Improved Cat-Firefly Algorithm with Facts Controllers for Improvement of Voltage Profile in IEEE Modified 14 Bus Systems

A. Naraina*, G. R. Kunkolienkar
Department of EEE, Goa College of Engineering, Goa, India
*Corresponding Author
E-Mail Id: Narainaprof@ieee.org

ABSTRACT
In recent years there is much advancement in deregulated power market. It has become a desirable practice to reach advanced efficient power operation along with facilitated competitions among the power system market players. An acceptable and sustainable power delivery scheme is a key issue in healthy completion of power industry. Thus transmission network should satisfy all the required delivery schemes set by the power industry, but when there is sudden accession in loads connected to power network, the transmission system is revealed to transitory failures and instability issues. Conventional methods don’t support enough to handle the deregulated power system failures. Hence a contemporary method which can deal such failures is proposed in this research work. In the proposed research work Flexible AC Transmission System (FACTS) controllers are gripped in the transmission network to enhance the voltage profile thereby enhancing the stability of the system and this is achieved by optimizing the control parameters of the FACTS controllers to their opted values. In this proposed work the multi objective optimization problem for control parameters is solved by Improved Catfirefly Algorithm (ICFA) technique. The proposed work is validated through simulations on modified IEEE 14 bus system using MATLAB 14 simulation tool.

Keywords: Improved catfirefly algorithm (ICFA), TCSC-SVC-modified IEEE 14 bus system

INTRODUCTION
In the restructured power market scenario day by day the demand of power is increasing drastically as there is enormous addition of loads into the system. Hence it has become mandate that the operators of transmission system have to maintain the system at steady state and without transitory shortcomings, as discussed conventional methodologies as voltage regulation, generator side control and installation of compensation banks, will not cope the new deregulated market scenarios. This resulted in development of techniques that will cope the current issues and aid the system to operate under standard conditions Bhattacharyya & Gupta (2014),[5] Bhattacharyya & Kumar S (2016).[3] Ghahremani & Kamwa (2013)[7] suggested the solution that is installing of FACTS controllers for steady state operation along with dynamic stability for transmission networks. But as the controllers are tuned for better performance of system, control variable of controllers can lead to interference with each other and result in conflict of overall performance Das et al. (2016).[6] The proposed research work is associated with development of multi objective optimization solving algorithm named ICFA for optimizing the control variables of FACTS controllers and thereby improving the voltage profile along with stability of the system.

PROBLEM FORMULATION
In family of FACTS controllers, the blending combination with SVC and
TCSC have better results as per literature reviews,[1,2,9] hence these two controllers are contemplated for the proposed work. The objective (fitness) function derived has the functionality to optimize the control parameters with tuned values of the FACTS controllers and thereby enhance the voltage profile along with stability in the system.[8] The power losses in the system are calculated by finding the solutions using conventional load flow methods.

The control variables of the SVC-TSCS are given by,

\[ X_{FACTS,j} = [V_{su,j}, \theta_{su,j}, V_{sc,j}, \theta_{sc,j}] \quad (1) \]

Where,
- \( V_{su,j} \): PCC factor limits for complex voltage connected in the shunt
- \( V_{sc,j} \): PCC factor limits for complex voltage connected in the series
- \( \theta_{su,j} \): Phase limits for complex voltage connected in the shunt branch
- \( \theta_{sc,j} \): Phase limits for complex voltage connected in the series branch

The operating coercions for the power system connected with generators, feeders, nodes and FACTS controllers are given by,

\[ I_i \leq I_{max} \; \; ; \; \; V_{min} \leq V_j \leq V_{max} \; \; ; \; Q_{min} \leq Q_i \leq Q_{max} \quad (2) \]

where,
- \( V_{max}, V_{min} \): Voltage limits in Bus
- \( Q_{max}, Q_{min} \): Reactive power limit for connected generators
- \( I_{max} \): Thermal limits for transmission lines with FACTS controllers

By consolidation of the equations from Eq (1) to Eq (4), multi objective function to tune control parameters of SVC-TSCS controllers is obtained and illustrated by,

\[ \min f(X(s,\alpha)) = \sum_{j=1}^{d} \left[ |s_{j,1} + \alpha_1| + |s_{j,2} + \alpha_2| + \ldots + |s_{j,d} + \alpha_d| \right] \quad (4) \]

where,
- \( X_i \): Individual dimensions of FACTS control parameters
- \( \alpha \): SD correlated to FACTS control parameters. Thus concluding the set of equations from Eq (1) to Eq (4), the FACTS control parameters are determined. This framed Multi objective function is solved using proposed Improved Catfirefly Algorithm.

