OVERLOAD ALLEVIATION AND PERFORMANCE ENHANCEMENT OF POWER SYSTEM USING FIREFLY OPTIMIZATION ALGORITHM INVOLVING DISTRIBUTED GENERATORS

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Abstract—*The advent of restructuring in electricity markets and increasing load demands have considerable impact on the loading pattern of the transmission system. This would cause congestion in transmission line which would further lead to instability of the system, resulting in a poor voltage profile. This paper proposes an efficient method for transmission line overload alleviation and enhancement of system performance with the integration of Distributed Generators (DGs). For secure operation of power system, it is essential to maintain the network loading within specified limits to avoid the system from collapsing due to cascading outages. An analytical approach to recognize the ideal location and size of DGs using Firefly Algorithm (FA) is presented in this paper. The optimization process is executed by changing the load randomly from the base case. Maximum Power Stability Index (MPSI) is employed as the objective function to identify the optimal DG location. Then, a Firefly based model with randomized load is evolved to optimize the DG sizing in view of minimizing systems' real power losses. The improvement is measured in terms of voltage profile, congestion relief and available transfer capability using IEEE 30 - bus and IEEE 118 - bus test system. The results of the proposed method are compared with similar methods from the literature.*

Keywords: *Congestion management; Distributed Generator (DG); Firefly algorithm(FA); Maximum Power Stability Index (MPSI)*

1. Introduction

Most of the intricacies of power system ascend from the inherent variability of the load demand of the users. This has led to a more intensified problem of overloading of transmission lines. If not alleviated this would further lead to instability of the power system. Untreated big and feeble networks with frequent voltage variations are certainly liable to voltage collapse. Thus, congestion management in power systems is pertinent and of vital importance to the power industry.

Numerous techniques for congestion management have been reported in the literature. An extensive and critical analysis on the topic of congestion management in power system has been presented in [1-2]. The review initially emphases on the conventional approaches of congestion management.

Necessary discussions are made under each topic. It is also established that optimization tools play a very vital role in relieving congestion. Among the various methods available, one of the renowned methods to avoid congestion of transmission lines is generator rescheduling. An enormous number of contributions are found in the literature. Techniques for optimal selection of generators for congestion management based on their sensitivities to the power flow in congested line is demonstrated in [3,4]. Particle Swarm Optimization (PSO) has been used in the former to minimize the deviations of rescheduled values of generator power outputs from scheduled levels while Cuckoo search algorithm (CSA) is used to minimize the rescheduling cost in the latter. Also, in [5] the concept of Relative Electrical Distance RED) to determine the desired proportions of generation for the desired overload relieving is obtained. An Optimal dispatch considering dynamic security constraints is presented in [6]. Optimal dispatch model to handle congestion for the possible contracts is presented in [7]. There are also several publications available that describes direct methods for line overload alleviation using generation rescheduling and load shedding [8-10].

In addition the FACTS controllers play a vital role in mitigating transmission line congestion in deregulated power market. FACTS devices and their associated benefits for efficient operation of power markets are addressed in a significant volume of technical literature

[11-14]. The promotion of distributed generator resources in power system offers benefits, such as reduction in power loss and improvement in voltage profile. The utilization of DG can serve as a hedge against transmission and distribution expansion costs. Two major facets, viz. location and size of DG require careful attention. The optimum location and size of DG units is determined using multi objective performance index (MOPI) for improving the voltage stability of the radial distribution system [15]. The various technical matters are combined using weighting coefficients and resolved under various operating limitations using a Chaotic Artificial Bee Colony (CABC) algorithm. The performance of the recommended algorithm is validated by experimenting it in 38 and 69 node radial distribution systems.

