Firefly Technique Based on Optimal Congestion Management in an Electricity Market

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ABSTRACT

Nowadays, congestion management is one of the major tasks accomplished by system operators to warrant the operation of transmission system within operating limits. This has resulted in unanticipated congestion interfaces in regional transmission systems. The system is, however, unable to evolve at a rate which is required to meet the quickly changing demand of competitive markets. To make the matters worse, the functional unbundling of generation company and system operator will further threaten reliable operation of entire grid due to the lack of coordination between generation and transmission. Thus, a sensible way of dealing with congestion has become vital to maintaining current level of high reliability. In this paper Firefly Algorithm (FA) is used for solving economic load dispatch problem for raise efficiency, increase safety margins and reduce cost of distribution network unit production regarding to practical constraints such as maximum network voltage, maximum transmission line current, power balance and load level. The proposed technique is applied on 30 and 118 buses power system in comparison with CPSO, PSOTVAC, PSOTVIW and ABC

Keywords:

Firefly Algorithm, Congestion Management, Electricity Market

Nomenclature

g: Participating generator
N_g: Number of participating generators
IC_g: Incremental and decremented cost of generator g
ΔP_g Active power adjustment at bus g.
ΔP_g^{min}: Minimum adjustment limit of generator g.
ΔP_g^{max}: Maximum adjustment limit of generator g.
P_g: Active power output.
P_g^{min}: Minimum generation limit of generator g.
P_g^{min}: Maximum generation limit of generator g.
F_l^0: Power flow caused by all contracts requesting the transmission service.
F_l^{max}: Power flow limit of line l.
n_l: Number of transmission lines in the system.
ΔP_{ij}: Changed in active power flow on the line connected between buses i and j.
ΔPG_g: Changed in active power of generator g.
n: Number of all the buses in the system.
V_i, V_j: Voltage magnitude at buses i and j.
θ_i, θ_j: Phase angle at buses i and j.
G_{ij}: Conductance of the line connected between buses i and j.
B_{ij}: Susceptance of the line connected between buses i and j.
K: Current iteration number

1. Introduction

Actually the congestion of transmission occurs when there is inexpressive valency in transmission to simultaneously embed all demands for transmission service within a zone. Basically, vertically confederate utilities managed this condition by constraining the economic load dispatch of generators with the object of certifying security and reliability of their own and/or vicinage systems. The deregulating of the power electric industry has moved a generation enterprise and operations determination into the competitive market however has left transmission as a universal resource in the ordered zone [1]. This humor of competitive generation and regulated transmission produce formidable congestion management. The obstacle is compounded by enhancements in the amount of congestion outcome from increased tradespeople transactions and the comparative decrement in the amount of transmission [2].

The Mandatory System Operator model is improved based on the methods by prevalent regional power pools. In this strategy a system operator becomes the lone market maker for basically, functionally and economically concomitant energy and transmission trades. Initially, market participants bid supply (and demand) curves to the system operator. The system operator then simultaneously dispatches generators and devotes transmission capacity using Optimal Power Flow (OPF) plan which determines the most economical mix of generation for given load [3].

Recently, several congestion management problems are [2-6]. In [7], congestion factor of distribution network description is presented. Ranking zone categorized by sensitivity index is divided to active and reactive power. This technique in computational aspect is complex. The OPF with minimization congestion cost and service are presented in [8]. In [9], is described OPF for synchronization between the producing company and ISO using disconnected port. Also OPF can be injected power to adjust the system condition for instability state and over load heat [10]. The significance of Relative Electrical Distance (RED) to alleviate overloaded lines by the timing of active power is described in [11]. This method minimized system Loss and improved voltage profile. However, in this paper has been not raised schedule cost. In [12], presents method of production scheduling optimization considering scheduling based on cost minimization objective PSO.

$H\infty$ optimization techniques [13-14] have been pragmatic to the optimization problem in power system. However, the increasable and/or operated by multiplication uncertainty delegation cannot act situations where a nominal stable system goes unstable after being perturbed. This gives rise to the twisted structure of such optimization problem and reduces their applicability.

