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RESEARCH ARTICLE

Effective Transmission Congestion Management via Optimal DG Capacity Using Hybrid Swarm Optimization for Contemporary Power System Operations

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ABSTRACT Managing transmission congestion had been a major problem with growing competition in the power networks. Accordingly, competitiveness emerges through the network's reconfiguration and the proliferation of secondary facilities. Congestion of transmission lines is a critical issue, and their regulation poses a technical challenge as the power system is deregulated. Therefore, the present research illustrates a multi-objective strategy for reaching the optimal capabilities of distributed generators (DG) like wind power plants and geothermal power-producing plants to alleviate congestion throughout the transmission network. Goals such as congestion management during power delivery, power loss reduction, power flow improvement with the enhancement of voltage profile, and investment expenditure minimization are considered to boost the network's technological and economic reliability. The congestion management is achieved using the locational marginal price (LMP) and calculation of transmission congestion cost (TCC) for the optimal location of DG. After identification of congested lines, DG is optimally sized by particle swarm optimization (PSO) and a newly proposed technique that combines the features of modified IL-SHADE and PSO called hybrid swarm optimization (HSO) which employs linear population size reduction technique which improves its performance greatly by reducing the population size by elimination of least fit individuals at every generation giving far better results than those obtained with PSO. In addition, optimal rescheduling of generations from generators has been done to fulfill the load demand resulting in alleviation of congested lines thereby enhancing the performance of the network under investigation. Furthermore, the performance of the proposed methodology of HSO and PSO has been tested successfully on standard benchmark IEEE-30 & IEEE-57 bus configurations in a MATLAB environment with the application of MATPOWER power system package.

INDEX TERMS Distributed generator, locational marginal price, particle swarm optimization, hybrid swarm optimization, congestion.

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I. INTRODUCTION

Energy grids are growing more diverse due to national grid interconnections, deregulation of its total energy sector, and rising energy consumption. Therefore, utility companies are finding ways to allow greater use of their current transmission networks. There could be congestion or overload through one or many other transmission lines owing to the communication gap between energy generation and transmission serving companies and even as a consequence of unforeseen exigencies like outages triggered by development, the rapid rise in connected load, and sometimes equipment breakdown. Managing transmission congestion seems to have been a major problem with enhanced competition in the power networks. A competitive spirit arises through the consolidation of networks and the growth of peripheral facilities. Optimized power flow through redistribution of generation is indeed an effective approach for greater use of the current network. Rescheduling of generators and dropping off loads were introduced as control acts to relieve congestion in network lines. Under this perspective, to find the right approach, a strategy focused on local optimization is deployed [1]. Furthermore, the sensitivity of any overloaded sections due to power injection at any bus is often regarded as consistent with the earlier frameworks [2]. Similarly, the locational marginal pricing (LMP) approach is used to optimally place and scale distributed power production for power pools in energy sector markets [3]. The LMP is also being used for zonal congestion management which focuses on real and practical congestion delivery variables [4].

Similar numerous approaches are explored in the literature on congestion control in transmission networks [5]–[8]. As there is a strong rivalry in the energy markets, mostly demand-side regulation is favored rather than supply-side control for the management of transmission congestion [9]. In this way, in order to boost the stability and efficiency of the power grid, supplementary utilities are introduced into the present dynamic energy market [10]. A number of scientific investigations show the usage of DGs in delivery networks to increase voltage and reduction of actual power losses, thereby enhancing network output. Solutions based on soft computing approaches are implemented with single and multi-objective functions to achieve the desired capabilities concurrently in order to achieve targets such as improvement in power flows, reducing losses, voltage enhancement, and operational costs [11]. Such a hybrid technique based on PSO has been used to reduce the loadability of the system to achieve the optimum position and sizing of DGs for the network under inspection [12]. A network reconfiguration process along with integration by DG is implemented in [13] while a genetic algorithm is used to assess the optimal potential for the transmission congestion management issue by taking into consideration the factors of voltage change and contraction of real power loss in [14]. In [15] the authors suggested a hybrid method that combines approaches such as the gravitational search algorithm (GSA) and fuzzy adaptive particle swarm optimization (FAPSO) having better global searching capabilities for addressing congestion challenges. In [16], a collaboration of LMP-dependent DG is suggested for transmission congestion management issues. A big challenge in developing efficient electricity market systems is promoting constructive interaction of distributed energy infrastructure by customers that can be accomplished by locational marginal pricing implemented in retail energy scenarios [17], [18]. The optimum power flow (OPF) is indeed a power flow challenge where certain factors are configured to mitigate an optimal solution like the price of active power production including losses. Numerous productive OPF methods have been established such as popular reduced gradient methodology [19], evolutionary programming [20], Newton process [21], etc. Demand effects are assessed when a network becomes overloaded, and LMP increases [22]. The interface gap, LMP, is a criterion for evaluating how congested the connected lines are. The greater the LMP gap, the more crowded the connection will get [23]. Using the LMP approach, network management costs may be minimized, resulting in increased network surplus [24]. The authors in [25] propose the use of a distributed generator to bridge the gap between generation and demand in terms of distributed LMP differential. Encouraging active involvement by consumers with distributed energy resources (DERs), which can be achieved through LMP applied in the wholesale electricity markets, is a fundamental challenge in the establishment of smart energy flow arrangements [18], [27]. The use of decentralized generation aids in meeting the ever-increasing demands. The deployment and sizing of DG units restrict network extension [28]. The researchers in [29] used the ant lion optimization approach to position wind turbines as DG in the electrical network, whereas the researchers of [30] used the invasive weed optimization method to tackle the same issue. The researchers of [31], [32] employed heuristic techniques to address the DG allocation challenge whereas [33], [34] applied metaheuristic techniques for the same. Both DG assignment and network reconfiguration are handled concurrently in [35], which is proved to be more beneficial than examining them independently.

From the literature survey, it is observed that although the generation side management of transmission congestion is a well-established method, the demand side management is becoming a vital tool in the efficient and economic management of congestion in the transmission network. To achieve this several optimization techniques are utilized. However, the performance of the algorithms is based on their capabilities to give optimized results considering various parameters. In this work, for effective management of congestion along with improvement of the performance of the power system network in terms of power loss, power flow, and voltage profile, a multi-objective strategy for reaching the optimal capabilities of distributed generators (DG) along with optimal rescheduling of conventional generators has been proposed. The optimal locations for placing DG are determined by the proposed approach of LMP and TCC. The PSO and proposed algorithm based on PSO and modified IL-Shade algorithms known as hybrid swarm optimization (HSO) is finally used to evaluate the optimal size of DG to address the concern of congestion and enhance the technological and economic performance of power system networks under inspection.

II. PROBLEM STATEMENT

Congestion is a serious concern to manage on technical and economic aspects. Therefore, the problem is formulated to solve the issue of congestion management along with minimization of losses and improvement in power flow as well as voltage profile. The proposed methodology of LMP and TCC is implemented to identify the optimal locations of DG to achieve the above objectives in order to fulfill the load demand in situations where load consumption increases. Thereafter, optimal sizing of DG is computed by PSO and proposed hybrid approach for solving the optimization problem. The results obtained are compared with those obtained with PSO to show the effectiveness of the proposed technique. The proposed work is structured in the following sections as:

- Optimal power flow modeling
- LMP
- Management of congestion in deliberation with optimum capacities of DG
- Intelligent analytical approach to solve the optimization problem.