Taking into account the time sequence characteristics of the load and distributed generator (DG) output, a unique method is offered for optimal placement and sizing of DG in distributed systems [16]. Multi-objective functions have been devised with the consideration of minimum expenditure of DG, minimum electricity procurement cost from the main grid and minimum voltage violation. To solve the multi-objective optimization problem, an improved Non–dominated Sorting Genetic Algorithm II has been suggested. Tests have been performed on the modified PG & E 69 bus and multiple actual test cases with the consideration of multiple DGs.

A new long term scheduling for optimal sitting and sizing of various types of DG units in the distribution system in order to curtail the power loss is proposed [17]. The optimization process is executed by continuously varying the demand on the system in the planning time horizon. In each load step, the optimum size and position of different types of DG units are estimated. The proposed method is realized in IEEE 33 bus test system by both analytical method and particle swarm optimization (PSO) algorithm.

The issue of multi-objective optimal allocation and sizing of DG units in the distribution system are solved using an interactive fuzzy satisfying technique, which is based on hybrid modified shuffled frog leaping algorithm [18]. Curtailing total electrical energy loss, total electrical energy cost and total pollutant emissions produced are the objective functions in this problem. The multi-objective problem is converted into a min-max problem, which is then handled by evolutionary algorithms. Ultimately, the algorithm is tested on a 69 bus distribution test system in view of technical, economic and environmental protection.

A sensitivity method for assigning DGs taking into account congestion relief and voltage security concurrently is presented in [19]. The sensitivities of the overloaded lines with regard to bus injections are considered for grading the load buses. The generating capacities for DGs connected at these load buses are then determined by genetic algorithm (GA) with an intention of improving the system performance.

In [20], a new combined genetic algorithm (GA) / particle swarm optimization (PSO) is proposed for optimal allocation and size of DG on distribution systems. The objective is to minimize network power losses, enhance voltage regulation and voltage stability within the framework of system operation and security constraints in radial distribution systems. An exhaustive performance analysis is carried out on 33 and 69 bus systems to validate the effectiveness of the proposed approach.

The literature discussed so far indicates the availability of various techniques to improve the network security by relieving congestion. It is also seen that in the last two decades, more than a dozen new algorithms appeared and they have shown great potential in obtaining solution for complex engineering optimization problems. But not much contribution is done on implementing Firefly algorithm to solve the congestion management problem. Among the new algorithms, it has been shown that firefly algorithm is very efficient in dealing with multimodal, global optimization problems [21]. Hence, in this paper an attempt is made to apply Firefly algorithm to alleviate congestion on transmission line due to random load variation. The rest of this manuscript is organized as follows: The determination of MPSI index is presented in Section 2. The proposed DG placement and sizing algorithm are elaborated in Section 3. Section 4 presents the impact analysis of available transfer capability in the electricity market. Section 5 discusses the results obtained with IEEE 30 and 118 bus systems. In Section 6 the significance of the work done is exemplified.

2. Maximum Power Stability Index

The continuous increment of load demand has a substantial impact on the voltage drop in power system. This is tested by progressively increasing the load above the base case from 0% to 25% until the voltage drops below the minimum limit. In this condition, the voltage at the bus collapses resulting in divergence of load flow solution such as Newton-Raphson method. The critical bus in the system is investigated with respect to load increasing contingency. In this paper MPSI is used as a

Voltage Collapse Indicator. MPSI is based on Maximum Power Transfer Theorem. For an AC circuit, Maximum Power Transfer condition can be met when load impedance Z_L is equal to the source or Thevenin's impedance Z_{th}. For an AC circuit, Thevenin's impedance Z_{th} can be written as, $Z_{th} = R_{th} + jX_{th}$. The formula for the proposed voltage stability Index is given below,

$$MPSI = \frac{4V_L^2}{\left[\frac{\sum_{i=1, i\neq j}^{n} Y_{ji} V_i}{(Y_{jj})^2}\right]} \qquad (1)$$

Where,

V_L Load voltage.

Y_{ji} Admittance between the nodes *j* and *i*.

V_i Voltage at the node *i*.

Y_{jj} Self admittance of node *j*.