Genetic Algorithm (GA) is an intense optimization technique, independent on the complexity of optimization problems where no prior kenning is available. Actually several optimization problems have been solved by this technique in power systems were presented in [15-16]. These works check the use of genetic algorithms for simultaneously stabilization of multi-machine power system over a wide range of scenarios. Although GA is very competent in distinguishing the global or near global solution of the problem, it needs a very lengthy run time. Hence, according to the optimization problem the run time of GA will be several minutes/hours. [17].

Ant Colony (AC) is a powerful optimization algorithm which mimics on the behavior of the artificial ants which is inspired from real ants [5]. This meta-heuristic technique works concurrently and independently and collective interaction through indirect communication leads to good solutions. The avid heuristic helps find appropriate solution in the soon solution in the soon steps of the search procedure [6]. However, this algorithm has some backwashes in literature as slow speed of convergence than other heuristics and no centralized processor to guide the algorithm towards good solutions.

Consequently, this paper presents Firefly Algorithm (FA) to re-dispatched system with congestion management to minimize cost, congestion lines for overload condition and satisfied production constraints and generator loads. The yield of the proposed technique is tested over two case studies as 30 and 118 buses standard power systems in comparison with CPSO, PSOTVIW, PSOIVAC and ABC [22-23]. The achieved numerical results show the inflection and robustness of the proposed technique against compared techniques.

2. Congestion Management Formulation

The optimal congestion management minimizing re-dispatch cost can be expressed as [6].

$$Min \sum_{g=1}^{Ng} Ic_g\,(\Delta P_g)\Delta P_g$$

IC_g and ΔP_g are incremental, decremental cost respectively and active power adjustment is of generator g, respectively. N_g is Number of participating generators. Subject to:

- Power balance constraint:

$$\sum_{g=1}^{Ng} (GS_g^{ij}.\Delta P_g) + F_l^0 \le F_l^{\max}$$

- Operating limit constraints:

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max};\, g = 1,2,...,Ng$$

$$\Delta P_g^{\min} = P_g^{\min} - P_g;\Delta P_g^{\min} = P_g^{\min} - P_g$$

- Line flow constraints:

$$\sum_{g=1}^{Ng} (GS_g^{ij}.\Delta P_g) + F_l^0 \le F_l^{\max}$$

3. Selecting Re-dispatched Generators

The Generator Sensitivity (GS) technique presents the change of active power flow according to change in active power generation. This value of generator g on the line connected amongst buses i and j can be defined as [4-8].

$$GS_g^{ij} = \frac{\Delta P_{ij}}{\Delta P_{Gg}} = \frac{\partial P_{ij}}{\partial \theta_i}.\frac{\partial \theta_i}{\partial P_{Gg}} + \frac{\partial P_{ji}}{\partial \theta_j}.\frac{\partial \theta_j}{\partial P_{Gg}}$$

The power flow equation on congested lines can be formulated as:

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_iV_j.G_{ij}.\sin(\theta_i - \theta_j) + V_iV_j.B_{ij}.\sin(\theta_j - \theta_i)$$

$$\frac{\partial P_{ij}}{\partial \theta_i} = +V_iV_j.G_{ij}.\sin(\theta_i - \theta_j) - V_iV_j.B_{ij}.\sin(\theta_j - \theta_i) = -\frac{\partial P_{ij}}{\partial \theta_i}$$

The relevancy between the change in active power at each bus and voltage phase angles can be described in literature as:

$$[\Delta P]_{n\times 1} = [\mathrm{H}]_{n\times n} \times [\Delta\theta]_{n\times 1}$$

Bus 1 is the slack bus, the first row and first column of [M] can be eliminated. Therefore, the modified [M] is written as:

$$[\Delta\theta]_{n\times 1} = \begin{bmatrix} 0 & 0 \\ 0 & [\mathrm{M}-1] \end{bmatrix}_{n\times n} \times [\Delta P]_{n\times 1}$$

The [M] is described as; Where, $[M]=[H]^{-1}$ and $[\Delta\theta]_{m\times 1}=[M]_{m\times n}[\Delta P]_{m\times 1}$.

$$[\mathrm{H}]_{n\times n} = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_1} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ \vdots & \vdots & & \vdots \\ \frac{\partial P_n}{\partial \theta_1} & \frac{\partial P_n}{\partial \theta_2} & \cdots & \frac{\partial P_n}{\partial \theta_n} \end{bmatrix}_{n\times n}$$

The modified [M] represents the values of $\frac{\partial\theta_i}{\partial P_{Gq}}$ and $\frac{\partial\theta_j}{\partial P_{Gq}}$ in [23] to calculate GS values. Large GS generators will be selected for re-dispatched since they are more influential on the congested line.