III. MODELLING OF OPTIMAL POWER FLOW

Consider two bus networks to reflect the flow of power among 2 buses which can be seen in Figure.1. The OPF issue is formulated in a deregulated context by reducing the output costs of generators assigned under constraints of power balance and line flow. The generated power is S_i having components Sij (flow of power among two buses) and demand power (S_D).

The OPF solution is developed as:

$$\min C_i = \sum_{i}^{Ng} F_{gi} \tag{1}$$

Complex power at for any bus can be written as:

$$S_i = S_{ij} + S_D \tag{2}$$

In the same way, real power & reactive power can be expressed in Eq. (3) & Eq. (4)

$$P_{gi} = P_{di} + \sum_{j=1}^{N} |V_i| \left|V_j\right| \left(G_{ij}cos\delta_{ij} + B_{ij}sin\delta_{ij}\right) \tag{3}$$

For all i = 1, 2, 3 . . . N.

Here P_{gi} & P_{di} represent generation of i^{th} bus and real power demand; $\delta_{ij} = \delta_j - \delta_i$; N represents the total number of buses.

$$Q_{gi} = Q_{di} + \sum_{j=1}^{N} |V_i| \left|V_j\right| \left(G_{ij}cos\delta_{ij} + B_{ij}sin\delta_{ij}\right) \tag{4}$$

For all i = 1, 2, 3 . . . N

$$Pl_{ij} \leq Pl_{ij}^{max}; \quad \text{ij} \in n_l \tag{5}$$

Pl_{ij} and Pl_{ij}^{max} are the real power flows through line i-j and line maximum capability; n_l is total no. of lines.

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}; \quad i = 1, 2 \ldots, N_g \tag{6}$$

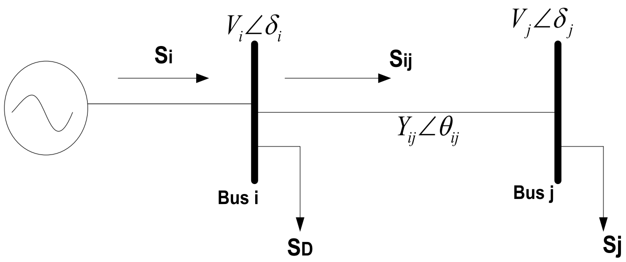

FIGURE 1. General representation of optimal power flow between two buses.

$$\delta_i^{min} \leq \delta_i \leq \delta_i^{max}; \quad i = 1, 2 \ldots, N \tag{7}$$

$$V_i^{min} \leq V_i \leq V_i^{max}; \quad i = 1, 2 \ldots, N \tag{8}$$

Here P_{gi}^{min} & P_{gi}^{max} represent minimum & maximum capacity of the i^{th} generator; δ_i, δ_i^{min}, δ_i^{max} depicts voltage angle and corresponding minimum & maximum limits and N_g represent a number of total generators.

The i^{th} generator's production function in \$-h^{-1} is analytically represented as:

$$F_{gi} = 0.5x_{gi}P_{gi}^2 + y_{gi}P_{gi} + z_{gi} \tag{9}$$

Here x_{gi}, y_{gi}, z_{gi} represent the coefficients of fuel cost of the i^{th} generator.

IV. LOCATIONAL MARGINAL PRICING (LMP)

Since LMP is defined as the total cost of supplying the anticipated rise in energy on a single bus, bearing in mind the variable production costs and other elements of that same transmission network in a deregulated environment to provide the best congestion control approach. In electricity markets, different zones of distribution networks have different requirements for the flow of power. The energy use ranges from small to large in various areas of the network. The primary issue is indeed the economic dimension of power delivery in numerous zones. LMP is among the most flexible congestion control approach in the deregulated environment [36]. It offers competent, effective delivery network solutions.

The appropriate expression of electricity production cost minimization under the specified constraint is defined as:

$$\sum_{i=1}^{n} C_i(F_{gi}) = C_i \tag{10}$$

'n' is the number of generating units where $C_i(F_{gi})$ is electricity generating cost is formulated by:

$$F_{gi} = 0.5a_{gi}(P_{gi})^2 + b_{gi}(P_i) + c_{gi} \tag{11}$$

where a_{gi}, b_{gi} & c_{gi} represents the fuel coefficients of a quadratic function.

Constraint limit on power is already discussed in Eq. (5)-Eq (8)

A. FORMULATION OF LMP

The optimal economical aspects of LMP at a particular bus consist of the sum of all 3 parts namely- marginal energy cost (MEC), *loss component* (LC), and *congestion component* (CC) as given by Eq. (12).

$$\mathrm{LMP} = \mathrm{MEC} + \mathrm{LC} + \mathrm{CC} \tag{12}$$

1) MARGINAL ENERGY COST (MEC)

It is considered to be a fixed energy cost for all the buses.

2) LOSS COMPONENT (LC)

This is a transmission line expense factor comparable with losses in the transmission line. When withdrawal or injection occurs at a bus, the resulting losses and their associated costs will escalate. For any variability in generating capacity, the optimum rate of transmission losses must be maintained.

3) CONGESTION COMPONENT (CC)

The major reasons for congestion include line breakdowns, abrupt load rise, thermal limit contraction, and a mixture of bi-lateral or multi-lateral activities. The cost portion of this congestion is a unique task to manage. Congestion costs are determined by the LMP gap between two buses and their related power movement as shown by Eq. (13).

$$\mathrm{CC_l} = LMP_l \,{}^{*}\, Pl_{ij} \quad \text{where } \mathrm{l} = 1, 2, \ldots \mathrm{n_l} \tag{13}$$

The total TCC i.e. transmission congestion cost is devised as given by Eq. (14):

$$\mathrm{TCC} = \sum\nolimits_{L=1}^{nl} LMP_l \,{}^{*}\, Pl_{ij} \tag{14}$$

where $\mathrm{CC_l}$ expense of congestion of a particular line; LMP_l is the difference in LMP across that particular line; Pl_{ij} = related line i-j power movement; $\mathrm{n_l}$ is the total number of lines.

V. MANAGEMENT OF CONGESTION IN DELIBERATION WITH OPTIMUM CAPACITY OF DG

In this current work; congestion control with the improvement of voltage and actual power losses are regarded as technological considerations while the cost of the output of both distributed and traditional generators is regarded to be an economical consideration in achieving optimal DG unit power. The goal of this research is to boost technological efficiency together with appropriate investments in DG systems by the way of optimal allocation of DGs. In the recommended multi-objective strategy, weighted technological parameters including economic parameters are concurrently regarded for achieving the optimum sizing and placement of DG. The multi-objective framework for optimized scaling and placement of DGs is devised by integrating the technological and economic factors with the following weighting criteria as shown in Eq. (15):

$$\mathrm{Min}\ C_i = \sum\nolimits_{i=1}^{Ng} F_{gi} + \sum\nolimits_{i=1}^{Ndg} F_{dg,i} \tag{15}$$

where *Fdg*, *i* denotes the ith DG cost of production function in ($-h^{-1}) determined through the slope $x_{dg,i}$ and intercept $y_{dg,i}$ as given by:

$$F_{dg,i} = 0.5x_{dg,i}P_{dg,i}^2 + y_{dg,i}P_{dg,i}$$

where $x_{dg,i} = 0.25$, $y_{dg,i} = 40$ for a type-2 DG like wind power plants [22].

