the mathematical models of the PV curves, separate mathematical derivations for the extensive SLIB algorithm for the parallel STATCOM, FACTS devices, and SVC were explained. The impact of the SVC, SSSC, STATCOM, and CSC on the voltage control was described by considering the prospect of deviating a controllable parameter of the specific FACTS device.

In 2018, Junmin Zhang et al [4] developed a model of the three-stage bridge that includes an extra leg linked to an AC capacitor on the basis of the single-phase H-bridge. In single-stage, the 2-ripple energy of the electrolytic capacitor, H-bridge had the ability to transform the film capacitor of the AC side in three-phase H-Bridge. The single-stage FACTS size was minimized by ten times when evaluated with the single-stage H-bridge.

In 2019, Yuanrui Sang and Mostafa Sahraei-Ardakani [5], developed an OPF model which included both FACTS and TS. It was exploited to examine the connection between the two power flow control algorithms. The experimentation outcomes on an RTS 96-bus system indicates that considerable economic savings were attained by consumption of both FACTS and TS, further than the self-governing abilities of each algorithm. Moreover, the performance of TS actions had an effect on the optimal positioning and set point of FACTS devices. Operation of FACTS devices had an effect on the position and frequency of TS actions.

In 2018, Xiaohu Zhang et al [6] presented a bilevel optimization algorithm to optimally place the PST and VSR in the transmission network taking into consideration of high diffusion of wind power. Here, the higher-level problem searches for to reduce the cost investment on series FACTS, probable load shedding, and the wind power cost limitation. Under different operating cases, the lower-level problems detain the market clearing.

In 2018, Zhifang Yang et al [7], proposed an efficient OPF algorithm for hybrid AC/DC grids with discrete control devices. In both AC/DC grids, a successive linear approximation algorithm was introduced for the power flow equations. The convexity of the VSC framework, the conferred power flow equations for the linearization effortlessness. To hold the highly nonlinear converter losses, a pretended branch was augmented to the AC grid. In the converter station, the discrete nature of the LTC transformer was precisely modeled. For the OPF model, an iterative solving algorithm was presented.

3. Objective Model of OPF with FACTS Device

3.1 Objective Model

Generally, a vital objective model of an existing OPF problem is to attain the optimal amalgamation of committed units to provide the demand when reducing the total fuel cost. By the operation of a single fuel, the common smooth cost and quadratic is exploited to propose the output power of generators. Eq. (1) states the mathematical model of the cost function. Here, $\mathrm{TFC}(a,v)$ represents the total fuel cost objective model by means of the single fuel operation $(\$/h)$; $x_i\left(\frac{\$}{h}\mathrm{MW}^2\right)$, $y_i\left(\frac{\$}{h}\mathrm{MW}\right)$ and $z_i\left(\frac{\$}{h}\right)$ represents the smooth and coefficients of convex cost for a unit i.

$$f = \mathrm{TFC}(a,v) = \sum_{i=1}^{N_H}\left(x_i M_{H_i}^2 + y_i M_{H_i} + z_i\right) \tag{1}$$

3.2 Modeling of FACTS Device

The electrical length of the transmission line adapted with a little delay by means of positioning the TCSC element in some transmission lines among two stated buses, i and j, for the power network, and it is termed as a compensated line. The stability of power systems can be increased by the TCSCs [8]. Here, the TCSC steady-state representation is designed. This design is on the basis of imagining the TCSC is considered as series variable reactance with the control variable Y_{TCSC}. Fig. 1 represents the transmission line incorporated with TCSC.

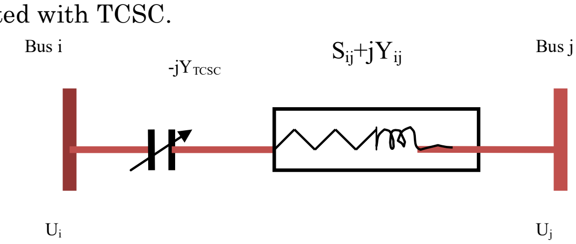


Fig. 1. *Diagrammatic illustration of TCSC model*

Based on Fig. 1, adapted and new line reactance is stated in eq. (2). Here, Y_{TCSC} represents the reactance of TCSC; Y_{ij} represents the reactance of line among bus i and j; Y_P represents the adapted reactance of line among bus i and j subsequent to deploying the TCSC device.

