RESEARCH ARTICLE OPEN ACCESS

Determination of optimal location of UPFC to improve the voltage stability of the power system

Bairu Vijay Kumar
EEED, KITS, Warangal, India.

ABSTRACT
In this paper, the Firefly algorithm based optimal location of UPFC to improve the voltage stability of the power system is proposed. The novelty of the proposed method is exemplified in the improved searching ability, random reduction and reduced complexity. In this regard, the generator outage affects the system voltage stability constraints and increase power loss. Here, the FA technique optimizes the maximum power loss line as the suitable location of the UPFC. The voltage profile at various buses is restored into secure limits by using UPFC at the optimum location. The proposed method is implemented in the MATLAB/Simulink platform and tested on IEEE 14 bus standard bench mark system. The proposed method performance is evaluated by comparison with those of different techniques such as ABC, GSA algorithms. The comparison results invariably prove the effectiveness of the proposed method and confirm its potential to solve the related problems.
Key words: FA, power loss, voltage, voltage stability, UPFC

Date Of Submission: 09-05-2019 Date Of Acceptance: 24-05-2019

I. INTRODUCTION

The amount of electric power by safety and steadiness restraints, that can be passed on between two positions via a transmission network is limited [1]. Electric power systems have been forced to work to more or less their full capacities around the world due to the environmental and economic limitations to upright new generating plants and transmission lines [2]. Power flow in the lines and transformers should not be allowed to increase to a level where a arbitrary incident could cause the network fall down as cascaded outages [3].

New opportunities for controlling power and enhancing the utilizable capacity of surviving transmission lines are discharged up by the look of FACTS tools [4]. FACTS is recognized as "a power electronic based system and other fixed device that present control of one or more AC transmission system parameters to develop controllability and increase power transfer capability" [5]. The different types of FACTS devices available for this purpose includes Static Var Compensator (SVC), Thyristor controlled series Capacitor (TCSC), Static Synchronous series compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Interlink Power Flow Controller (IPFC) [6]. UPFC is one of the FACTS devices among them, that can administer the power flow in transmission line by including active and reactive voltage component in chain with the transmission line [7].

An optimal location of UPFC device allows to control its power flows for a interconnected network, and as a result to increase the system load ability [8]. The optimal location particular number of FACTS in a power system is a hinder of combinatorial revise [9]. Different types of optimization algorithm have been used to effort out this kind of problem, such as genetic algorithms, reproduced annealing, tabu search and etc [10].

This paper presents the Firefly algorithm based optimal location of UPFC to improve the voltage stability of the power system. Here, the FA technique optimizes the maximum power loss line as the suitable location of the UPFC. The affected location parameters and voltage deviations are restored into secure limits using the UPFC at optimal location. Power flows are analyzed before and after connecting UPFC. Rest of the paper sorted by the following: the recent analysis works is usually reviewed throughout section 2; the proposed work elaborate the evidence is usually described throughout section 3; the suggested techniques approach good results effects as well as the related discussions receive throughout section 4; as well as section 5 conclude the paper.

II. RECENT RESEARCH WORK: A BRIEF REVIEW

Numbers of related works are available in literature, which based on improving the power transfer capability and voltage stability of power system. Some of them are reviewed here. H.I. Shaheen et al. has been scrutinized the competence of the optimal location of UPFC for enhancing the safety of power systems under single line contingencies [11].DE has been successfully used to the problem under distress. Maximization of power system security was considered as the optimization rule. They were performed two case studies using IEEE 14-bus system and IEEE 30-bus system.

Seyed Abbas Taher et al. have got introduced this demands connected with hybrid immune algorithm to have the optimum location of UPFCs for attaining minimum total active and reactive power production cost of generators and reducing the installation cost of UPFCs [12].. They executed simulations upon IEEE 14-bus and 30-bus test system.

A.R. Phadke et al. have suggested an approach regarding engagement and sizing of shunt FACTS controller by means of Fuzzy logic and Real Coded Genetic Algorithm [13]. A fuzzy appearance index according to distance to impede node bifurcation, voltage profile and capacity of shunt FACTS controller is proposed. The proposed strategy has been used with IEEE 14-bus along with IEEE 57-bus test systems.