Any value closer to zero indicates the stable operating condition in contrary to the value closer to 1 denotes critical operating conditions. Among the other voltage stability Indices such as Voltage Collapse Prediction Index (VCPI) and Power Transfer Stability Index (PTSI), MPSI shows better proximity of voltage collapse [22]. The PTSI is devised based on derivative of maximum load apparent power with respect to load impedance change while VCPI is devised based on determinant evaluation of partial derivative matrix in Newton Raphson power flow.

In this paper, MPSI changes with the increasing load. Bus position corresponding to a maximum value of MPSI is considered to be the weak bus and the optimal location for DG placement.

3. Proposed DG Placement and Sizing Algorithm

3.1 Firefly Algorithm

The Firefly Algorithm is a metaheuristic algorithm, inspired by the flashing behavior of fireflies [21].The firefly's flash acts as a signal system to attract other fireflies. Xin-She Yang framed the Firefly algorithm by assuming:

- All fireflies are unisexual, so that any individual firefly will be attracted to all other fireflies.
- Attractiveness is proportional to their brightness, and for any two fireflies, the less bright one will be attracted by the brighter one; however, the intensity decrease as their mutual distance increases. If there are no fireflies brighter than a given firefly, it will move randomly.
- The brightness should be associated with the objective function.

The parameters considered here are,

1) Attractiveness of firefly given by,

$$\beta(r) = \beta_0 * \exp\left(-\gamma r_{ij}^{\,2}\right) \qquad (2)$$

Where,

r Distance between any 2 fireflies

γ Absorption Coefficient

β_0 Initial Attractiveness

2) Randomization parameter varies from [0,1] for the current iteration,

$$\alpha(iter) = \alpha_{max} - \frac{(\alpha_{max} - \alpha_{min}) * iter}{iter_{max}} \qquad (3)$$

3) Movement of a firefly *i* attracted to another more attractive (brighter) firefly *j* is determined by

$$x_j = x_i + \beta_0 \exp\left(-\gamma r_{ij}^{\,2}\right) * \left(x_j - x_i\right) + \alpha * \left(rand - \frac{1}{x}\right) \qquad (4)$$

where the second term is due to the attraction while the third term is randomization with α being the randomization parameter.

The pseudo code of the algorithm is summarized as:

Objective function $f(x)$, $x = (x1, x2 \ldots, xd)^T$

Generate an initial population of fireflies x_i $(i = 1, 2,..n)$

Light intensity I_i at x_i is determined by $f(x_i)$

Define light absorption coefficient γ

While (t < max generation)

for *i=1:n* (all *n* fireflies)

for *j=1:n* (all n fireflies)

if (I_i <. I_j)

Move firefly *i* towards *j*

end if

Attractiveness varies with distance *r* via exp $[-\gamma r^2]$

Evaluate new solutions and update light intensity

end for *j*

end for *i*

Rank the fireflies and find the current best

End while

Post process results and visualization

3.2. Optimal DG placement

The problem of DG placement is a nonlinear constrained optimization problem. According to the proposed algorithm a set of loading cases is generated randomly as the major concern in voltage stability estimation is to evaluate the bus voltage when the load increases. A load flow is run for each loading case and the MPSI index for each load bus is calculated to identify the weak bus. The best firefly with higher value of MPSI epitomizes the optimal DG location. The index maximization is formulated as:

$$G = Max\big(MPSI(i)\big)\ for\ i = 1; 2\ .\ .\ .n; \tag{5}$$

Where,

n is the number of load buses

Subject to

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{6}$$

3.3. Optimal DG sizing

Firefly based optimization technique deduces the optimal value of the DG capacity to be connected with the existing system for maximizing the system performance by reducing the real power losses, increasing the voltage profile and relieving congestion. The size of load delivery area influences the selection of the capacity of DG. There is a direct connection between total power loss and total demand. Hence, the size of the DG is a function of power loss[22]. When the power loss of the system reaches minimum value, the optimal capacity of the DG is obtained. If the power injected by the DG is further increased, minimized loss value is exceeded and power loss starts to increase. This is due to the fact that excessive current from DG flows into adjacent buses and increases the transmission line losses.