Eq. (3) and Eq. (4) are modified to incorporate the impact of DG as given in Eq. (16):

$$P_{gi} = P_{di} + \sum\nolimits_{j=1}^{N} ViVj(Gijcos\delta ij + Bijsin\delta ij) \tag{16}$$

For all i = 1, 2, 3 . . . N, i ≠ k

Eq. (16) can be modified as Eq. (17) for a particular kth bus.

$$P_{gi} + P_{dg,k} = P_{di} + \sum\nolimits_{\substack{j=1\\ i=k}}^{N} ViVj\,(Gijcos\delta ij + Bijsin\delta ij) \tag{17}$$

Also, $0 \le P_{dg,k} \le P_{dg}^{max}$ where P_{dg}^{max} is maximum infiltration of the kth DG.

The transmission congestion management challenge for DG comprises of an objective function given by Eq. (15) subject to the constraints given by Eq. (4) to Eq. (8) and Eq. (16) to Eq. (17).

A. TRANSMISSION CONGESTION CONTROL BY OPTIMAL SIZING OF DG AND ENTIRE GENERATION RESCHEDULING

The transmission congestion control is done by considering the following main factors:

1. *Factor of Transmission Congestion:* Across all power lines, the proportion of actual power passing via the line after the positioning of DG(s) towards its line constraints is determined, and the highest of all such ratios is called as Factor of transmission congestion given as:

$$\mathrm{T_c} = 200\ max\left\{Pl_{ij}^{dg} \mid Pl_{ij}^{max}\right\} \tag{18}$$

Pl_{ij}^{dg} and Pl_{ij}^{max} (are the real power flows through line i-j after placement of DG and line capability.

It will be calculated for violated line limits after load increment.

2. *Voltage Profile Enhancement* (V_E)*:* It is characterized as in Eq. (19):

$$\mathrm{V_E} = 200\frac{\sum_{i=1}^{N}(V_i^{dg} - 1)^2}{\sum_{i=1}^{N}(V_{i,ALI} - 1)^2} \tag{19}$$

V_i^{dg} depicts voltage figure after placement of DG of ith bus and $V_{i,ALI}$ is the voltage figure of ith bus after load increment.

3. *Active Power Loss (APL):* It is accustomed as in Eq. (20)

$$\mathrm{APL} = 200\frac{P_{loss}^{dg}}{P_{loss}^{ALI}} \tag{20}$$

P_{loss}^{dg} exemplify the active loss in power subsequently placement of DG and P_{loss}^{ALI} is a real loss in power after load increment. The aim of such a factor is to minimize the actual loss of power throughout the channel of the electricity grid.

4. *Price Metric (PM):* It is devised as in Eq. (21):

$$\mathrm{PM} = \frac{\left(\sum_{i=1}^{Ng} F_{gi} + \sum_{i=1}^{Ndg} F_{dg,i}\right)}{\sum_{i=1}^{Ng} F_{dg,i}} \tag{21}$$

The PM's key goal is to achieve the optimal capital expenditures of both DGs and traditional generators at the same time.

This research aims at improving the functional capacity of the issue of optimal allocation of DGs, alongside optimized investments of DGs. In order to obtain the optimum sizing of DGs, weighted technological parameters and economic factors are regarded concurrently in the current multi-objective strategy. This multi-objective model for the optimal sizing of DGs is derived by integrating the technological and economic variables with weighting variables devised as in Eq. (22):

$$\mathrm{Z} = \mathrm{w1} \times \mathrm{T_c} + \mathrm{w2} \times \mathrm{V_E} + \mathrm{w3} \times \mathrm{APL} + \mathrm{w4} \times \mathrm{PM} \tag{22}$$

In the above equation, w1, w2, w3, w4 sites weighting factors of the corresponding variables. The multi-objective challenge of optimization is devised to minimize the functionality Z subjected to constraints Eq. (4-8) and Eq. (16)-(17) & additionally one more restraint given by Eq.(23):

$$\sum_{i=1}^{4} \mathrm{wi} = 1, \quad \mathrm{wi} \in [0, 1] \tag{23}$$

The test setup of the IEEE standard 30 bus system is selected for analyzing the performance of the deregulated system. The system base is 100MVA. The six conventional generators are located at bus locations 1, 2, 13, 22, 23 and 27 of ratings G1 = 80 MW, G2 = 80 MW, G3 = 40 MW, G4 = 50 MW, G5 = 30MW, and G6 = 55 MW. These generators are initially producing 23.54 MW, 60.97 MW, 37 MW, 21.59 MW, 19.2 MW & 26.91 MW for existing loading conditions. In this research work, the optimal rescheduling of generations in the presence of DGs for transmission congestion management is proposed. Congestion is created in the network by increasing the demand by 100% throughout the network. The optimal locations of DGs are obtained using transmission congestion cost (TCC) given by Eq. (24). The locations are obtained by calculating the TCC in the base case so that the optimal locations remain the same irrespective of loading conditions because it is practically infeasible to shift the locations of DGs at different loading conditions. The optimal size of DGs and the optimal generations from the generators are calculated using both by PSO and a new technique which is combining features of Modified IL-SHADE and PSO-based hybrid optimization. Initially, we removed the line limit constraints from the lines so that any amount of power can be transferred through the transmission corridors. When the load increases in the network, the power flow through many lines exceeds the original line limit. Our objective through generation rescheduling in the presence of DG is to remove the violations by penetrating minimum DG into the network.

$$TCC_L = |LMP_L| * \left|Pl_{ij}\right| = \left|LMP_i - LMP_j\right| * \left|Pl_{ij}\right| \tag{24}$$

where LMP_L is the absolute LMP difference in branch L connecting node i and node j. Pl_{ij} is the absolute power flow in branch L.

The fitness function to be evaluated is given by Eq. (15) subjected to an additional constraint given by equation (25) along with the constraint presented by equation (4) to equation (8) and equation (16)- equation (17).

$$Pl_{ij}^{dg} \leq Pl_{ij}^{max} \tag{25}$$

where Pl_{ij}^{dg} is the power flow after DG placement & Pl_{ij}^{max} is the maximum line limit from bus i to j.

VI. INTELLIGENT ANALYTICAL APPROACH

A. PERFORMANCE OF IEEE 30-BUS SYSTEM UNDER PSO AND EVOLUTION OF HYBRID SWARM OPTIMIZATION (HSO) APPROACH

The performance of 30 bus system IEEE [37] is checked under PSO. The typical diagram of the 30 IEEE bus system is shown in Figure. 2. The internal parameters of IEEE 30-bus systems are shown in Table.1. This evolutionary computational methodology has been contemplated as it is having broad applicability in finding solutions to issues that entail non-differentiability, non-linearity, and numerous optima. PSO is centered on a swarm-a group of "particles," the solutions and alternative courses of action-the concurrent exploring of the quest space. In this algorithm, likely solutions known as particles float about a multi-dimensional problem field. The particle population can be defined as a swarm. Every particle in a cluster flight to an optimal or quasi-optimum solution in the searching region, depending on one's own expertise, neighboring particle perspective, and also the global best location amongst these particles in the flock. Throughout the swarm, the particles are iteratively modified in accordance with the equation given by Eq. (26) and Eq. (27).

$$\begin{aligned} \boldsymbol{v_{pd}^{j+1}} &= \mathrm{u} \times \boldsymbol{v_{pd}^{j}} + \mathrm{c}_1 \times \mathrm{Rand}_1 \times (p_{Best,pd} - x_{pd}^{t}) \\ &\quad + c_2 \times \mathrm{Rand}_2 \times (g_{Best} - x_{pd}^{t}) \qquad (26) \\ Z_{pd}^{j+1} &= Z_{pd}^{j} + v_{pd}^{j+1} \qquad (27) \end{aligned}$$

where $\boldsymbol{v_p} = (v_{p1}, v_{p2}, \ldots v_{pd})$ represent the vector velocity and $\boldsymbol{Z_p} = (Z_{p1}, Z_{p2} \ldots Z_{pd})$ represent the vector location of p$^{\mathrm{th}}$ particle. F_{Best} is the best solution and the dimensions correlated with the best solution become p_{Best}.