Lokman H.Hassan et al. [14] have demonstrated the application of Genetic Algorithm (GA) technique for the simultaneous stabilization of power systems using a Unified Power Flow Controller (UPFC). The GA was applied to find the optimal location of the UPFC and to tune its control parameters under different operating conditions. The approach was successfully tested on the 16-machine 68-bus New England–New York interconnected system.

Mehrdad Tarafdar Hagh et al. [15] have presented a novel method to solve security based optimal placement and parameter setting of unified power flow controller (UPFC) problem based on hybrid group search optimization (HGSO) technique. Simulation studies are carried out on the IEEE 6-bus, IEEE 14-bus and IEEE 30-bus sytem.

The heavily loaded lines, sustain the bus voltages at desired levels, and enhance the stability of the power network are increased uncontrolled exchanges in power systems. For that reason, power systems need to be supervised in sequence to make use of the obtainable network competently. FACTS devices depends on the advance of semiconductor technology released positive latest prospects for controlling the power flow and expanding the loadability of the accessible power transmission system. Among the FACTS devices, the UPFC is one of the most promising FACTS devices for load flow control seeing as it can either concurrently manage the active and reactive power flow alongside the lines in addition to the nodal voltages. As per the characteristics of the UPFC, scheduling the implementations, it has some practical concern for finding the optimal location. In practically, the optimal location of UPFC tends not by randomly, and the matching methodical exploration is not frequently adequate. Several researches have effort to solve the optimal location of UPFCs with respect to different purposes and methods. For determining the optimal location, the operating condition of UPFC must be pre-assigned. Some of the optimization algorithms are introduced to determine the location of UPFC such as genetic algorithm, particle swarm optimization, differential evaluation and etc. , but the results obtained are still not promising. Still there is a chance for the improvement of voltage stability. The proposed method is briefly described in the following section 3.

III. PROPOSED METHODOLOGY

3.1. UPFC model and power flow equation

In two machine system, the figure 1 displays the conceptual representation of UPFC. The UPFC contains two switching converters, which are activated from a common dc link offered by a dc storage capacitor [16]. The power flow for a two-bus system depends on the magnitude of bus voltages, their phase difference and the impedance of the transmission line in a power system. At the UPFC terminals the UPFC permits concurrent control of the active and reactive power flow and voltage magnitude. On the other hand, the controller may be placed to control one or more of these parameters in any combination or to control none of them [17]. In the figure 1, the UPFC is connected between the buses i and j , where shunt converter and series converters are connected to the transmission line via shunt and series transformers. By the shunt converter through the common DC link, the real power demanded by the series converter is delivered from the AC power system. The shunt converter is proficient to deliver or absorb controllable reactive power in both operating modes (i.e., inverter and rectifier) [18]. At a specified value, the independently controlled shunt reactive compensation can be applied to sustain the shunt converter terminal AC voltage magnitude. The equivalent circuit of the UPFC is described in the following figure 2.