The mathematical formulation for loss minimization is given by,

$$F(x) = Min \sum P_{loss}(x) \tag{7}$$

Subject to,

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{8}$$

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \tag{9}$$

$$S_{ij} \leq S_{ij}^{max} \tag{10}$$

4. Impact Analysis on Available Transfer Capability in Electricity Market

With the increasing of load demand scenario, the DGs are expected to play a vital role in a deregulated electricity market. Such a scenario will necessitate the exploration of the impact of DG on electricity market such as available transfer capability (*ATC*).

According to the North American Electric Reliability Council (NERC) report, *ATC* is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed users. The term capability refers to the ability of the lines to reliably transfer power from one bus / area to another. *ATC* between two areas gives the upper limit of additional power flow between them for the specified time period under given conditions [23].

Mathematically, ATC is defined as,

$$ATC = TTC - TRM - (CBM + ETC) \tag{11}$$

Where,

TTC Total Transfer Capability

TRM Transmission Reliability Margin

CBM Capacity Benefit Margin

ETC Existing Transfer Commitments

Among the available methods used for *ATC* calculation, such as AC Power Transfer Distribution Factor method, Optimal Power Flow method and Continuation Power Flow method, this work uses AC Power Transfer Distribution Method (ACPTDF) as it is more accurate.

4.1 AC PTDF method

AC based approach utilizes sensitivity factor based approach termed as Real Power Transfer Distribution Factor (ACPTDF) [12]. Consider a transaction Pmn between a seller bus *m* and buyer bus *n*. Further, consider a line l carrying a part of the transaction power. Let the line be connected between buses *i* and *j*. For a change in the real power transaction between the above seller and buyer by ΔP_{mn}, if the change in transmission line quantity P_{ij} is ΔP_{ij}, the ACPTDF can be defined as,

$$ACPTDF_{ij,mn} = \frac{\Delta P_{ij}}{\Delta P_{mn}} \tag{12}$$

Where,

ΔP_{ij} Change in real power flow in the line between buses *i* and *j*

ΔP_{mn} Change in real power transaction between a seller bus *m* and buyer bus *n*

4.1.1 ATC calculation using ACPTDF

ATC determination for intact system methodology remains same for calculation of ATC. Real power flows in base case obtained from N-R approach and line limits are utilized for ATC determination. Now real power flow through any line connected between buses *i* and *j* for any transaction between seller bus *m* and buyer bus *n* can be obtained as,

$$P_{ij,mn} = \begin{cases} \dfrac{P_{ij}^{max} - P_{ij}^{0}}{ACPTDF_{ij,mn}} \; ; \; ACPTDF_{ij,mn} > 0 \\ \infty ; ACPTDF_{ij,mn} = 0 \\ \dfrac{-P_{ij}^{max} - P_{ij}^{0}}{ACPTDF_{ij,mn}} \; ; ACPTDF_{ij,mn} < 0 \end{cases} \quad (13)$$

Where,

$P_{ij,mn}$ Real power flow through line between buses *i* and *j*

$P_{ij}^{\max}$ Thermal limit of line between buses *i* and *j*

P_{ij}^{0} Base case power flow in the line between buses *i* and *j*

For the given transaction ATC can be defined as,

$$ATC_{mn} = \min\{P_{ij,mn}\}, ij \in N_L \quad (14)$$

Where,

N_L Total number of lines

5. Results and Discussion

The effectiveness of the proposed methodology is verified on IEEE 30 -bus and IEEE 118 –bus test systems. The simulation is carried out using MATLAB R2010a on Intel core i3, 4GB RAM i3 processor. The objective of this simulation is to determine the optimum location and size of DGs to minimize the real power loss, relieve congestion and improve the voltage profile for increased load demand scenario. The impact of integration of DGs is also analyzed in terms of the *ATC*.