In each and every iteration, the best prior locations of the particles are reported in $p_{Best} = (p_{Best,p1}, p_{Best,p2} \ldots p_{Best,pd})$. The total best value, as well as its corresponding coordinates, are stored by PSO called g_{Best}. Throughout each stage approaching p_{Best} and g_{Best}, the optimization process reviews the velocity as well as the location of the particle to select the finest solution. The other variables like c_1, c_2 denote acceleration constant, u depicts vector weight of inertia and Rand_1 & Rand_2 are randomly selected values between 0 & 1.

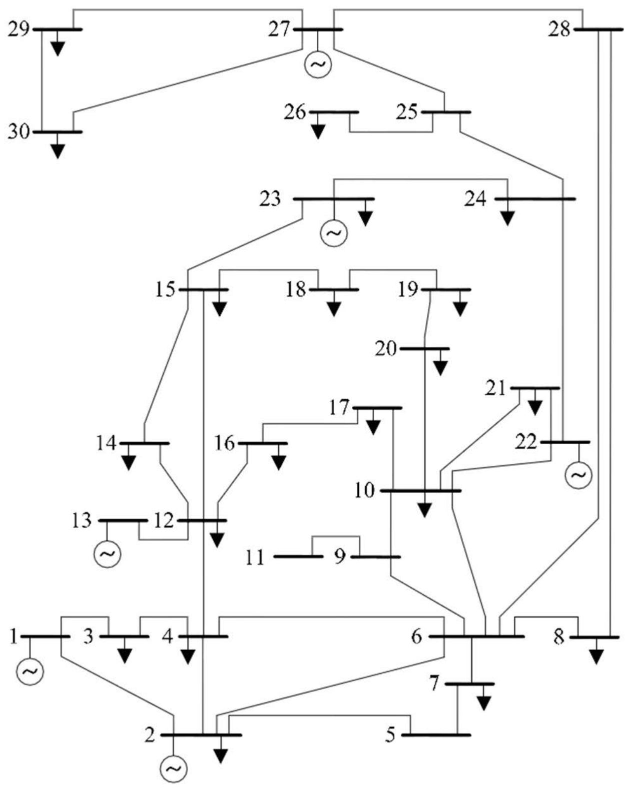

FIGURE 2. IEEE 30 bus configuration [37].

The vector weight of inertia is calculated as in Eq. (28):

$$u = u_{max} - \frac{u_{max} - u_{min}}{N_{iter,max}} \times N_{iter} \tag{28}$$

In the above equation, $u_{max}(0.9)$ & u_{min} (0.5) is max and min value of weighing inertia and N_{iter}, $N_{iter,max}$ represent a count of iterations and maximum no. of iterations.

An updated version for resolving single objective computation of real parameters is provided in this segment. We'll call the algorithm hybrid swarm optimization. It is the expanded IL-SHADE variant [38]. Actually, IL-SHADE & L-SHADE implements DE-current to pbest-1 mutation methodology for the generation of testing vector as represented in Eq. (29).

$$\vec{\boldsymbol{v}}_{\boldsymbol{i,j}} = \vec{\boldsymbol{x}}_{\boldsymbol{i,j}} + \vec{\boldsymbol{F}}\left(\vec{\boldsymbol{x}}_{\boldsymbol{pbest},\boldsymbol{g}} - \vec{\boldsymbol{x}}_{\boldsymbol{i},\boldsymbol{g}}\right) + \vec{\boldsymbol{F}}\left(\vec{\boldsymbol{x}}_{\boldsymbol{r}1,\boldsymbol{g}} - \vec{\boldsymbol{x}}_{\boldsymbol{r}2,\boldsymbol{g}}\right) \tag{29}$$

whereas PSO utilizes a contemporary weighted form attributed to mutation approach is known as DE-current to pbest-w-1 given as in Eq. (30):

$$\vec{\boldsymbol{v}}_{\boldsymbol{i,j}} = \vec{\boldsymbol{x}}_{\boldsymbol{i,j}} + F_w\left(\vec{\boldsymbol{x}}_{\boldsymbol{pbest},\boldsymbol{g}} - \vec{\boldsymbol{x}}_{\boldsymbol{i},\boldsymbol{g}}\right) + \vec{\boldsymbol{F}}\left(\vec{\boldsymbol{x}}_{\boldsymbol{r}1,\boldsymbol{g}} - \vec{\boldsymbol{x}}_{\boldsymbol{r}2,\boldsymbol{g}}\right) \tag{30}$$

The parameter F_w is modified by Eq. (31):

$$F_w = \begin{cases} 0.7 \times \text{F}, & \text{itertaion current} < 0.2 \times \textit{iteration} \text{ max} \\ 0.8 \times \text{F}, & \text{itertaion current} < 0.4 \times \textit{iteration} \text{ max} \\ 1.2 \times F, & \textit{othwerwise} \end{cases} \tag{31}$$

The altered equation for mutation is now given as in Eq. (32):

$$\vec{\boldsymbol{v_i}} = \vec{\boldsymbol{x_i}} + F_w\left(gBest - \vec{\boldsymbol{x_i}}\right) + \vec{F}\left(pBest_{r1} - pBest_{r2}\right) \tag{32}$$

In the above equation, r_1 & r_2 represent two arbitrary numbers between 1 and population size but $r_1 \neq r_2 \neq i$. The complete process is explained through a flowchart in Figure.3.

B. PERFORMANCE OF IEEE 30- SYSTEM UNDER HYBRID SWARM OPTIMIZATION

1) CROSSOVER

For the next exercise named as crossover, $\vec{\boldsymbol{v}}_{\boldsymbol{i,g}}$ a mutant vector has been created by the mutation approach. The binomial type of crossover is extensively implemented in DE and the alternative is exponential.

The binomial type generates a trial vector, $\vec{\boldsymbol{u}}_{\boldsymbol{i,g}}$ given as in Eq. (33):

$$\vec{\boldsymbol{u}}_{\boldsymbol{i,g}} = \left\{ \begin{matrix} \vec{\boldsymbol{v}}_{\boldsymbol{i,j,g}}, & \textit{if Rand } (0,1) \leq \text{CR or j} = j_{Rand}, \\ x_{i,j,g}, & \textit{othwerwise} \end{matrix} \right\} \tag{33}$$

for i = 1, 2, . . . , NP & j = 1, 2, . . . , D and CR ∈ [0, 1] represents parameter of crossover & represents the anticipation of building a test vector against mutant vector. If the composing part of mutant vector has not been chosen, then it must be taken from father vector $x_{i,g}$.

Arbitrarily selected indicator $j_{Rand} \in (1, 2, \ldots, NP)$ is answerable for the test vector to accommodate at least one integral part of the mutant vector. If any of the test vector parameters seem to be out of boundaries, the mechanism of repeat is introduced.

2) SELECTION

The test vector is assessed after the crossover operation; then an objective function $f(u_{i,g})$ is determined.