$$Y_P = Y_{ij} - Y_{TCSC} \tag{2}$$

In eq. (3) to (6), transmission lines power flows are represented. Here, U_i and U_j represents voltage amplitudes at bus i and j γ_i, γ_j, and γ_{ij} represents voltage phase angles at bus i and j and dissimilarity of voltage angle among buses i and j, correspondingly; and H_{ij} and C_{ij} are explained in (7) & (8).

$$M_{ij} = |U_i|^2 H_{ij} - |U_i||U_j|(H_{ij}\cos\gamma_{ij} + C_{ij}\sin\gamma_{ij}) \quad (3)$$

$$N_{ij} = -|U_i|^2 C_{ij} - |U_i||U_j|(H_{ij}\sin\gamma_{ij} - C_{ij}\cos\gamma_{ij}) \quad (4)$$

$$M_{ji} = |U_j|^2 H_{ij} - |U_i||U_j|(H_{ij}\cos\gamma_{ij} - C_{ij}\sin\gamma_{ij}) \quad (5)$$

$$N_{ji} = -|U_j|^2 C_{ij} - |U_i||U_j|(H_{ij}\sin\gamma_{ij} + C_{ij}\cos\gamma_{ij}) \quad (6)$$

$$H_{ij} = \frac{S_{ij}}{S_{ij}^2 + Y_P^2} \quad (7)$$

$$C_{ij} = \frac{Y_Q}{S_{ij}^2 + Y_P^2} \quad (8)$$

In eq. (7) and (8), H_{ij} and C_{ij} represents the conductance and susceptance among i and j, S_{ij} represents the resistance of transmission line among i and j; correspondingly.

3.3 Constraints

a) Equality constraints

The equality constraints are communicated to topology and structure of the network power in the OPF concept. Eq. (9) and (10) states the implementation of constraints [9]. Here, M_{B_i} represents real power demand and N_{B_i} represents reactive power demand at the bus i, M_{H_i} represents generated real power at bus and N_{H_i} represents generated reactive power at the bus i, correspondingly; and N_C represents the number of buses.

$$M_{H_i} - M_{B_i} - U_i \sum_{j=1}^{N_H} U_j (H_{ij}\cos\gamma_{ij} + C_{ij}\sin\gamma_{ij}) = 0, \forall i \in N_C \quad (9)$$

$$N_{H_i} - N_{B_i} - U_i \sum_{j=1}^{N_H} U_j (H_{ij}\sin\gamma_{ij} - C_{ij}\cos\gamma_{ij}) = 0, \forall i \in N_C \quad (10)$$

b) Inequality constraints

The inequality constraints and restrictions indicate the limitations of physical equipment in OPF concept that can be expressed in eq. (11) to (15) [10]. Here, M_{ij} represents the active power that can flow among buses i and j; R_{ij} represents capacity of transmission for ij^{th} transmission line; $N_{H_i}^{max}$ and $N_{H_i}^{min}$ represents the maximum and minimum boundaries of reactive power generation by unit i, correspondingly; $M_{H_i}^{max}$ and $M_{H_i}^{min}$ represents the maximum and minimum boundaries of active power generation by unit i, correspondingly; and N_{Line} represents the count of transmission lines.

$$M_{H_i}^{min} \le M_{H_i} \le M_{H_i}^{max}, \forall i \in N_H \quad (11)$$

$$N_{H_i}^{min} \le N_{H_i} \le N_{H_i}^{max}, \forall i \in N_H \quad (12)$$

$$U_{H_i}^{min} \le U_{H_i} \le U_{H_i}^{max}, \forall i \in N_C \quad (13)$$

$$|R_{ij}| \le M_{ij}^{max}, \forall i \in N_{Line} \quad (14)$$

$$|M_{ij}| \le M_{ij}^{max} \quad (15)$$

3.4 Valve-point Effect

The steam flow should be changed to control the generators output power in real power plants. An unexpected variation can happen in power losses by performing this procedure. Therefore, the cost scheme can be related to a few discontinuities and ripples in these circumstances. The aforesaid general problem is termed as a valve-point effect. In the occurrence of the valve point result, to demonstrate the cost function, the supplementary sinusoidal term can be increased to eq. (1) as stated as eq. (16).