5.1 Case 1: IEEE 30 –bus system

The IEEE 30-bus system comprises of 6 generator buses, 24 load buses and 41 transmission lines as shown in the Fig. 1 [24]. The total system load is 283.4MW.

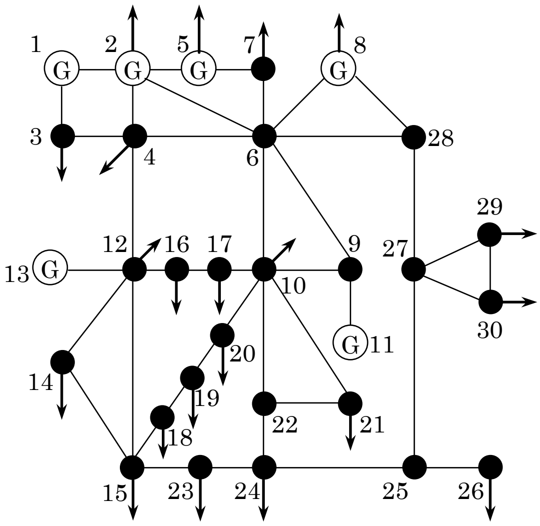

Fig. 1.Single line diagram of IEEE 30 bus system

5.1.1 Optimal location of DG using Firefly Algorithm

The increasing load demand scenario is simulated by varying the system load randomly from 0% to 25% above the base case. It is known that load variation results in a poor voltage profile. In order to improve the voltage profile the optimal location of DG is determined using Firefly algorithm. The Firefly parameters have great influence on the convergence of the algorithm. Hence, the algorithm is run for various values and the parameters finally selected for which consistent and superior results were found are shown in Table 1.

Table 1. Control Parameters

Parameters	Values
Number of fireflies	50
Number of iterations	100
α_{min}	0
α_{max}	1
γ	5
β_0	1

The algorithm discussed in section 3.2 identifies the bus with the highest value of MPSI which undergoes severe voltage collapse and affects the stability of the system. Then, it is declared as the optimal location for DG placement. The MPSI values for the ten weakest buses are listed in descending order in Table 2.

Table 2. Ranking of buses based on MPSI value for IEEE 30-bus system

Bus No.	MPSI value
30	0.3187
26	0.2531
29	0.1746
28	0.1719
24	0.1534
14	0.1456
17	0.1399
19	0.1311
23	0.1306
15	0.1283

The maximum value of MPSI obtained for the increased load demand scenario of the test system considered above, is 0.3187 corresponding to bus 30. Hence bus 30 is considered to be the optimal location for DG placement.

5.1.2 Optimal sizing of DG using Firefly Algorithm

In order to investigate the influence of optimal DG sizing on the test system considered, an analytical test showing the variation of active power loss corresponding to DG injection at the identified weak bus is carried out. The analysis is done on two different cases viz. single and double DG placement. It is evident from Table 2 that the buses 30 and 26 with greater MPSI values are the appropriate locations for the DGs. The optimal DG size to be placed at these buses are calculated for the increase in demand from 283.4 MW to 307.8 MW. This random increase in demand causes an escalation in real power loss of the system by 26% and overloads the line connected between buses 1 and 2 by 15%. Hence, the firefly algorithm adjusts the appropriate DG size by lessening the active power loss in the system while relieving congestion. Table 3 compares the real power loss in the system and the real power flow in the congested line for different conditions.