The selection procedure then contrasts two maps, the population vector according to their objective function values, $\vec{\boldsymbol{x}}_{\boldsymbol{i,j}}$ and its related test vector, $\vec{\text{u}}_{\boldsymbol{i,j}}$. The superior vector will be constituting a member of a later generation. The strategy of selection for a minimal optimal problem is given as in Eq. (34):

$$\vec{\boldsymbol{x}}_{\boldsymbol{i,g+1}} = \left\{ \begin{matrix} \overrightarrow{\boldsymbol{u_g}}, & \textit{if } f\left(\overrightarrow{\boldsymbol{u_{i,g}}}\right) \leq f\left(\overrightarrow{\boldsymbol{x_{i,g}}}\right) \\ \overrightarrow{\boldsymbol{x_{i,g}}}, & \textit{otherwise.} \end{matrix} \right\} \tag{34}$$

This approach of selection is highly applicable for DE. The complete process is explained through a flowchart in Figure.4.

VII. RESULTS AND DISCUSSIONS

A. DETERMINATION OF OPTIMAL LOCATION FOR PLACEMENT OF DG

The following steps are considered for checking the technical & economical aspects and for congestion management of the deregulated system. Throughout the network, congestion

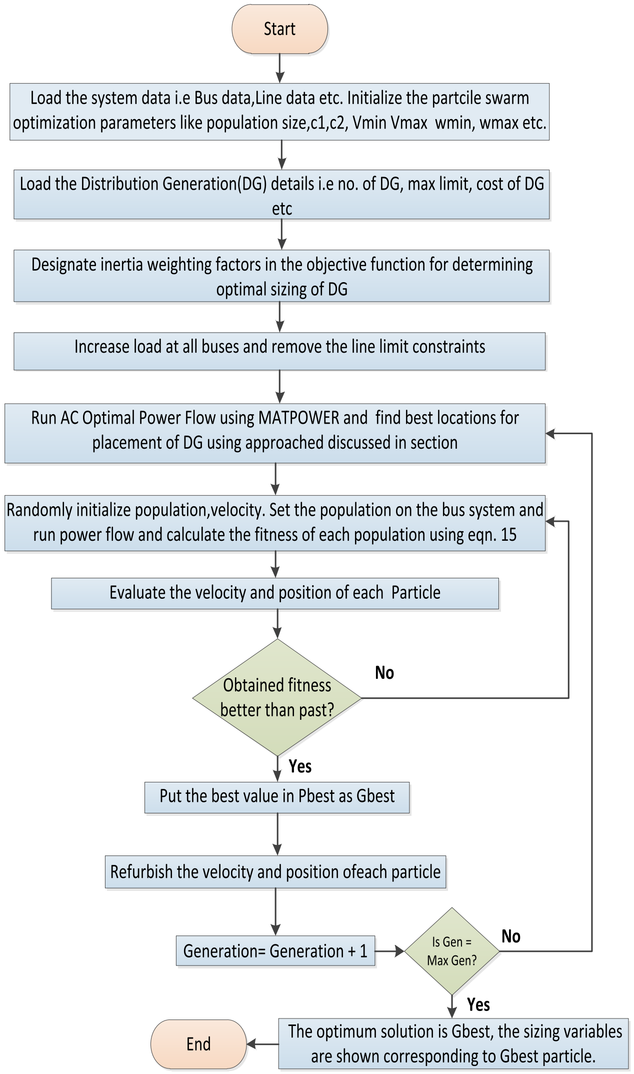

FIGURE 3. Methodology for determining optimum sizing of DG by PSO.

is generated by increasing demand by 100%, and then the following procedure is adopted.

1) Calculation of LMP at every bus.

2) The TCC of all branches is calculated and sorted in descending order. The candidate locations are obtained by first selecting the most congested line, and then the node of this line having the higher LMP is the first optimal location while the node having lower LMP will be the second optimal location for placement of DG. The second most congested line will give the 3rd and 4th optimal locations and so on.

Table 1 shows the calculated values of TCC and LMP at different bus locations on the basis of the procedure as described earlier. On analyzing the table, it can be easily determined that optimal locations for placement of DG are buses no. 8, 6, 28, and 3 on the basis of the value of TCC as shown in Table 1; the higher the value of TCC, the more congested the line connecting buses and hence the most optimal location for the placement of DG as we have decided to integrate four DG with the existing power system network as per load requirements.

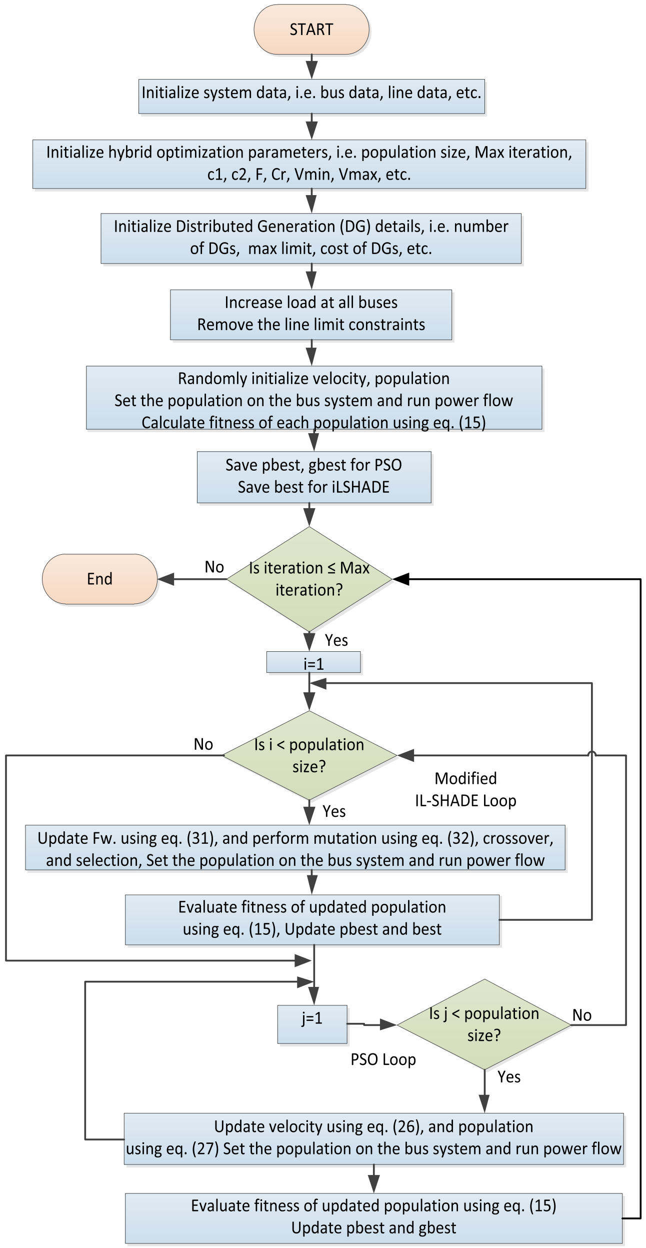

FIGURE 4. Methodology for determining the optimal size of DG by hybrid technique.

B. DETERMINATION OF OPTIMAL SIZE OF DG FOR CONGESTION MANAGEMENT

After determination of optimal locations for placement of DG based on TCC and LMP; estimation of optimum sizing of DG is done both by PSO and hybrid approach which will be discussed in one by one in the next sections.