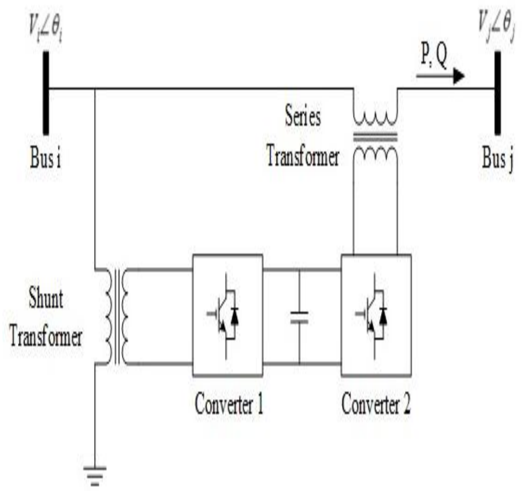

Figure.1: UPFC installation between the buses

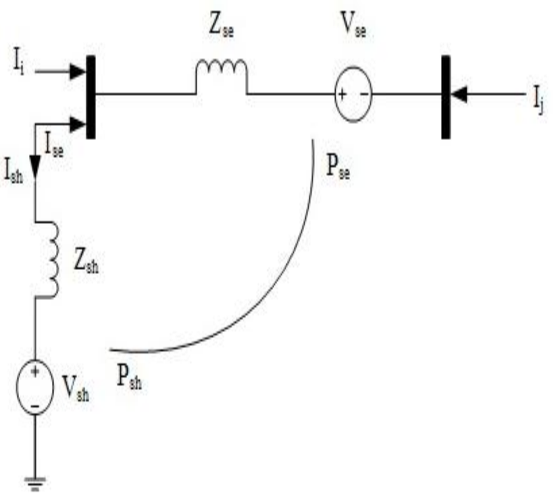

Figure.2: UPFC equivalent circuit model

As shown in the figure 2, based on the equivalent circuit, the active and reactive power equations are described in the following equations (1) and (2). Using the power flow equations, the power injection at each node can be obtained from the equivalent circuit model. The power flow equations from node i to j and j to i are described in the following equations [19-20].

Power flows from i to j:

$$P_{ij}(t) = \left(V_i^{2(t)} + V_{kl}^{2(t)}\right)G_{ij}^{(t)} + 2V_i^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) - V_j^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) + b_{ij}^{(t)}(\sin\alpha_{kl} - \phi_j)\right] - V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} + b_{ij}^{(t)}\sin\phi_{ij}\right) \quad (1)$$

$$Q_{ij}(t) = -V_i^{(t)}I^{(t)} - V_i^{2(t)}(b_{ij}^{(t)} + B/2) - V_i^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_i) + b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_i)\right] - V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right) \quad (2)$$

Where, $G_{ij} + jb_{ij} = \dfrac{1}{R_{ij} + jX_{ij}}$; V_i and V_j are the voltage of the buses i and j respectively and V_{kl} is the voltage of the compensating device, similarly the real and reactive power flow from the bus j to i is given by the following equation (3) and (4) [33].

Power flows from j to i:

$$P_{ji}(t) = V_j^{2(t)}G_{ij}^{(t)} - [V_j^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}G^{(t)}\sin(\alpha_{kl} - \phi_j)] - V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} - b_{ij}^{(t)}\sin\phi_{ij}\right) \quad (3)$$

$$Q_{ji}(t) = -V_j^{2(t)}(b_{ij}^{(t)} + B/2) - V_j^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_j)\right] + V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right) \quad (4)$$

The UPFC power flow equations are used to find the capacity of the UPFC, which is based on the affected location requirements. The UPFC location and capacity selection depends on the voltage stability constraints or control variables such as power balance condition, voltage stability, power loss, UPFC cost, real and reactive power flow equations. Because the voltage stability is achieved by maintaining the voltage stability constraints at secure limits. The required voltage stability constraints are described as follows.

3.2. Power balance equation

The demand of the system and the power loss should get assured by the power generated from the power system. The generators existing in the system may get outage, which means the power loss of the system is raised, which breaks the power balance condition. In the equation (5), the necessary power balance condition is described.

$$\sum_{i=1}^{N_G} P_G^i = P_D + \sum_{j=1}^{N_L} (P_L^j) \quad (5)$$

Where, P_G^i is the power generated in the i^{th} bus; P_D is the demand; N_L is the total number of transmission lines; N_G is the total number of generators; P_L^j is the real power loss of the j^{th} line. The generators generation limits and demand of the system are described in the following equation (6) and (7) [21].

$$P_G^{i(\min)} \le P_G^i \le P_G^{i(\max)} \quad (6)$$

$$P_D^{(\min)} \le P_D \le P_D^{(\max)} \quad (7)$$

Where, $P_G^{i(\min)}$ and $P_G^{i(\max)}$ are the minimum maximum range of the generators generation limits, $P_D^{(\min)}$ and $P_D^{(\max)}$ are the minimum maximum range of the load demand limits.