$$f = VPE(y,v) = \sum_{i=1}^{N_H} x_i M_{H_i}^2 + y_i M_{H_i} + z_{i,1} + \left|k_i \sin\left(l_i\left(M_{H_i}^{min} - M_{H_i}\right)\right)\right| \quad (16)$$

In eq. (16), $k_i\left(\frac{\$}{h}\right)$ and $l_i\left(\frac{rad}{MW}\right)$ represents non-convex cost coefficients for generation unit i, and $VPE(y,v)$ represents cost function taking into consideration of a valve-point effect $\left(\frac{\$}{h}\right)$.

3.5 Multi-fuel Option

Few units possess the ability to work in various fuels and they can switch to the main economical fuel and offer more suppleness to the system. The cost function of each unit must be altered to a multidisciplinary valve-point effect, correspondingly [11] [12].

$$f = MFO_w(y,v) = \begin{cases} \text{FuelType1}; \sum_{i=1}^{N_H} x_{i,1} M_{H_i}^2 + y_{i,1} M_{Hi} + z_{i,1} + \left| k_{i,1} \sin\left(l_{i,1}\left(M_{H_i}^{min} - M_{H_i} \right)\right)\right| M_{H,1i}^{min} \le M_{H_i} \le M_{H_{i,1}} \\ \text{FuelType2}; \sum_{i=1}^{N_H} x_{i,2} M_{H_i}^2 + y_{i,2} M_{Hi} + z_{i,2} + \left| k_{i,2} \sin\left(l_{i,2}\left(M_{H_i}^{min} - M_{H_i} \right)\right)\right| M_{H_{i,2}}^{min} \le M_{H_i} \le M_{H_{i,2}} \\ \vdots \\ \text{FuelTypeF}; \sum_{i=1}^{N_H} x_{i,F} M_{H_i}^2 + y_{i,F} M_{Hi} + z_{i,F} + \left| k_{i,F} \sin\left(l_{i,F}\left(M_{H_i}^{min} - M_{H_i} \right)\right)\right| M_{H_{i,(F-1)}}^{min} \le M_{H_i} \le M_{H_{i,F}}^{max} \end{cases} \quad (17)$$

$$f = MFO_{w,0}(y,v) = \begin{cases} \text{FuelType1}; \sum_{i=1}^{N_H} x_{i,1} M_{H_i}^2 + y_{i,1} M_{Hi} + z_{i,1} \\ \quad M_{H_i}^{min} \le M_{H_i} \le M_{H_{i,1}} \\ \text{FuelType2}; \sum_{i=1}^{N_H} x_{i,2} M_{H_i}^2 + y_{i,2} M_{Hi} + z_{i,2} \\ \quad M_{H_i}^{min} \le M_{H_i} \le M_{H_{i,2}} \\ \vdots \\ \text{FuelTypeF}; \sum_{i=1}^{N_H} x_{i,F} M_{H_i}^2 + y_{i,F} M_{Hi} + z_{i,F} \\ \quad M_{H_i,(F-1)}^{min} \le M_{H_i} \le M_{H_{i,F}}^{max} \end{cases} \quad (18)$$

In eq. (17) and (18), $MFO_w(y,v)$ and $MFO_{w,0}(y,v)$ represents the total fuel cost $\left(\frac{\$}{h}\right)$ taking into consideration of multi-fuel option without and with the valve-point effect, correspondingly; F represents a number of fuels, $M_{H_i}^{max}$ and $M_{H_i}^{min}$ represents the maximum and minimum limits of power generation by unit i, correspondingly.

3.6 Operating Zones in Prohibited Areas

Because of the technical problems like fluctuations or vibration of machines shaft and other components namely pumps, boilers, and etc; the real three-stage synchronous generators can have few of the hazardous areas, forbidden operating zones.