1) PSO METHODOLOGY FOR OPTIMAL SIZING OF DG

On the basis of the suggested PSO method, the optimum potential of DGs is achieved and the results are verified on IEEE 30 bus topology. The controlling parameters are as follows: Population Size = 30; Maximum Iteration = 100;

TABLE 1. LMP values and TCC values at different bus locations for IEEE-30 bus.

S.No	From_ bus	To_ bus	TCC ($-h^{-1})	LMP_ from_ bus ($/MWh)	LMP_ to_bus ($/MWh)
1	6	8	38.202	3.7791	5.3827
2	8	28	8.0273	5.3827	4.1058
3	28	27	2.1768	4.1058	3.9157
4	2	6	1.9498	3.6891	3.7791
5	1	3	1.8957	3.6617	3.7542
6	6	28	1.6491	3.7791	4.1058
7	2	4	1.5243	3.6891	3.7709
8	27	30	0.95945	3.9157	4.0508
9	5	7	0.80472	3.7444	3.8008
10	2	5	0.79414	3.6891	3.7444
11	1	2	0.5762	3.6617	3.6891
12	24	25	0.53259	3.8844	3.932
13	10	20	0.50108	3.8462	3.91
14	15	23	0.46673	3.8561	3.8133
15	4	12	0.43301	3.7709	3.81
16	15	18	0.39663	3.8561	3.9112
17	6	9	0.32093	3.7791	3.8232
18	27	29	0.31218	3.9157	3.9664
19	29	30	0.31055	3.9664	4.0508
20	3	4	0.2988	3.7542	3.7709
21	12	15	0.27981	3.81	3.8561
22	6	10	0.27878	3.7791	3.8462
23	12	14	0.2704	3.81	3.8677
24	21	22	0.25091	3.854	3.8425
25	25	27	0.24476	3.932	3.9157
26	25	26	0.23603	3.932	3.9987
27	12	16	0.205936	3.81	3.8488
28	6	7	0.18913	3.7791	3.8008
29	22	24	0.18679	3.8425	3.8844
30	9	10	0.16694	3.8232	3.8462
31	4	6	0.14441	3.7709	3.7791
32	23	24	0.14396	3.8133	3.8844
33	10	17	0.11829	3.8462	3.8625
34	19	20	0.090322	3.9262	3.91
35	18	19	0.059261	3.9112	3.9262
36	10	21	0.034375	3.8462	3.854
37	16	17	0.024111	3.8488	3.8625
38	10	22	0.018506	3.8462	3.8425
39	14	15	0.017989	3.8677	3.8561
40	12	13	2.14E-07	3.81	3.81
41	9	11	0	3.8232	3.8232

c1 = 2.5; c2 = 2.5; $u_{max} = 0.9$ & $u_{min} = 0.5$. The optimal power flow solution has been done by MATPOWER [39], [40] for total 51 rounds; each round consisting of 100 iterations extensively. The best results are obtained in round 26; samples of which are tabulated as in Table 2:

2) HYBRID SWARM OPTIMIZATION APPROACH FOR DETERMINATION OF OPTIMUM SIZING OF DG

Now, for effective congestion management and to determine the optimal capacity of DG, this hybrid approach as discussed earlier is proposed and the results are verified successfully on IEEE 30 bus configuration. The controlling variables are described as: Population Size = 30; Maximum Iteration = 30; F = 0.8; $C_r = 0.7$, w = 1; damp = 0.99. The optimal power flow solution has been determined by MATPOWER for 51 rounds; each round consisting of 100 iterations. The best results are obtained in round 28; samples of which are given in Table 7.

TABLE 2. OPF for IEEE 30 bus system for round 26 under PSO.

Branch	From_ Bus	To_ Bus	Pl_{ij}^{max} (MW)	Pl_{ij}^{base} (MW)	Pl_{ij}^{ALI} (MW)	Pl_{ij}^{dg} (MW)
1	1	2	130	10.89	151.9	46.01
2	1	3	130	15.08	81.66	33.97
4	3	4	130	12.55	73.49	28.58
6	2	6	65	20.27	68.79	30.66
7	4	6	90	22.49	72.08	17.49
9	6	7	130	9.270	6.872	23.09
10	6	8	32	24.82	55.27	10.153
12	6	10	32	3.307	20.16	14.91
14	9	10	65	5.788	35.28	26.10
15	4	12	65	1.671	39.02	23.50
17	12	14	32	5.387	12.61	10.73
19	12	16	32	9.263	14.97	12.40
20	14	15	16	0.849	0.018	1.813
24	19	20	32	3.654	11.40	11.49
26	10	17	32	3.369	10.35	12.83
27	10	21	32	2.233	13.93	3.231
29	21	22	32	19.77	21.28	31.83
30	15	23	16	8.805	5.156	14.66
31	22	24	16	2.097	3.410	0.355
35	25	27	16	7.438	13.95	15.91
38	27	30	16	7.122	14.58	14.58
39	29	30	16	3.683	7.462	7.462
40	8	28	32	5.305	5.133	1.430
41	6	28	32	0.770	19.75	2.485

TABLE 3. Lines violating the power flow limit after load increment and power flow improvement after placement of DG for IEEE-30 under PSO.

Branch	From_Bus	To_Bus	Pl_{ij}^{max} (MW)	Pl_{ij}^{base} (MW)	Pl_{ij}^{ALI} (MW)	Pl_{ij}^{dg} (MW)
1	1	2	130	10.89	151.99	46.016
6	2	6	65	20.27	68.794	30.661
10	6	8	32	24.82	55.278	10.153

TABLE 4. Optimal scheduling of generators by PSO for efficient congestion management for IEEE-30 bus under PSO.

Gen_1 (MW)	Gen_2 (MW)	Gen_3 (MW)	Gen_4 (MW)	Gen_5 (MW)	Gen_6 (MW)
79.98	80	40	35.317	30	42.38

C. PERFORMANCE EVALUATION OF IEEE-57 BUS SETUP UNDER PSO & HSO

The test setup of the IEEE-57 bus is selected for evaluating the performance of the deregulated system as given in Figure 7. The system base is 100MVA. The seven conventional generators are located at bus locations 1, 2, 3, 6, 8,9 and 12 of ratings G1 = 575.88 MW, G2 = 100 MW, G3 = 140 MW, G4 = 100 MW, G5 = 550 MW, G6 = 100 MW & G7 = 410 MW.

TABLE 5. Optimal sizing of DG by PSO for placement at optimal locations of buses for effective management of congested lines for IEEE-30 bus.

Bus Location	DG No.	Best Optimal Size (MW) Round 26	Worst Optimal Size (MW) Round 31
8	DG1	48.48	51.92
6	DG2	31.25	0
28	DG3	0	1.397
3	DG4	0	66.238
	Total Cumulative Sizing	79.74	119.55

TABLE 6. Power loss in base case, after load increment and after placement of DG for IEEE-30 bus under PSO.

P^{0}_{loss} (MW)	P^{ALI}_{loss} (MW)	P^{dg}_{loss} (MW)	
		Round 26	Round 31(worst)
2.443803	20.93049	7.042	8.567

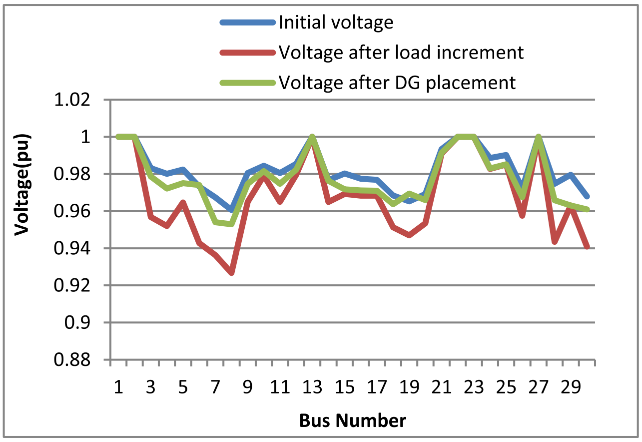

FIGURE 5. Enhancement of voltage profile after placement of DG for IEEE 30 bus setup under PSO.