4. Firefly Algorithm

The Firefly Algorithm (FA) is a new meta-heuristic, nature-inspired, optimization algorithm which is based on the social (flashing) behavior of fireflies in the summer. This technique is introduced by Xin-She Yang [24]. Although FA has many similarities with other methods which are based on the so-called swarm intelligence; it is indeed very simpler both in significance and performance [24–26]. Also this algorithm is very impressive and can outperform other classical algorithms, for solving many optimization problems; where the actuarial performance of the firefly algorithm was measured versus other well-known optimization algorithms using several standard stochastic test functions [24]. For simplicity, we can epitomize these flashing specifications as the following three rules:

- All fireflies are unisex; afterwards that one firefly is possessed to other fireflies irrespective of their sex.
- Neighborliness is commensurate to their brightness, thus for each two flashing fireflies, the less bright one will motion to the brighter one. The attractiveness is commensurate to the brightness and they both decline as their distance increases. If no firefly is brighter than a specific one, it moves randomly.
- The brightness of a firefly is affected or specified by the landscape of the object function to be optimized [24-27].

A. Attractiveness

The form of neighborliness function of a firefly is the following uniform subtractive function [24]:

$$(\beta_r) = \beta_0^{*} \exp(-\gamma r^m), \text{ with } m \geq 1,$$

Where, r is the space between any two fireflies, β_0 is the primary attractiveness at $r = 0$.

γ, is an attraction factor which controls the reduction of the light intensity.

B. Distance

The space among each two fireflies i and j, at positions x_i and x_j , respectively, can be described as [24]:

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2}$$

Where $x_{i,k}$ is the k_{th} ingredient of the spatial peculiarities x_i of the i_{th} firefly and d is the number of dimensions.

However, the computation of distance r can also be explained by other distance metrics, based on the character of the problem [24].

C. Movement

The motion of a firefly i which is engrossed by a more attractive firefly j is given by the following equation:

$$x_i = x_j + \beta_0 * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \alpha * (rand - \frac{1}{2})$$

Where, the first period is the current location of a firefly, the secondary period is used for considering a firefly's attractiveness to light severity seen by adjoining fireflies, and the third period is used for the random motion of a firefly in case there are not any brighter ones. The coefficient α is a stochastic parameter which is described by the problem of fondness, while rand is a random number generator uniformly divided in the space [0, 1].

D. Convergence and Asymptotic Behavior

The convergence of the proposed new meta-heuristic technique is got for any large number of fireflies (n) if n >> m, where m is the number of local optima of an optimization problem. The convergence of the algorithm into all the local and global optima is achieved, as the iterations of the algorithm continue, by comparing the best solutions of each iteration with these optima. However, it is under research a formal proof of the convergence of the algorithm and particularly that the algorithm will approach global optima when n → ∞and t >>1. In practice, the algorithm converges very quickly in less than 80 iterations and less than 50 fireflies, as it is demonstrated in several research papers using some standard test functions [24-26]. Indeed, the appropriate choice of the number of iterations together with the γ, β, α, and n parameters highly depends on the nature of the given optimization problem as this affects the convergence of the algorithm and the efficient find of both local and global optima. Note that the firefly algorithm has computational complexity of $O(n^2)$, where n is the population of fireflies.

5. Numerical Results

E. IEEE 30-bus system

Results of proposed FA technique are compared with CPSO [23], PSO-TVAC [23], PSO-TVIW [23] and ABC [22]. The first case study for this paper is IEEE 30-bus power system with six generators and forty one lines [23] which the bus 1 is considered as the reference bus/slack. A congested line between buses 1 and 2 exists as shown in Table 1. And Table 2 shows the GS values considering for re-dispatched of 6 generation units.