Table 3. Optimal results with DGs in IEEE 30 bus system

Case	DG location	Optimal size of DG (MW)	Real power loss (MW)	Power loss reduction (%)	Power flow in the congested line (MW)	Line limit
Base case	NA	NA	10.52	NA	128.7	130
Increased demand case	NA	NA	13.29	NA	148.2	
1 DG Unit	30	31.8469	10.54	20.69	125.3	
2 DG Units	30 26	16.9512 16.5529	10.06	24.30	128.6	

Table 3 reveals that, with the increase in injection of active power from the DGs at the identified potential locations, the reduction of real power loss also increases. After placing the DGs in the selected locations, it is evident that the congestion in the line is completely alleviated and the voltage profile at the weaker buses is improved as depicted in Fig. 2.

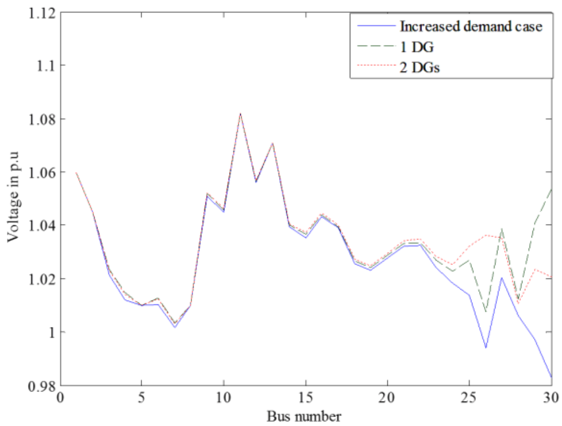

Fig 2.Voltage profile for different cases in IEEE 30 bus system

5.2. Case 2: IEEE 118- bus system

The IEEE 118-bus system comprises of 54 generator buses, 64 load buses, 186 transmission lines and a total load of 4242 MW [24].The line rating of transmission line alone is modified as in [25].

5.2.1 Optimal Location of DG using Firefly Algorithm

The proposed algorithm for identifying the optimal location for the placement of DGs is applied on IEEE 118-

bus system. Increasing the load randomly from 0% to 25% above the base case results in a voltage drop in some of the load buses. The MPSI values for the ten weakest buses are listed in descending order in Table 4.

Table 4. Ranking of buses based on MPSI value for IEEE 118 - bus system

Bus No.	MPSI value
38	0.4047
81	0.2747
117	0.2544
63	0.2496
45	0.2492
95	0.2046
101	0.2045
13	0.2035
106	0.2023
30	0.2003

It is observed that the optimum location for the placement of single DG is 38 with a maximum MPSI value of 0.4047.

5.2.2 Optimal sizing of DG using Firefly Algorithm

The optimization problem is solved using Firefly algorithm to obtain the minimum real power loss while satisfying the voltage and transmission line constraints when the system demand increases from 4242MW to 4825MW. Since the test system is large, the effect of integration of up to five DGs is analyzed. The buses 38, 81, 117, 63 and 45 are identified as the potential buses for the location of DGs. These are the buses corresponding to the maximum MPSI value as mentioned in Table 4. Every time the number of DG is increased, the algorithm is repeated to search for the optimal capacity of DGs. Taking into account the size of the system, the performance is investigated with the limit on DG capacity set up to 100 MW and 200MW respectively. The results are presented in Tables 5 and 6.

Table 5 Optimal results with DGs in IEEE 118 - bus system with DG_{max} = 100 MW

Case	DG location	Optimal size of DG (MW)	Real power loss (MW)	Power loss reduction (%)	Power flow in the congested line (MW)	Line limit (MW)
Base Case	NA	NA	77	NA	73.93	175
Increased demand case	NA	NA	146.86	NA	177.26	
1 DG Unit	38	99.93	134.13	8.67	166.09	
2 DG Units	38 81	99.59 99.78	130.44	11.18	146.39	
3 DG Units	38 81 117	99.39 99.76 98.79	120.56	17.91	135.81	
4 DG Units	38 81 117 63	99.50 97.18 99.34 99.57	114.62	21.95	125.79	
5 DG Units	38 81 117 63 45	99.96 86.85 94.97 99.24 99.88	105.97	27.85	119.45	