3.3. Real and Reactive power flow

The real and reactive power at bus i can be described by the following equations (8) and (9) [21].

$$P_i = |V_i||V_j|\sum_{j=1}^{N_B}\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) \quad (8)$$

$$Q_i = |V_i||V_j|\sum_{j=1}^{N_B}\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) \quad (9)$$

Where, V_i and V_j are the voltage of i and j buses respectively; N_B is the total number of buses; δ_{ij} and δ_{ij} are the angle between i and j buses respectively; G_{ij} and B_{ij} are the conductance and susceptance values respectively. The voltage stability constraint is described in the following section 3.4.

3.4. Voltage stability

The voltage stability of the each bus is the main factor of the voltage stability, which can be described by the following equations (10) [21].

$$\Delta V_i = \frac{1}{\sqrt{l}}\sqrt{\sum_{i=1}^{l}\left(V_i^{\,k}\right)^2} \quad (10)$$

Where, $V_i^{\,k} = V_{slack} - \sum_{i=1}^{n} Z_i\left(\frac{P_i - jQ_i}{V_i}\right)$

With, V_{slack} is the slack bus voltage, ΔV_i is the voltage stability index of the bus i, V_i is voltage of the bus, where $i = 1,2,3\ldots n$, Z_i is the impedance of the i^{th} bus, P_i and Q_i are the real and reactive power of bus i and j is the number of nodes.

For finding the optimum location of the UPFC FA algorithm is used. The FA algorithm based on optimum location of the UPFC determination is briefly described in the following section 3.5.

3.5. Optimization of UPFC location using FA technique

FA is invented by Xin-She Yang for solving multimodal optimization problem, which works based on the flashing behavior of fireflies [22, 23]. The IEEE standard bench mark system load flow analysis has been done by using the Newton Raphson (N-R) method. Initially the normal power flow of the system is analyzed. Then different types of generator fault are introduced in the generator bus, which ensures the voltage stability constraints away from the secure limit. During this condition, the FA technique optimizes the location to place the UPFC based on the objective function, i.e., minimum voltage deviations at the buses.

Steps to find the optimum location

Step 1: Initialization of the fireflies.

Step 2: Input fireflies are randomly generated at n dimension. Here, the bus voltage and line losses are the input fireflies.

Step 3: Evaluate the fitness function for the random number of the fireflies.

Step 4: Into two groups the solutions are divided, the first groups have the least good solutions and one more group has maximum best solutions.

Step 5: According to the objective function the best solution could be found out and accumulate the current population.

Step 6: Arbitrarily revise the current firefly's population to update position vector and velocity vector of the micro-bats.

Step 7: Assess the objective for the novel firefly's population and among the solution choose the best solution.

Step 8: Find the power loss, voltage, real and reactive power flow of the best solution.

Step 9: Check the termination criterion. If it is satisfied terminate or else go to step 10.

Step 10: Generate the new agents to generate new solutions. Go to Step 3.

Once the above process is over the system is to provide the optimum location of the UPFC at the corresponding generator outage conditions.

The proposed technique is tested in the MATLAB/simulink platform and the results are analyzed in Section 4.

IV. RESULTS AND DISCUSSION

The proposed method is implemented in MATLAB/Simulink 7.10.0 (R2012a) platform, and tested on IEEE 14 bus system. The effectiveness of the proposed method is observed from a comparative analysis between ABC, GSA and Bat algorithms.

4.1 Validation of IEEE 14 bus system

The Section details the employment of proposed technique in IEEE 14 bus system, which has two generator buses. One among the two generators is in slack bus and the remainder is in the second bus. Figure 3 illustrates the structure of

IEEE 14 bus test system. The load flow solution at normal condition is estimated by means of N-R load flow analysis, which recognizes the entire system load flow parameters and the voltage stability constraints. The single generator outage is introduced in the IEEE 14 bus system. This causes voltage deviations in the system and hence voltage instability and increased power loss occur. However, the problem can be overcome by identifying the optimal location and by connecting UPFC. The power loss comparison for different conditions is tabulated in Table 1 [24].