As a result, in OPF computations taking into consideration of POZs aids in identifying a precise and practical solution. Hence, each generation unit with $(S-1)$ prohibited areas is represented using S separate operating sub-zones. Hence, the prohibited areas mathematical model is represented in [13].

$$M_{H_i} \in \begin{cases} M_{H_i}^{min} \le M_{H_i} \le M_{H_{i,1}}^{low} \\ M_{H_{i(s-1)}}^{up} \le M_{H_i} \le M_{H_{i,r}}^{low} \quad \forall i = 1,2,\ldots,N_{H;} \forall s = 2,3\ldots,S \\ M_{H_i}^{up} \le M_{H_i} \le M_{H_{i,1}}^{max}, \end{cases} \tag{19}$$

In eq. (19), $M_{H_{i,1}}^{low}$ represents lower limits and $M_{H_i}^{up}$ represents the upper limit of the prohibited area s of the unit i, correspondingly; and S represents a number of prohibited areas.

3.7 Constraints of FACTS Device

At transmission lines, all TCSCs implementations are represented as series variable reactance. Additionally, the control variable boundary for all TCSC elements, Y_{TCSC}, are represented in this way hence the proportional association of utmost series capacitors restricts to line reactance, which is equivalent to or above 50%. Therefore, for all TCSC devices, the Y_{TCSC} is indicated as $-0.2 \le Y_{TCSC} \le 0.2$p.u.

4. Proposed Algorithm for Solving OPF Problem

In this section, the process of the proposed method to resolve the OPF problem incorporated with TCSCs and causes to undergo fulfilling various further practical constraints. The below important steps should be considered to resolve the OPF problem.

a) Initialize the cost coefficients of multi and single fuel and other practical limitations such as valve-points effect, load constraints, prohibited operating zones, and TCSCs information.

b) Change the constrained problem into an unconstrained problem. It is significance explaining in that order to use the proposed method on the OPF problem; it must be become an unconstrained problem by using an objective model. Finally, penalty coefficients are used as eq. (20).

$$F(y,u) = \begin{Bmatrix} f(y,u) + PC_1 \times \left(\sum_{j=1}^{N_{EQ}} \left(h_j(y,u)^2 \right) \right) \\ + PC_2 \times \left(\sum_{j=1}^{N_{IEQ}} \left(\max\left\{0, -h_j(y,u)^2\right\} \right) \right) \end{Bmatrix} \tag{20}$$

c) Subsequently, the objective model $f(y,u)$ is calculated and constraints are verified.

d) Later, the proposed objective model $F(y,u)$ is calculated by using the penalty coefficients to hold the constraints on the basis of the attained values in the preceding phase.

• Finally, if any variable intrudes the constraints, it will be altered by using the coefficients of the penalty.

4.1 Conventional Chicken Swarm Algorithm

The CSA algorithm emulates the hierarchical classification, and individual foraging behavior, and the chickens are partitioned into the hierarchical classification and individual foraging behavior, and the chickens are partitioned into several flocks [24]. Each flock comprises of flock hens, 1 rooster, and chicks, and each individual, determine its location based on the motion law. An individual with higher fitness and the enhanced location will obtain previous to scavenge.

The conventional CSA algorithm is defined as below.

a) Partition the individuals into numerous flocks, and each flock comprise numerous hens, 1 rooster, and numerous chicks.

b) The individuals with the optimal fitness are represented as roosters and each rooster indicates as the head of the flock in the chickens. Moreover, the individual's posses the worst fitness is considered as hens and others are chicks. Hens will select flock arbitrarily and the connection with the chicks and hens is arbitrarily too.

c) When the chicken hierarchy is described; the supremacy and the association of chicks and hens will not be altered until the iteration attains a particular number.

d) The individuals will scavenge around the rooster and prohibit the other individuals to divest food in every flock. Each chick will go after their mother hen to search for food and presume chicks be able to take the food from other individuals. Individuals who possess the leading location possess the optimal spirited benefit, and they will discover food prior to other individuals. In the population, each individual indicates an equivalent solution for the optimization problem.