**Declination of Improved Catfirefly Algorithm (ICFA)**

Basically the algorithm is derived from exiting cat swarm optimization technique. But the conventional methods have some demerits one such is results derived that lie near boundary may be stranded in local optima. Such case results lead to unavoidable blindfold of control values. Thus to avoid this issues in existing algorithm modifications are adopted in CSO. The proposed improved CSO has modified strategies to overcome the local optima issue. The modifications adopted are change in boundary conditions in tracing mode of CSO. The Improved algorithm illustrated as given below

**Condition 1:** For any set vector \( P_{best} (d) < \min(d) \), as, \( P_{best} (d) = \min(d) \) \quad (5)

As velocity of CSO is updated the equation is given as,

\[ V_{k,d} = V_{k,d}r^1 \cdot ([P_{k,d}]) \quad (6) \]

**Condition 2:** For any set vector \( P_{best} (d) > \min(d) \), as, \( P_{best} (d) = \max(d) \) \quad (7)

As velocity of CSO is updated the equation is given as,

\[ V_{k,d} = -V_{k,d}r^1 \cdot ([P_{k,d}]) \quad (8) \]

The modification for improved algorithm is given in mutation factor and given by,

\[ W_{(j)} = ( \sum_{j=1}^{d} V_{k,j} / d ) \quad (9) \]

where \( V_{k,j} \): element vector of \( k^{th} \) cat,
- \( W_{(j)} \): modified vector with range of \([-W_{(min)}, W_{(max)}]\]
- \( d \): dimensions of elements for \( k^{th} \) particle.
Hence the improved CSO is represented by
\[
P_{g,d}^{new(k)} = P_{g,d}(k) + W_{(j)}(X_{min,d} - X_{max,d}) \quad , d = 1,2,\ldots, M
\]
(10)
\[P_{g,d}^{new(k)} : \text{Out element of } k^{th} \text{ cat}
\]
\[W_{(j)} : \text{modified vector}
\]
\[(X_{min,d} - X_{max,d}) : \text{range of set vector.}
\]
The range of \([-W_{(\text{min})}, W_{(\text{max})}]\) is between [0.7 to -0.7].

This modification in the proposed CSO possesses the improved CSO that overcomes the local minima issues and helps the system to converge to required values. The capability of the proposed algorithm is tested with numerical experiments and simulated to standard conditions.

VALIDATION WITH SIMULATION RESULTS
To show the effectiveness of the proposed algorithm conventional algorithms from literature are taken for comparison. The optimization techniques studied for comparison are GA and NPSO. The details of algorithm parameters are given in Table 1.

### Table 1: Parametric Value of the Algorithms for Comparison.

| S.No. | Executed Algorithms                  | Parameters considered | Parametric Values |
|-------|--------------------------------------|-----------------------|-------------------|
| 1     | Genetic Algorithm (GA)               | Population Size       | 50                |
|       |                                      | Crossover Rate        | 0.5               |
|       |                                      | Mutation Rate         | 0.04              |
|       |                                      | No. of Generations    | 70                |
| 2     | Novel Particle Swarm Optimization (NPSO) | Number of Particles   | 50                |
|       |                                      | Number of Iterations  | 70                |
|       |                                      | Inertial Weights      | 0.35              |
|       |                                      | \(c_1 = c_2\)         | 0.2               |
| 3     | Proposed ICFA Parameters             | Number of fly         | 50                |
|       |                                      | Absorption co-efficient | 0.25            |
|       |                                      | Number of Iteration   | 70                |
|       |                                      | Location vector range | [0-20]           |
|       |                                      | Mutation Factor       | [0.5 – 0.7]       |

**Modification of IEEE 14 – Bus System**
The modifications carried with simulation of different cases for study purpose in IEEE 14 bus system are depicted through Figure 1. The results simulated under standard conditions are tabulated in Table 2, later the profile for voltage values at each bus is computed to show the capability of the proposed ICFA.

The standard case considered for simulating the proposed work includes that the system operates with 100% nominal load and firstly the load flow is derived using conventional NR method. Later profile of voltage at each bus is taken into consideration.

![Fig. 1: IEEE 14 Bus Test Systems with Modification.](image-url)
Table 2: Simulated Results for IEEE 14 Bus Modified System with Different Case Considered.