TABLE I. A CONGESTED LINE ON THE IEEE 30-BUS SYSTEM

Congested line	Active power flow (MW)	Line limit (MVA)	Overload (MW)
1 to 2	170	130	40

TABLE II. GENERATION SENSITIVITY OF 6 UNITS ON THE IEEE 30-BUS SYSTEM

Gen no	1	3	5	8	11	13
GS 1_2	0	-0.8908	-0.8527	-0.7394	-0.7258	-0.6869

The GS values of all six generators in the IEEE 30-bus system are high therefore it is needed to use all generators for re-dispatch to relieve the congested line. To achieve this goal, selected group of generators having the largest GS values may be used to save the computational effort. Comparison of FA technique with other techniques ate presented in Table III. The GS values and generation re-dispatch on the IEEE 30-bus system have been shown in Fig. 1. According to the achieved numerical results, it is obvious that the proposed technique calculate 224.6952 $ for minimum re-dispatch cost solution which is lower than other compared techniques. The convergence of the proposed technique over first case study is presented in Fig. 2.

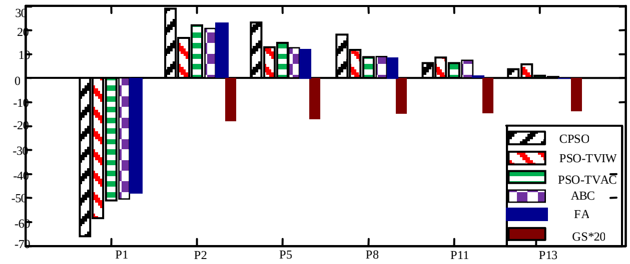

Figure 1. **GS values and generation redispatch on the IEEE 30-bus system.**

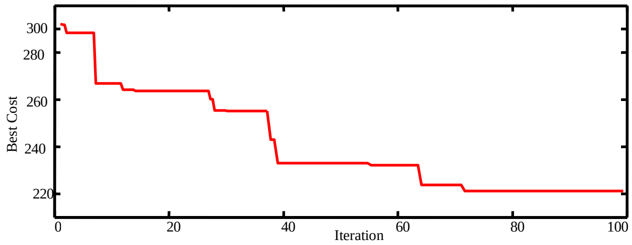

Figure 2. **Convergence characteristics of FA schemes on the IEEE 30-bus system.**

TABLE III. COMPARISON OF IGSA SOLUTIONS ON THE IEEE 30-BUS SYSTEM

Algorithm	MW	ΔP_1	ΔP_2	ΔP_5	ΔP_8	ΔP_{11}	ΔP_{13}	Total ΔP	Cost ($ /h)
CPSO	Max	-66.1	28.9	23.3	18.1	6.2	3.7	146.3	403.1
	Min	-47.9	18.6	16.5	11.3	2.8	0.1	97.2	240.3
	Mean	-55.9	22.6	16.2	10.5	5.6	2.6	113.2	287.1
	SD	8.3	7.6	3.5	3.3	3.2	3.3	15.9	48.2
PSO-TVIW	Max	-58.5	16.7	13.0	11.8	8.6	5.7	114.2	288.0
	Min	-47.3	20.1	14.5	10.5	4.8	0.5	97.7	239.2
	Mean	-50.1	18.9	13.2	9.2	5.9	4.1	101.4	253.1
	SD	2.8	3.5	5.4	3.3	3.5	6.1	13.3	3.8
PSO-TVAC	Max	-51.1	22.0	14.7	8.8	6.2	1.0	103.8	254.9
	Min	-47.3	25.1	16.0	7.6	0.6	0.0	96.7	237.9
	Mean	-49.3	17.5	14.0	9.9	6.8	3.0	100.5	247.5
	SD	0.8	2.1	2.1	2.2	2.3	2.4	4.6	1.6
ABC	Max	-50.5	20.8	12.7	9.0	7.5	0.5	101.0	250.1
	Min	-46.1	20.4	15.2	7.4	2.9	0.2	92.2	232.4
	Mean	-50.2	19.3	16.3	9.0	3.5	2.1	100.4	244.2
	SD	0.76	2.1	2.08	2.03	2.1	2.0	4.26	1.44
FA	Max	-48.421	22.727	18.455	6.757	1.35	0.33	98.0176	245.7787
	Min	-46.634	27.127	10.330	8.733	1.02	0.21	94.0720	224.6952
	Mean	-47.426	26.445	13.232	7.343	1.03	0.24	95.6783	230.8376
	SD	0.721	1.975	1.983	1.976	2.00	2.03	2.065	1.320

6. IEEE 118-bus system

For second case study the system configuration of the IEEE 118-bus system with 54 generators and 186 lines [22] is used which the bus 1 is assigned as the reference bus. The congested line data is shown in Table 4. Also Fig. 3, shows the GS values. Accordingly, the generator buses 85, 87, 89, 90, and 91 which are among the largest magnitude of GS, considered as re-dispatched generators. Also the results of GS values of 54 generators are presented in Table. 5.