In the conventional CSA algorithm, the population is N and the rooster percentage is RN and population of hen is HN, correspondingly, $y_{i,j}(t)$ indicates the location of the i^{th} individual in j^{th} dimension space, MN indicates the mother hens proportion of total hens, and H indicates the renovation factor of chickens. In population, the rooster is considered as the optimal individual, and its update equation is demonstrated in Eq. (21).

$$y_{i,j}(t+1) = y_{i,j}(t)\cdot\left(1 + rn\left(0\omega^2\right)\right) \tag{21}$$

$$\omega^2 = \begin{cases} 1 \ \ , \text{if } f_1 \le f_b \\ \exp\left(\dfrac{(f_b - f_i)}{|f_i| + \varepsilon}\right) \end{cases} \tag{22}$$

$b = [1,....., N], b \neq i$

In eq. (21), $y_{i,j}(t)$ signifies the i^{th} rooster in the j^{th} dimension space. rn $(0, \omega^2)$ indicates the Gauss distribution and its mean value is 0 and the standard deviation indicates ω^2. ω^2 indicates computed as eq. (22). f_i represents the current individual fitness. f_b represents the randomly chosen rooster's fitness apart from the current individual. ε indicates a constant and its value is too little. Eq. (23) indicates the updating of hens.

$$y_{i,j}(t+1) = y_{i,j}(t) + L_1 \cdot rn \cdot \left(y_{r_1,j}(t) - y_{i,j}(t)\right) + L_2 \cdot rn \cdot \left(y_{r_2,j}(t) - y_{i,j}(t)\right) \tag{23}$$

$$L_1 = \frac{\exp\left(\left(f_i + f_{r_1}\right)\right)}{\left(abs(f_i) + \varepsilon\right)} \tag{24}$$

$$L_2 = \exp\left(f_{r_2} - f_i\right)_{r_1} \varepsilon[1,....,N], r_1 \neq r_2 \neq i \tag{25}$$

In eq. (23), $y_{i,j}(t)$ indicates the location of the i^{th} hen in j^{th} dimension space. L_1 and L_2 represents the learning factor and it is computed as eq. (24) and (25), correspondingly. rn indicates a random constant, and its range is (0,1). $y_{r_2,j}(t)$ represents the location of any individuals apart from the present hen. $y_{r_1,j}(t)$ represents the location of the rooster, which goes after by hens. ε represents an extremely little constant value. f_{r_1} represents the fitness of rooster which goes after by hens, r_1 signifies the index of a rooster which goes after by hens, f_{r_2} represents the fitness of any individuals apart from the i^{th} hen. r_2 represents the index of any individuals apart from the i^{th} hen, and both r_1 and r_2 are different from the present index. Eq. (26) indicates the updating model of chicks.

$$y_{i,j}(t+1) = y_{i,j}(t) + F\cdot\left(y_{pj}(t) - y_{i,j}(t)\right) \ p \in [1,....N], p \neq i \tag{26}$$

In eq. (26), $y_{i,j}(t)$ represents the location of the i^{th} chick in j^{th} dimension space. F represents the chicks coefficient, and its range is [0,2]. $y_{pj}(t)$ represents the location of hens, which goes after by chicks.

4.2 Proposed Adaptive Chicken Swarm Algorithm

The CSA method completely succeeds in the features of swarm intelligent, namely searching the best solution and evading the premature occurrence. On the other hand, the CSA method has high dimension and can simply origin variation, and the iteration time of optimizing is quite high. Therefore, the Adaptive CSA algorithm is presented and the enhancements are stated below. The chaotic series is proposed to allocate the primary value to improve the ergodicity and uniformity of the population in the adaptive CSA algorithm.

Generally, Chaos is considered as an exceptional nonperiodic movement of nonlinear systems and its features like ergodicness, randomness and the vulnerability for the early value, which can enhance the effectiveness of the optimization algorithm. The general chaos model has cubic mapping, folding mapping, infinite logical mapping, and so forth, and the chaotic sequence created through the cubic mapping has adaptive balance. Hence, in the chickens, the initial location of individuals is arranged using the cubic mapping. At first, a random sequence will be created and all the elements among [0, 1], and after that, cubic mapping eq. (27) is exploited to produce a chaotic series.

$$C_{ij} = 4 \times y_{ij}^2 - 3 \times y_{ij} \tag{27}$$

If the initial value of the eq. (27) is not 0, the series is suitable andwill come back to the optimization space by eq. (28).

$$y_{ij} = \frac{1}{2(h-g)}C_{ij} + \frac{1}{2(g+h)} \tag{28}$$

In eq. (28), h and g represents the upper limit and lower limit of optimization, correspondingly.