| Bus number | Without FACTS controllers using conventional method Tso et al. (1997) | FACTS in Line without Tuning | With Optimised control values of FACTS using proposed ICFA |
|------------|-------------------------------------------------|--------------------------------|--------------------------------|
|            | Voltage profile (p.u) | power losses (MW) | Voltage profile (p.u) | power losses (MW) | Voltage profile (p.u) | power losses (MW) |
| 1          | 1.0500              | 16.49             | 1.0522              | 14.91             | 1.0534              | 11.86             |
| 2          | 1.0350              | 16.49             | 1.0301              | 14.91             | 1.0309              | 11.86             |
| 3          | 1.0010              | 16.49             | 1.0015              | 14.91             | 1.0297              | 11.86             |
| 4          | 1.0400              | 16.49             | 1.0489              | 14.91             | 1.0567              | 11.86             |
| 5          | 1.0700              | 16.49             | 1.0775              | 14.91             | 1.0819              | 11.86             |
| 6          | 1.0012              | 16.49             | 1.0022              | 14.91             | 1.0242              | 11.86             |
| 7          | 1.0066              | 16.49             | 1.0088              | 14.91             | 1.0098              | 11.86             |
| 8          | 1.0357              | 16.49             | 1.0399              | 14.91             | 1.0399              | 11.86             |
| 9          | 1.0305              | 16.49             | 1.0389              | 14.91             | 1.0393              | 11.86             |
| 10         | 1.0199              | 16.49             | 1.0292              | 14.91             | 1.0318              | 11.86             |
| 11         | 1.0361              | 16.49             | 1.0381              | 14.91             | 1.0398              | 11.86             |
| 12         | 1.0433              | 16.49             | 1.0452              | 14.91             | 1.0469              | 11.86             |
| 13         | 1.0366              | 16.49             | 1.0372              | 14.91             | 1.0399              | 11.86             |
| 14         | 1.0093              | 16.49             | 1.0159              | 14.91             | 1.0195              | 11.86             |

Table 3: Comparison of Voltage Profile using Conventional Algorithms with Proposed ICFA under Different Test Condition.

| Sl.No | Methods                              | Modified IEEE 14 Bus system |
|-------|--------------------------------------|-----------------------------|
|       |                                      | Voltage profile (p.u) | power losses (MW) |
| 1     | NPSO Benabid et al. (2009) [4]       | 1.0012                     | 16.49             |
| 2     | GABagriyanik et al. (2003)           | 1.0022                     | 14.91             |
| 3     | ICFA Technique                       | 1.0242                     | 11.86             |

Fig. 2: Voltage Profile Comparison for Modified IEEE 14 Bus System.

VALIDATION OF DERIVED RESULTS

The results are simulated and results depict that as the voltage profile in bus number 03 and bus number 06 is low these buses are taken into consideration for placement of SVC and TCSC FACTS controllers. The result validate that there is increase in improvement of voltage profile when power system is connected with SVC and TCSC with tuned parameters. Wherein system has shown better results as the parameters are tuned with proposed ICFA.
technique. To validate the results conventional algorithms were taken and simulated with similar conditions and the comparison results are shown in Table 3. The voltage profile comparison for modified 14 bus test system is pictured in Figure 2 and it clearly states by including modification in tracing mode of CSO, proposed ICFA helps the FACTS controllers SVC-TSCC to improve the voltage profiles of the transmission system.

CONCLUSION
Thus to enhance the voltage profile in hand reduce the losses in the transmission system. An innovative methodology by optimal placing of SVC-TSCCS with the control parameters tuned to their optimized values by proposed ICFA approach is experimented in this research work. Later a correlation work is carried out with existing methodology to prove the effectiveness of the proposed ICFA technique, and it is well proofed with experimental and standard simulation that the proposed ICFA enhances voltage profile.

REFERENCES
1. Avudayappan, N., & Deepa, S. N. (2016). Congestion management in deregulated power system using hybrid cat-firefly algorithm with TCSC and SVC FACTS devices. COMPEL-The international journal for computation and mathematics in electrical and electronic engineering.
2. Avudayappan, N., & Deepa, S. N. (2016). Optimal location of TCSC and SVC using hybrid fruit fly flyfirefly optimization algorithm in transmission system. Asian Journal of Information Technology, 15(16), 2863-2872.
3. Bhattacharyya, B., & Kumar, S. (2016). Approach for the solution of transmission congestion with multi-type FACTS devices. IET Generation, Transmission & Distribution, 10(11), 2802-2809.
4. Benabid, R., Boudour, M., & Abido, M. A. (2009). Optimal location and setting of SVC and TCSC devices using non-dominated sorting particle swarm optimization. Electric Power Systems Research, 79(12), 1668-1677.
5. Bhattacharyya, B., & Gupta, V. K. (2014). Fuzzy based evolutionary algorithm for reactive power optimization with FACTS devices. International Journal of Electrical Power & Energy Systems, 61, 39-47.
6. Saha, D., Datta, A., & Das, P. (2016). Optimal coordination of directional overcurrent relays in power systems using symbiotic organism search optimisation technique. IET Generation, Transmission & Distribution, 10(11), 2681-2688.
7. Ghahremani, E., & Kamwa, I. (2012). Optimal placement of multiple-type FACTS devices to maximize power system loadability using a generic graphical user interface. IEEE transactions on power systems, 28(2), 764-778.
8. Sahu, S. K., & Jayalaxmi, A. (2015). Application of Gravitational Search Algorithm to Improve Power System Security by Optimal Placement of FACTS Devices. Journal of Electrical Systems, 11(3).
9. Shahgholian, G., Movahedi, A., & Faiz, J. (2015). Coordinated design of TCSC and PSS controllers using VURPSO and genetic algorithms for multi-machine power system stability. International Journal of Control, Automation and Systems, 13(2), 398-409.