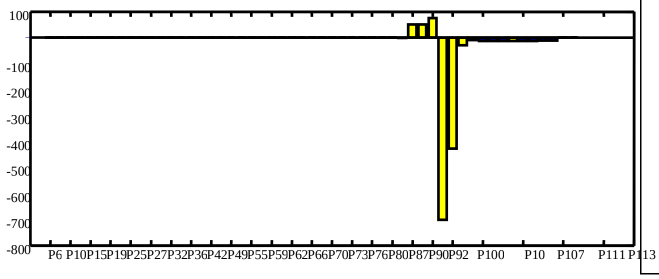

Figure 3. GS values of 54 units on the IEEE 118-bus system.

TABLE IV. A CONGESTED LINE ON THE IEEE 118-BUS SYSTEM.

Congested line	Active power flow (MW)	Line limit (MVA)	Overload (MW)
89 to 90	260	200	60

The comparisons of proposed FA technique for second case study with other techniques are presented in Table VI. This is clear that, the proposed FA provide minimum redispatch cost solution of $ 819.724. Actually, the GS at bus 85, 87, and 89 are positive, and the generation output at these buses is reduced. Against, the generators at bus 90 and 91 have negative GS values, thus the generation is increased. For the relationship of the GS values, Fig. 4 is presented. And the convergence characteristic of FA over the IEEE 118-bus system is presented in Fig. 5.

As the GS at bus 85, 87, and 89 are positive, the generation output at these buses is reduced. By contrast, the generators at bus 90 and 91 have negative GS values, thus the generation is increased. Moreover, the GS magnitude affects the amount of active power adjustment. The reference bus is used to maintain the power balance.

Accordant to the achieved numerical results, it should be mentioned that the proposed technique is premier and dominant than the other techniques in optimization problem of congestion management in electricity market regarding to distribution network constraints to decrease cost and enhancement yield and security of power system distribution network.

TABLE V. GS VALUES OF 54 GENERATORS ON THE IEEE 118-BUS SYSTEM

Gen no.	GS (10^-3)	Gen no.	GS (10^-3)	Gen no.	GS (10^-3)
1	0	42	-0.0375	80	-0.9250
4	-0.0005	46	-0.0242	85	50.068
6	-0.0001	49	-0.0460	87	50.654
8	-0.0014	54	-0.0838	89	74.455
10	-0.0014	55	-0.0871	90	-701.15
12	0.0004	56	-0.0854	91	-427.90
15	0.0021	59	-0.1100	92	-28.411
18	0.0051	61	-0.1160	99	-9.391
19	0.0046	62	-0.1130	100	-12.915
24	0.1350	65	-0.1350	103	-12.737
25	0.0484	66	-0.0983	104	-12.854
26	0.0337	69	0.2120	105	-12.772
27	0.0451	70	0.3690	107	-12.202
31	0.0339	72	0.2326	110	-12.274
32	0.0477	73	0.3400	111	-12.07
34	-0.0323	74	0.5410	112	-11.747
36	-0.0329	76	0.8650	113	0.0110
40	-0.0343	77	0.0012	116	-0.1750

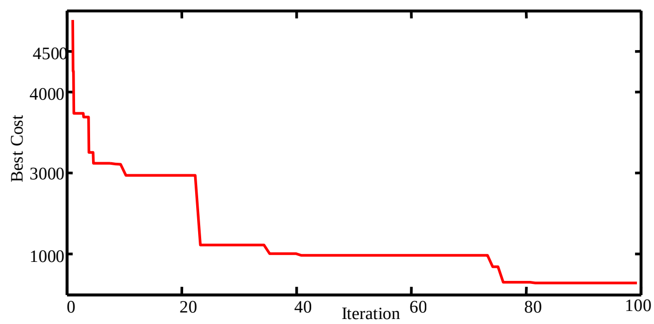

Figure 4. Convergence characteristics of SPGSA schemes on the IEEE 118-bus system.