To enhance the speed and convergence accuracy, and to improve the global search speed and the capability of local search the adaptive weight is introduced. Based on the fitness, the individual of the chickens will be arranging on the iteration. In certain iteration, the construction of the group is upheld, and it will be altered when a circumstance is fulfilled. The eq. (29) states the update equation of hens it augments adaptive weight $a(t)$, and the computation formula of the adaptive weight is represented in eq. (30).

$$y_{i,j}(t+1)=a(t)\cdot y_{i,j}(t)+L_1\cdot r\cdot\left(y_{r_1,j}(t)-y_{i,j}(t)\right)+L_2\cdot r\cdot\left(y_{r_2,j}(t)-y_{i,j}(t)\right) \tag{29}$$

$$a(t) = a_{max}\cdot\left(a_{max}-a_{min}\right)\cdot\left(T_{max}-t\right)/T_{max} \tag{30}$$

where a_{min} represents the minimum weight, a_{max} represents the initial weight, and T_{max} represents the maximum iteration number. To improve the randomness of poorer individuals and to shun effortlessly declining into local extremum, the enhanced update formula of chicks is represented in eq. (31) and the coefficient $FL(t)$ is augmented. Using eq. (32), the coefficient is computed.

$$y_{i,j}(t+1)=y_{i,j}(t)+FL(t)\cdot\left(y_{pj}(t)-y_{ij}(t)\right) \tag{31}$$

$$FL(t) = 0.1\times r + 0.4 \tag{32}$$

Algorithm 1: Pseudo code of the proposed method	
Initialize a population of N chickens and describe the interrelated parameters; compute the numbers of roosters RN, the number of hens MN, the number of chickens CN, and the number of mother hens HN;	
Compute the fitness values of N chickens;	
	Set $t = 0$;
	While $(t < max_{iter})$
If $(t\%H == 0)$	
	By fitness value sort the chicken swarm;
Partition the chicken swarm into various flocks. Every flock consists of a couple of hens, a leading rooster, and chicks;	
	In a flock decide the relationship among the mother hens and chicks
end if	
For $i = 1$ to N	
	If $i == RN$ using equation (21); update the rooster's location
	If $i == HN$ using equation (29); update the hen's location
	If $i == HN$ using the equation (31); update the chick's location
	The fitness value of the new solution is computed
By the new solution, the old solution is restored, if the new solution is superior to the old one;	
end for	
A global best solution is updated	
$t{+}{+}$	
end while	
output the global best solution;	

5. Results and Discussions

5.1 Simulation Procedure

In this section, the simulation model of the proposed Adaptive CS algorithm to resolve the OPF problem taking into consideration of TCSC and practical constraints like valve-point effect, multiple fuel options, and prohibited operating zones. Finally, the proposed algorithm is tested in IEEE 30 system with other conventional algorithms namely PSO, GA, SA, and DE.

5.2 Performance Analysis

Fig. 3 illustrates the graphical representation of the total fuel cost of the proposed and conventional models in IEEE 30 Buss system. Here, the proposed method is 19% better than the PSO, 20% better than the GA, 28% better than the SA, and 28% better than the DE with respect to the total fuel cost.

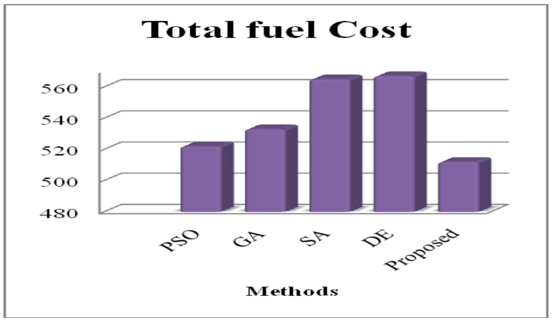


Fig. 2. *Graphical illustration of total fuel cost in IEEE 30 Bus system*

Fig. 3 illustrates the performance analysis of the total fuel cost of the proposed and conventional models in IEEE 30 Buss system. Here, the proposed method is 8% better than the PSO, 10% better than the GA, 12% better than the SA, and 15% better than the DE with respect best-case scenario.