Table 6.Optimal results with DGsin IEEE 118 - bus system with DG_{max} = 200 MW

Case	DG location	Optimal size of DG (MW)	Real power loss(MW)	Power loss reduction (%)	Power flow in the congested line (MW)	Line limit (MW)
Base Case	NA	NA	77	NA	73.93	175
Increased demand case	NA	NA	146.86	NA	177.26	
1 DG Unit	38	199.99	124.31	15.36	155.23	
2 DG Units	38 81	199.42 198.99	118.55	19.27	116.43	
3 DG Units	38 81 117	174.74 171.79 124.69	113.65	22.61	111.48	
4 DG Units	38 81 117 63	174.43 163.26 114.78 174.11	106.03	27.81	96.26	
5 DG Units	38 81 117 63 45	193.99 181.15 109.86 197.47 149.44	97.59	33.54	76.61	

With an increase of demand randomly between 0% and 25%, it is observed that the system demand rises by 583MW from the base case and hence the real power loss increases from 77MW to 146.86MW, which is about 90% more than the base case. The real power flow in the line connected between buses 69 and 77 also increases drastically from 73.93 MW to 177.26 MW. As the line limit is only 175 MW, this line is said to be congested. With the objective of reducing both the above mentioned quantities, the algorithm is applied to find the optimal capacities of DGs for all the locations.

It is noted from Tables 5 and 6, an increase in the number of DGs results in reduction of real power losses and the flow in the congested line. The tables also show that, the percentage of decrease is large as the number of DGs increase. The voltage profile has improved with real power injection at the identified weak buses as shown in Fig.3. During simulation, it was observed that when the maximum limit on DGs is increased with an attempt of decreasing the real power loss and power flow in the congested line, the losses started increasing and few more lines got congested.

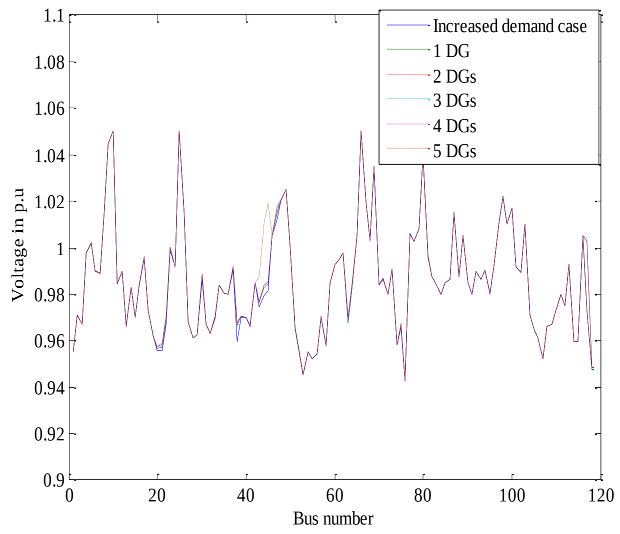

Fig.3.Voltage profile for different cases in IEEE 118 - bus system

5.3 Impact on electricity market after the placement of DG in terms of ATC calculation

ATC is a significant indicator for accommodating further transaction over and above the existing commitments. ATC is determined for a bilateral transaction between buses 3 and 5 for both IEEE 30 and 118 bus systems. The ACPTDFs have been obtained with and without DGs using NR load flow approach. The ATCs obtained with and without DGs are given in Table 7.