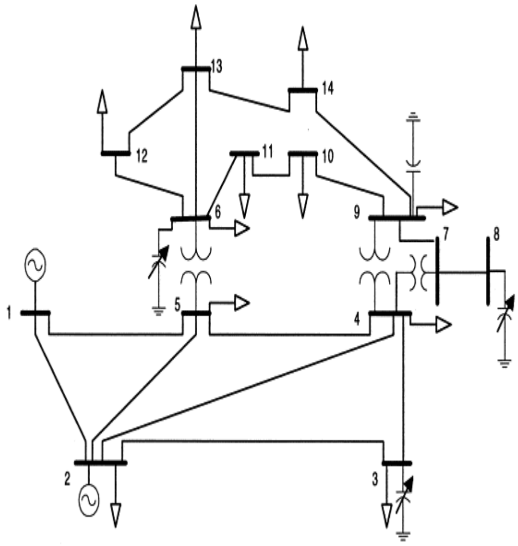

Figure.3: IEEE 14 bus system structure

Table.1: Power loss comparison using different techniques

Generator outage at bus no.	Best location		Power loss in MW					
	From bus	To bus	Normal	Outage condition	ABC	GSA	Bat	FA
2	4	5	13.592	15.428	11.175	10.275	9.623	9.145

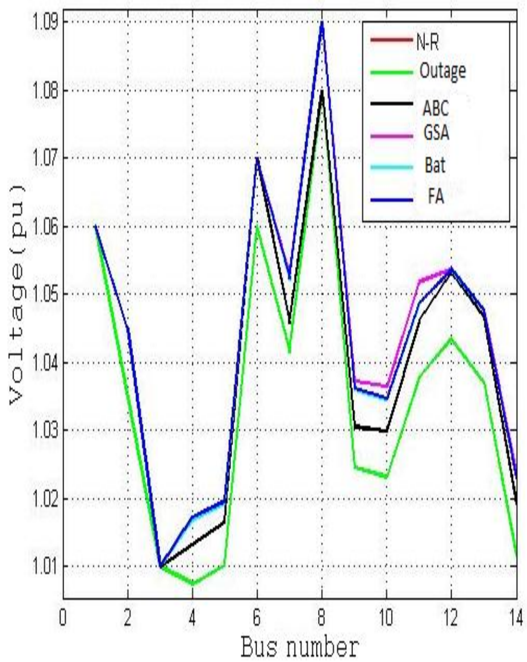

Figure.4: Voltage profile comparison at single generator problem

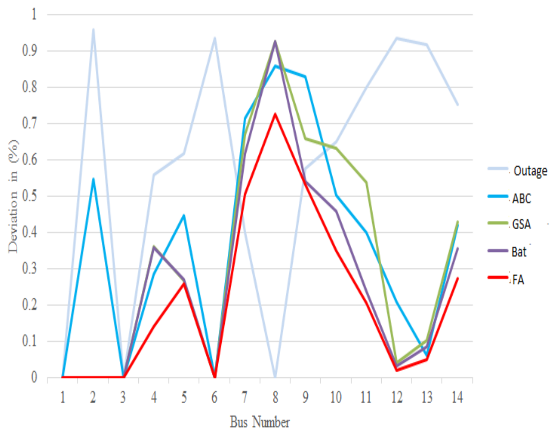

Figure.5: VDP of IEEE 14 bus system

The voltage profile of the IEEE 14 bus system at single generator outage under different techniques is described in the Figure 4. In the figure, voltage profile from the proposed method is compared with the ABC, GSA, Bat and FA techniques. It is clearly shown that the novel technique considerably enhances the voltage profile from the normal value. The figures demonstrates that the proposed technique preserves the voltage profile at the voltage stability margin, when compared with the other heuristic techniques. The proposed technique decreases the power loss of IEEE 14 bus system to 9.145 MW. It is relatively better than ABC, GSA and Bat algorithms. The voltage stability performance of different techniques is calculated using the following equation (11).

$$VDP(i) = \frac{V_N(i) - V_{ST}(i)}{V_N(i)} \times 100, \ i = 1,2,3 \ldots N_B \quad (11)$$

Where, $VDP(i)$ is the voltage deviation percentage of bus i; $V_N(i)$ is the normal voltage of the bus i and $V_{ST}(i)$ is the solution technique voltage of the bus i. Based on the VDP calculation, the figure 5 is plotted. It was clearly shown that the proposed method effectively reduces the voltage deviations. The results obtained from the comparative analysis prove the dominating performance of the proposed technique over the other techniques in terms of maintaining the voltage stability of power system.