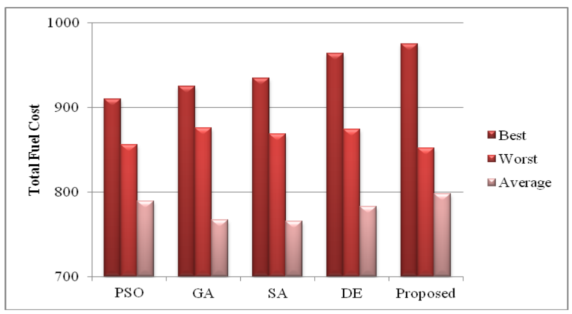


Fig. 3. *Performance analysis of total fuel cost considering FACTS device in the IEEE 30 Bus system*

Fig. 4 illustrates the graphical representation of active power transmission losses of the proposed and conventional models in IEEE 30 Buss system. Here, the proposed method is 5% better than the PSO, 8% better than the GA, 6% better than the SA, and 7% better than the DE with respect to the total fuel cost.

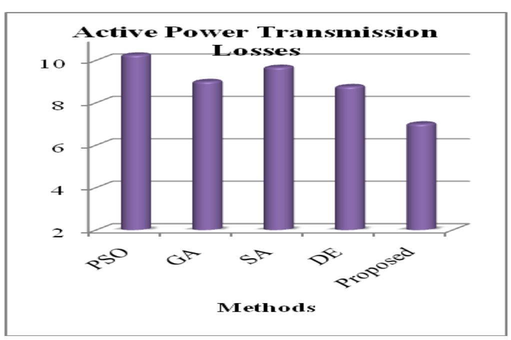


Fig. 4. *Graphical illustration of total fuel cost in IEEE 30 Bus system*

6. Conclusion

This paper proposes a complete solution of the OPF problem taking into consideration of practical constraints to attain the precise and considering real solutions. Here, the TCSC device was considered as significant and well-liked elements of FACTS devices type, which was exploited and examined. In this study, the TCSC's pivotal responsibility was controlled the power flow in transmission lines and enhanced the voltage profile to minimize the probability of incidence of perilous phenomena such as voltage collapse. Moreover, an effectual configuration of the ECSA algorithm was effectively exploited in this paper to resolve the OPF problem taking into consideration of FACTS devices and practical constraints.