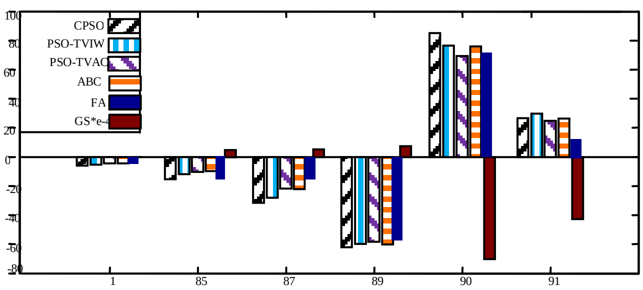

Figure 5. GS values and power re-dispatch on the IEEE 118-bus system.

TABLE VI. COMPARISON OF SPGSA SOLUTIONS ON THE IEEE 118-BUS SYSTEM

Algorithm	MW	ΔP_1	ΔP_2	ΔP_5	ΔP_8	ΔP_{11}	ΔP_{13}	Total ΔP	Cost ($ /h)
CPSO	Max	-5.1	-6.4	-8.6	-122.9	117.8	18.9	279.8	1604.5
	Min	-5.1	-27.3	-27.5	-28.9	68.1	25.9	182.7	875.0
	Mean	-5.9	-15.3	-31.5	-62.0	85.1	26.8	226.6	1183.8
	SD	4.4	8.4	11.4	17.5	23.2	14.6	30.5	196.4

Algorithm	MW	ΔP_1	ΔP_2	ΔP_5	ΔP_8	ΔP_{11}	ΔP_{13}	Total ΔP	Cost ($ /h)
PSO-TVIW	Max	-2.7	-13.8	-23.4	-97.7	121.4	10.4	269.4	1497.8
	Min	-6.8	-18.2	-28.2	-33.1	78.3	8.9	173.5	853.8
	Mean	-5.5	-12.1	-28.2	-59.8	76.4	29.8	211.7	1088.4
	SD	4.3	6.7	10.7	16.9	21.1	13.5	26.3	165.8
PSO-TVAC	Max	-5.9	-6.2	-6.5	-96.2	80.1	30.5	225.5	1229.6
	Min	-0.8	-12.1	-13.9	-52.3	81.6	3.3	163.8	829.5
	Mean	-4.4	-10.3	-22.0	-58.5	69.4	24.7	189.3	970.7
	SD	2.9	5.0	10.0	15.1	9.8	16.1	16.5	94.5
ABC	Max	-5.2	-6.0	-6.9	-96.0	83.9	31.2	227.2	1218.99
	Min	-0.73	-11.7	-14.0	-50.4	85.6	3.0	165.43	820.1
	Mean	-4.6	-9.8	-22.2	-60.1	75.9	26.2	198.8	968.5
	SD	2.78	4.9	9.2	15.03	9.65	16	16.32	94.36
FA	Max	-48.013	-2.959	-38.65	-2.166	79.581	12.812	184.175	906.429
	Min	-2.153	-14.34	-11.34	-52.12	75.540	5.422	160.961	819.724
	Mean	-3.532	-15.34	-15.46	-50.13	79.640	5.874	169.964	861.407
	SD	2.734	4.728	9.827	14.25	8.716	15.26	15.775	23.191

7. Conclusion

The operational aspects of power systems condition some of the most challenging problems encountered in the restructuring of the electric power industry. In this paper, the Firefly Algorithm (FA) is applied to re-dispatched system with congestion management to minimize cost, congestion lines for overload condition and satisfied production constraints and generator loads. The Firefly Algorithm (FA) is a meta-heuristic, nature-inspired, optimization algorithm which is based on the social (flashing) treatment of fireflies, or lighting bugs, in the summer. Its main preference is the fact that it uses mainly actual random numbers, and it is based on the global communication between the swarming particles, and as a result, it seems more effective in optimization of congestion management problem. Purposed algorithm had an appropriate convergence rate compared with other techniques. The proposed technique convergence rate is really less than in comparison with CPSO, PSOTVIW, PSOTVAC and ABC in solving complex mathematical problems. The efficacy of the proposed technique is applied over two case studies of 30 and 118 buses power system. The approach is validated through numerical results and demonstrates that it has better ability in finding optimal answers and possibility of particle placed in local zone.

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