V. CONCLUSION

This paper proudly proposes the heuristic approach based voltage stability enhancement of the power system using the UPFC. The advantage of the proposed method was highlighted in the enhanced searching ability and the lesser complexity in achieving the optimal solutions. The IEEE 14 bus system was utilized for testing the proposed method performance. In the bus system generator outage was created and the most affected location was determined by using the FA technique. The affected voltage stability constraints such as voltage, power loss, were restored into secure limits by using the UPFC at optimum location, which, in turn, was given by the FA algorithm. The proposed method numerical results were validated through the comparison analysis with those of the different techniques like ABC, GSA, and Bat algorithms. Also the proposed hybrid approach voltage stability enhancement is analyzed with the VDP calculation. The comparison analysis proves that the proposed method is an effective technique to enhance the voltage stability of the power system, and is competent over the other techniques.

REFERENCE

[1]. P. Ramasubramanian, G. Uma Prasana, and K. Sumathi, "Optimal Location of FACTS Devices by Evolutionary Programming Based OPF in Deregulated Power Systems", British Journal of Mathematics & Computer Science, Vol.2, No.1, pp.21-30, 2012

[2]. Rakhmad Syafutra Lubis, Sasongko Pramono Hadi, and Tumiran, "Selection of Suitable Location of the FACTS Devices for Optimal Power Flow", International Journal of Electrical & Computer Sciences, Vol.12, No.3, pp.38-49, 2012

[3]. D. Devaraj, and J. Preetha Roselyn, "Genetic algorithm based reactive power dispatch for voltage stability improvement", International Journal of Electrical Power & Energy Systems, Vol.32, No.10, pp.1151–1156, December 2010

[4]. Jigar S.Sarda, Vibha N.Parmar, Dhaval G.Patel, and Lalit K.Patel, "Genetic Algorithm Approach for Optimal location of FACTS devices to improve system loadability and minimization of losses", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol.1, No.3, pp.114-125, 2012

[5]. H O Bansal, H P Agrawal, S Tiwana, A R Singal and L Shrivastava, "Optimal Location of FACT Devices to Control Reactive Power", International Journal of Engineering Science and Technology, Vol.2, No.6, pp.1556-1560, 2010

[6]. Xuan Wei, Joe H. Chow, Behruz Fardanesh and Abdel-Aty Edris, "A Common Modeling Framework of Voltage-Sourced Converters for Load Flow, Sensitivity, and Dispatch Analysis", IEEE Transactions On Power Systems, Vol.19, No.2, pp.934-941, May 2004.

[7]. D. Murali, and M. Rajaram, "Active and Reactive Power Flow Control using FACTS Devices", International Journal of Computer Applications, Vol.9, No.8, pp.45-50, 2010

[8]. Gerbex, S., Cherkaoui, R., and Germond, A.J., "Optimal location of FACTS devices to enhance power system security", IEEE Bologna Power Tech Conference Proceedings, 2003

[9]. Wang Feng, and Shrestha, G.B., "Allocation of TCSC devices to optimize total transmission capacity in a competitive power market", IEEE Power Engineering Society Winter Meeting, 2001

[10]. Mahdad, B., Bouktir, T., and Srairi, K., "GA Coordinated with Practical Fuzzy Rules with Multi Shunt FACTS Devices to Enhance the Optimal Power Flow", The International Conference on Computer and Tool, 2007