These generators are initially producing 128.9 MW, 0 MW, 40 MW, 0 MW,450 MW, 0 MW & 310 MW for existing loading conditions. The loading conditions are increased by 100% throughout the network. Firstly, the optimal locations for placement of DG are determined as per the method discussed in section VII-A.

From Table.14; It can be analyzed that optimal locations for the location of DG based on TCC are buses no. 29, 7, 54 & 55.

TABLE 7. OPF for IEEE 30 bus system under HSO approach for round 28.

Branch	From_ Bus	To_ Bus	Pl^{max}_{ij} (MW)	Pl^{base}_{ij} (MW)	Pl^{ALI}_{ij} (MW)	Pl^{dg}_{ij} (MW)
1	1	2	130	10.89	151.9	46.03
2	1	3	130	15.08	81.66	33.96
3	2	4	65	16.06	55.31	28.20
5	2	5	130	13.79	40.48	23.28
6	2	6	65	20.27	68.79	29.68
7	4	6	90	22.49	72.08	17.57
9	6	7	130	9.270	6.872	23.08
10	6	8	32	24.82	55.27	9.87
11	6	9	65	5.788	35.28	25.96
14	9	10	65	5.788	35.28	25.96
16	12	13	65	37	37	39.99
17	12	14	32	5.387	12.61	10.71
19	12	16	32	9.263	14.97	12.37
21	16	17	16	5.684	7.765	5.230
23	18	19	16	5.867	7.637	7.529
24	19	20	32	3.654	11.40	11.50
28	10	22	32	3.754	3.443	2.962
31	22	24	16	2.097	3.410	0.336
33	24	25	16	3.856	6.696	8.658
36	28	27	65	6.112	14.47	0.309
38	27	30	16	7.122	14.58	14.58
41	6	28	32	0.770	19.75	5.176

TABLE 8. Lines violating the power flow limit after load increment and power flow improvement after placement of DG in IEEE-30 bus under HSO.

Branch	From_ Bus	To_ Bus	Pl^{max}_{ij} (MW)	Pl^{base}_{ij} (MW)	Pl^{ALI}_{ij} (MW)	Pl^{dg}_{ij} (MW)
1	1	2	130	10.89	151.99	46.03
6	2	6	65	20.27	68.79	29.68
10	6	8	32	24.82	55.27	9.87

TABLE 9. Optimal scheduling of generators under HSO approach for efficient congestion management in IEEE-30 bus.

Gen_1 (MW)	Gen_2 (MW)	Gen_3 (MW)	Gen_4 (MW)	Gen_5 (MW)	Gen_6 (MW)
79.998	80	39.999	35.550	29.999	43.215

TABLE 10. Optimal sizing of DG by HSO for placement at optimal locations of buses for effective management of congested lines in IEEE-30 bus.

Bus Location	DG No.	Best Optimal Size (MW) Round 28	Worst Optimal Size (MW) Round 34
8	DG1	23.41	67.25
6	DG2	53.28	10.58
28	DG3	0	0
3	DG4	0	0
	Total Cumulative Sizing	76.69	77.83

1) EVALUATION UNDER PSO METHODOLOGY FOR IEEE-57 BUS SETUP

For the evaluation of the proposed methodology of PSO as discussed in section 6.1 and section 7.2.1 on IEEE-57 setup, OPF was determined by MATPOWER for 51 rounds; each round consisting of 100 iterations. The best OPF results are obtained in round 42; samples of which are given in Table 15. In this; the MVA limit of all branches is set to zero except branch 41 connecting bus 7 to bus 29. The line limit limitations were eliminated, allowing any amount of power to

TABLE 11. Power loss during the base case, after load increment, and after placement of DG under HSO in IEEE-30 bus.

P_{loss}^{0} (MW)	P_{loss}^{ALI} (MW)	P_{loss}^{dg} (MW)	
		Round 28	Round 34(worst)
2.443803	20.93049	6.712	7.17

TABLE 12. Comparison of total power loss after placement of DG in IEEE-30 bus.

Type of Technique	Pl_{loss}^{dg} Total Power Loss(MW)	
	Best Results during optimization	Worst Results during optimization
Hybrid Swarm Optimization	6.712	7.17
PSO	7.042	8.567

TABLE 13. Comparison of effective total cumulative DG size for management of congestion in IEEE-30 bus.

Type of Technique	Total Cumulative DG Size (MW)	
	Best Results during optimization	Worst Results during optimization
Hybrid Swarm Optimization	76.69	77.83
PSO	77.74	119.55

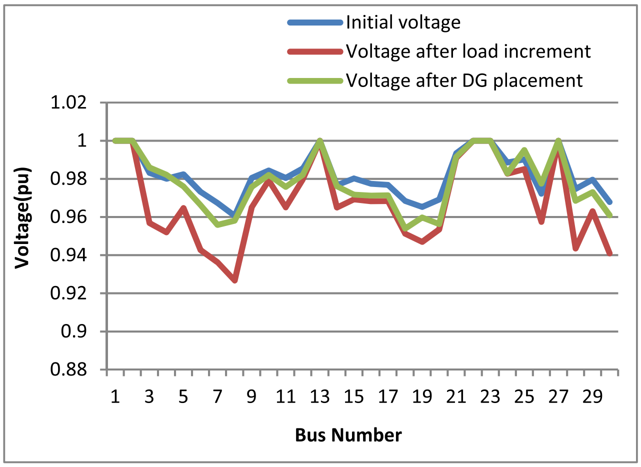

FIGURE 6. Enhancement of voltage profile after placement of DG for IEEE 30 bus setup by HSO.

TABLE 14. LMP and TCC values for IEEE57-bus system.

Branch	From _bus	To_ bus	TCC ($\$$-h^{-1})	LMP_ from_ bus ($/MWh)	LMP_ to_bus ($/MWh)
41	7	29	4434.3	35.097	108.3
8	8	9	793.81	39.668	45.086
22	7	8	410.66	35.097	39.668
70	54	55	296.25	71.189	50.419
69	53	54	219.86	93.292	71.189
72	44	45	166.75	54.313	48.328
6	6	7	145.24	40.092	35.097
80	9	55	114.42	45.086	50.419
43	30	31	110.32	106.54	133.89
42	25	30	99.7	93.675	106.54
44	31	32	80.444	133.89	90.314
10	9	11	71.674	45.086	46.995
64	50	51	60.537	50.623	47.034
55	41	42	55.081	49.663	55.265
9	9	10	48.086	45.086	46.816
49	36	37	41.227	64.945	62.34
47	34	35	36.413	74.388	69.383
3	3	4	30.347	44.749	43.794
35	24	25	28.103	89.752	93.675
34	23	24	20.579	61.717	89.752
20	4	18	19.955	43.794	44.93
11	9	12	14.831	45.086	46.479
28	14	15	11.986	46.834	46.488
71	11	43	9.6853	46.995	47.654
59	14	46	8.9331	46.834	47.035
77	57	56	7.789	61.163	59.023
4	4	5	6.1262	43.794	41.524
31	21	20	5.4991	59.303	55.85
23	10	12	4.3101	46.816	46.479
76	39	57	3.4854	62.302	61.163
27	12	17	2.014	46.479	46.005
32	21	22	1.0571	59.303	59.967
52	36	40	0.9022	64.945	64.571
26	12	16	0.3590	46.479	46.512
51	37	39	0.1160	62.34	62.302

be transmitted over the transmission corridors. So when the network's load rises, the power flow across numerous lines exceeds the line's original capacity. Our goal with generation rescheduling in the presence of DG is to eliminate violations by introducing as minimum DG as possible into the network.