Table 7. ATC for different conditions in IEEE 30 and IEEE 118 bus systems

Case	Transaction	Increased demand case ATC (MW)	ATC with 1 DG (MW)	ATC with 2 DGs (MW)	ATC with 3 DGs (MW)	ATC with 4 DGs (MW)	ATC with 5 DGs (MW)
Case 1	3-5	17.67	21.23	22.68	NA	NA	NA
Case2 (DGmax =100 MW	3-5	118.51	134.44	134.88	134.50	138.70	135.76
Case 2 (DGmax =200 MW		118.51	134.12	135.01	134.52	142.00	138.74

From Table 7, it is apparent that the ATC has improved from the load contingency condition for all the cases. However, it is found that there is no considerable increase in the value of ATC among the placement of DGs in IEEE 118 bus system as the power flow pattern changes with the injection of real power at different locations.

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5.4. Comparison of various methods

In order to validate the performance of the proposed method, the results achieved from the IEEE 30 bus system are compared with the results produced by various optimization techniques available in the literature [26, 27, 22]. Table 8 shows the penetration level of the DG and the Power loss reduction in terms of percentage. The penetration level is calculated as:

$$\text{Penetration Level}(\%) = \left(\frac{P_{DG}}{P_{load}}\right) * 100 \qquad (15)$$

Table 8.Comparison with different optimization techniques

	1 DG unit			2 DG units		
	Weak bus	Penetration Level %)	Power loss Reduction %	Weak bus	Penetration Level %)	Power loss Reduction %
Method 1 [26]	5	5	7.7	NA	NA	NA
Method 2 [27]	30	20	30.93	7,29	20	30.65
Method 3 [22]	26	1.2	4.05	19,26	2.2	6.5
Proposed method	30	10.3	20.66	30,26	10.88	24.44

A considerable reduction of total system real power loss, approximately 31% is obtained using Method 2 when a single DG is placed at bus 30. It is further observed that the loss reduction in Method 1 and 3is about 7.7% and 4.05%, respectively, whereas the proposed Method has a loss reduction around 20.66%.

In the scenario of increased load demand, the power flows in some of the transmission lines are expected to exceed the limit and thereby do create congestion. The DG optimization model in Method 1 considers only loss minimization approach while Method 3 considers both voltage stability and loss minimization. However, the constraints on transmission line limit are not taken into account while solving the optimization problem. The proposed method and Method 2 aims at relieving congestion in transmission lines in addition to seeking loss minimization and voltage stability enhancement.

In this perspective, the significance of adding DG interms of contribution against power losses quantified by dividing power loss reduction over penetration level is found more using the proposed method. As a result, the proposed method shows the highest effectiveness followed by Method 2 as evident from Table 8.

The Method 1 does not attempt to optimize the 2 units of DG. Method 2 considers different locations for both units, while the Method 3 and the proposed method places the first DG unit in the same location. The reduction of power loss is improved in Method 3 and in the proposed method by 6.5% and 24.44% respectively. Also, it is observed that the effectiveness is seen more in the proposed method when compared to method 2 in which the line limits are considered. Hence, the capability of firefly algorithm to solve the optimization problem is found promising.

An additional case study with IEEE 118 bus system is presented to confirm the optimal outcomes of the proposed algorithm. The results and discussions in section 5.2 is found promising. It is hence proved that, the method can effectively be implemented for higher order systems.

6. Conclusion

This study provides a solution for the overload alleviation of transmission line for increased loading scenario with enhancement of system performance. The Firefly algorithm employs Maximum Power Stability Index as the objective function to determine the optimal location of DGs. The optimal size of DG is evaluated based on the second objective function which minimizes the power losses subjected to network security constraints. A comparison of the results on IEEE-30 bus test system show the effectiveness of this method. The simulation results indicate that the integration of DGs has a positive impact on the voltage stability and proportionate reduction in power losses and efficient congestion management. The analysis also clearly indicates the impact of DGs in the electricity market in terms of increased *ATC*. The effectiveness of the method is also validated with IEEE 118 - bus system. Thus, it is concluded that the proposed approach is computationally efficient and can be easily updated for future expansion of the system. Also, it is hoped that this method provides a solution for planning and operation of system efficiently.

In future an impact analysis on the cost of operation of the system can be done considering an optimal mix of renewable resources.

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