[11]. H.I. Shaheen, G.I. Rashed, S.J. Cheng, "Application and comparison of computational intelligence techniques for optimal location and parameter setting of UPFC", Engineering Applications of Artificial Intelligence, Vol.23, pp.203–216, 2010

[12]. Seyed Abbas Taher, and Muhammad Karim Amooshahi, "New approach for optimal UPFC placement using hybrid immune algorithm in electric power systems", Electrical Power and Energy Systems, Vol.43, pp.899-909, 2012

[13]. A.R. Phadke, and Manoj Fozdar, K.R. Niazi, "A new multi-objective fuzzy-GA formulation for optimal placement and sizing of shunt FACTS controller", International Journal of Electrical Power & Energy Systems, Vol.40, No.1, pp.46–53, September 2012

[14]. Lokman H.Hassan, M.Moghavvemi, Haider A.F.Almurib, Otto Steinmayer, "Application of genetic algorithm in optimization of unified power flow controller parameters and its location in the power system network", International

Journal of Electrical Power & Energy Systems, Vol.46, pp.89-97, March 2013
[15]. Mehrdad Tarafdar Hagh, Manijeh Alipour and Saeed Teimourzadeh, "Application of HGSO to security based optimal placement and parameter setting of UPFC", Energy Conversion and Management, Vol.86, pp.873-885, October 2014
[16]. P.Ramesh and M.Damodara reddy, "Loss reduction through optimal placement of Unified Power-Flow Controller using Firefly Algorithm", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering", Vol.2, No.10, pp.4657-4667, October 2013
[17]. R.Jahani, "Optimal Placement of Unified Power Flow Controller in Power System Using Imperialist Competitive Algorithm", Middle-East Journal of Scientific Research, Vol.8, No.6, pp.999-1007, 2011
[18]. KJV.Satish babu, P.Harshavardhan reddy and M.Padma lalitha, "Optimal Location of UPFC for Voltage Stability Enhancement Using MPSO and ECI Algorithm for Power Flow Analysis", Vol.1, No.3, pp.2347-2812, 2013
[19]. Wanliang Fang, and H.W. Ngan, "A robust load flow technique for use in power system with unified power flow controllers", Electric Power Systems Research, Vol.53, No.3, pp.181-186, 2000
[20]. Arup Ratan Bhowmik and Champa Nandi, “Implementation of Unified Power Flow Controller (UPFC) for Power Quality Improvement in IEEE 14-Bus System”, Int. J. Comp. Tech. Appl, Vol.2, No.6, pp.1889-1896, 2011
[21]. A.Siva Sankar and K.S.R.Anjaneyulu, "Maintaining Voltage Stability by Optimal Locating and Sizing by Combined Evolutionary Algorithm", International Journal of Computer Applications, Vol.84, No.12, pp.39-45, December 2013
[22]. Yang, "Firefly algorithms for multimodal optimization”, Stochastic Algorithms: Foundation and Applications, vol. 5792, pp. 169-178, 2009
[23]. Xin-She Yang, Seyyed Soheil Sadat Hosseini and Amir Hossein Gandomic, "Firefly Algorithm for solving non-convex economic dispatch problems with valve loading effect", Applied Soft Computing, Vol.12, pp.1180–1186, 2012
[24]. B.Vijay kumar “Optimal Location of Upfc to Improve Power System Voltage Stability Using Artificial Bee Colony Algorithm”, American Journal of Electrical Power and Energy Systems 2019; 8(2): 42-49.

Author’s Biography

Dr.B. Vijay Kumar was born in Warangal, India, in April 1978. He received the B. Tech degree in Electrical & Electronics Engineering , M. Tech degree in Power Systems Engineering and Ph.D in electrical engineering from National Institute of Technology, Warangal, India, in 2002 , 2008 and 2015 respectively. He is currently working as Asst. professor in EEED of Kakatiya institute of Technology & Science, Warangal, India. He published papers in various sci indexed journal.s His Current research interest includes Enhancement of Power System Stability using FACTS devices and AI techniques.

Bairu Vijay Kumar" Determination of optimal location of UPFC to improve the voltage stability of the power system" International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.05, 2019, pp. 15-21