Compliance With Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

References

[1] Zora Luburic, Hrvoje Pandzic,"FACTS devices and energy storage in unit commitment",International Journal of Electrical Power & Energy Systems, Volume 104, January 2019, Pages 311-325.
[2] Yuanrui Sang, Mostafa Sahraei-Ardakani,"Effective power flow control via distributed FACTS considering future uncertainties", Electric Power Systems Research, Volume 168, March 2019, Pages 127-136.
[3] Samo Gasperic, Rafael Mihalic,"Estimation of the efficiency of FACTS devices for voltage-stability enhancement with PV area criteria" Renewable and Sustainable Energy Reviews, Volume 105, May 2019, Pages 144-156.
[4] J. Zhang, K. Liu, Y. Liu, S. He and W. Tian, "Active power decoupling and controlling for single-phase FACTS device," in The Journal of Engineering, vol. 2019, no. 16, pp. 1333-1337, 3 2019.
[5] Y. Sang and M. Sahraei-Ardakani, "The Interdependence Between Transmission Switching and Variable-Impedance Series FACTS Devices," in IEEE Transactions on Power Systems, vol. 33, no. 3, pp. 2792-2803, May 2018.
[6] X. Zhang et al., "Optimal Allocation of Series FACTS Devices Under High Penetration of Wind Power Within a Market Environment," in IEEE Transactions on Power Systems, vol. 33, no. 6, pp. 6206-6217, Nov. 2018.
[7] Z. Yang, H. Zhong, A. Bose, Q. Xia and C. Kang, "Optimal Power Flow in AC–DC Grids With Discrete Control Devices," in IEEE Transactions on Power Systems, vol. 33, no. 2, pp. 1461-1472, March 2018.
[8] S. Raj, B. Bhattacharyya, Optimal placement of TCSC and SVC for reactive power planning using Whale optimization algorithm, Swarm Evol. Comput. 40 (2018) 131–143.
[9] K. Abaci, V. Yamacli, A. Akdagli, Optimal power flow with SVC devices by using the artificial bee colony algorithm, Turkish J. Electr. Eng. Comput. Sci. 24 (2016) 341–353.
[10] S. Mahapatra, N. Malik, A hybrid approach for secured optimal power flow and voltage stability with TCSC placement, Int. J. Adv. Sci. Technol. 89 (2017) 1–8.
[11] M.R. Narimani, R. Azizpanah-Abarghooee, B. Zoghdar-Moghadam- Shahrekohne, K. Gholami, A novel approach to multi-objective optimal power flow by a new hybrid optimization algorithm considering generator constraints and multi-fuel type, Energy 49 (2013) 119–136.
[12] C.V. Suresh, S. Sivangarju, Analysis and effect of multi-fuel and practical constraints on economic load dispatch in the presence of unified power flow controller using UDTPSO, Ain Shams Eng. J. 6 (2015) 803–817.
[13] M. Pourakbari-Kasmaei, M.J. Rider, J.R.S. Mantovani, An unambiguous distance-based MIQP model to solve economic dispatch problems with disjoint operating zones, IEEE Trans. Power Syst. 31 (2015) 825–826.
[14] Abido, M.A.: 'Optimal power flow using particle swarm optimization', Proc. Int. J. Electr. Power Energy Syst., 2002, 24, (7), pp. 563 – 571.
[15] Lai, L.L., Ma, J.T.: 'Improved genetic algorithms for optimal power flow under both normal and contingent operation states', Int. J. Electr. Power Energy Syst., 1997, 19, (5), pp. 287–292.
[16] Abou El Ela, A.A., Abido, M.A.: 'Optimal power flow using differentialevolution algorithm', Electr. Power Syst. Res., 2010, 80, (7). pp. 878–885.
[17] Carpentier, J.: 'Contribution a l'Etude du Dispatching Economique', Bulletin de la Societe Francaise des Electriciens, 1962, 3, pp. 431 –474.
[18] D.I., Ashley, B., Brewer, B., Hughes, A., Tinney, W.F.: 'Optimal power flow by Newton approach', IEEE Trans. Power Appar. Syst.,1984, PAS-103, (10), pp. 2864–2875.
[19] Abou El-Ela, A.A., Abido, M.A.: 'Optimal operation strategy for reactive power control modeling', Simul. Control, Part A, 1992, 41, (3), pp. 19–40.
[20] SB Vinay Kumar, PV Rao, Manoj Kumar Singh,"Multi-culture diversity based self adaptive particle swarm optimization for optimal floorplanning",Multiagent and Grid Systems, vol14, no.1, pp.31-65, 2018.
[21] RT Satish, KT Reddy, "A technique to find optimal location for wavelet-based image watermarking using genetic algorithm", Machine Graphics & Vision International Journal,vol. 20 (2), pp.173-196, 2011.
[22] Naresh Kumar Yadav,"Optimal ATC Enhancement Model: Analysis of the Effect of Thyristor-Controlled Series Compensation "Journal of Computational Mechanics, Power System and Control (JCMPS), Volume 2, Issue 2, October 2019.
[23] Shilpa S. Shrawane Kapse,Dr. Manoj B. Daigavane and Dr. Prema M. Daigavane,"Localization and Sizing of UPFC: A Hybrid Optimization Algorithm for Solving Reactive Power Dispatch""Journal of Computational Mechanics, Power System and Control (JCMPS), Volume 2, Issue 2, October 2019.
[24] M. Han and S. Liu, "An Improved Binary Chicken Swarm Optimization Algorithm for Solving 0-1 Knapsack Problem," 2017 13th International Conference on Computational Intelligence and Security (CIS), Hong Kong, 2017, pp. 207-210.