2) EVALUATION UNDER HSO METHODOLOGY FOR IEEE-57 BUS SETUP

The proposed methodology of HSO as discussed in section VI-B & determination of the optimal location of DG as discussed in section VII has been tested on IEEE-57 setup; the best results are obtained in round 18 which are represented in Table.20.

3) COMPARISON BETWEEN DIFFERENT PARAMETERS FOR IEEE-30 & IEEE-57 BUS SET-UP FOR TRANSMISSION CONGESTION REGULATION

The comparison of the various results obtained with the PSO and HSO is illustrated with the help of Figure 10 to Figure 14. Figure.10 shows the factor of transmission congestion for IEEE-30 bus and IEEE-57 bus systems using PSO and HSO algorithms. Similarly, voltage profile improvement, active power loss reduction, price metric (PM) reduction, and functionality Z comparison using HSO in comparison with PSO for IEEE-30 bus and IEEE-57 are shown in Figure 11, Figure 12, Figure 13, and Figure 14, respectively.

4) DESCRIPTION OF RESULTS

Congestion can be generated in the network by rising demand across the entire network by a 100 percent increase in loading conditions which may be the due expansion of infrastructure and development activities. Using the TCC and LMP approach; the optimal locations for placement of Distributed Generators come out to be bus numbers 8, 6, 28, and 3 for

TABLE 15. OPF for IEEE-57 bus under PSO.

Branch	From_ Bus	To_ Bus	Pl_{ij}^{max} (MW)	Pl_{ij}^{base} (MW)	Pl_{ij}^{ALI} (MW)	Pl_{ij}^{dg} (MW)
1	1	2	0	102.08	655.65	97.542
3	3	4	0	60.212	373.59	210.83
4	4	5	0	13.798	121.58	63.130
6	6	7	0	17.778	63.691	19.546
8	8	9	0	178.02	125.63	50.762
13	13	14	0	10.354	137.34	33.616
15	1	15	0	148.98	742.73	182.47
20	4	18	0	17.872	38.310	34.193
25	12	13	0	0.4860	83.060	1.6420
28	14	15	0	68.835	270.66	80.682
30	19	20	0	1.2266	6.1199	1.1180
40	28	29	0	24.901	37.797	34.842
41	7	29	62	60.090	106.82	52.89
44	31	32	0	2.0279	4.6925	2.8043
47	34	35	0	7.4603	15.872	16.134
52	36	40	0	3.4647	8.2019	7.7508
67	29	52	0	17.916	33.829	19.232
69	53	54	0	7.5709	18.205	30.966
70	54	55	0	11.824	27.285	1.5096
80	9	55	0	18.933	42.470	12.074

TABLE 16. Lines violating the power flow limit after load increment and power flow improvement after placement of DG for IEEE-57 setup under PSO.

Branch	From_ Bus	To_Bus	PF_Orig (MW)	PF_Ali (MW)	PF_DG (MW)
41	7	29	62	106.82	52.89

TABLE 17. Optimal scheduling of generators for IEEE-57 for efficient congestion management under PSO.

Gen_1 (MW)	Gen_2 (MW)	Gen_3 (MW)	Gen_4 (MW)	Gen_5 (MW)	Gen_6 (MW)	Gen_7 (MW)
540.25	42.202	30.718	57.323	198.35	31.441	146.97

TABLE 18. Optimal size of DG by PSO in IEEE-57 bus.

Bus Location	DG No.	Best Optimal Size (MW) Round 42	Worst Optimal Size (MW) Round 18
27	DG1	68.16	193.70
7	DG2	27.09	200
54	DG3	42.60	200
55	DG4	0	0
	Total Cumulative Sizing	137.85	593.70

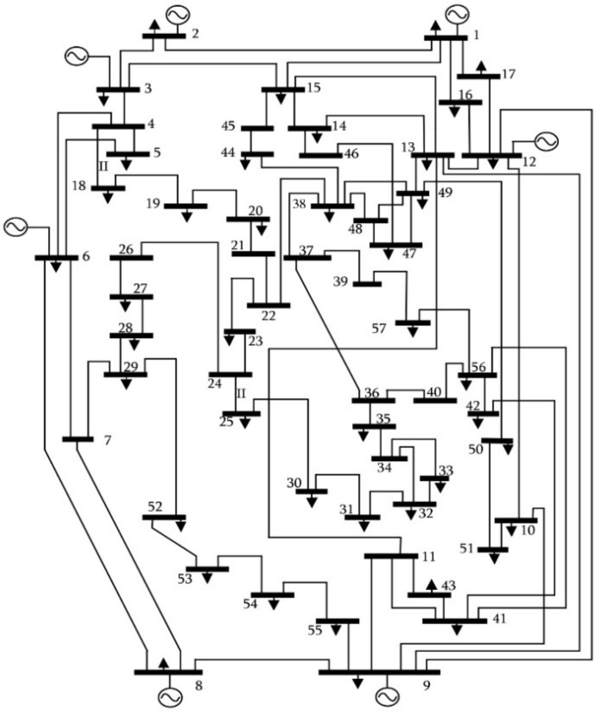

FIGURE 7. IEEE 57 bus setup [41].

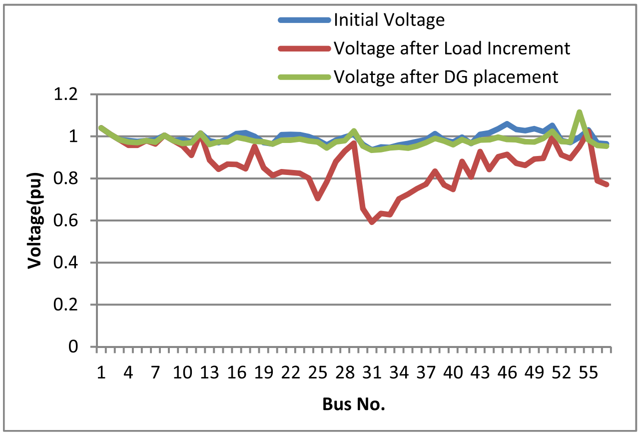

FIGURE 8. Voltage profile enhancement after placement of DG in IEEE-57 bus under PSO.

TABLE 19. Power loss reduction after placement of DG in IEEE-57 bus under PSO.

P_{loss}^{0} (MW)	P_{loss}^{ALI} (MW)	P_{loss}^{dg} (MW)	
		Round 42	Round 18(worst)
27.86	629.41	129.56	147.12

IEEE 30 bus and buses no. 29, 7, 54, and 55 for the IEEE-57 bus system. The next challenge is an optimal rescheduling of conventional generators and optimum DG sizing in the most efficient manner to alleviate congestion in lines and simultaneously minimize the real power loss and voltage profile enhancement of the network after an increase in loading conditions. The optimal power flow solution of the IEEE 30 bus and IEEE 57 bus system is shown in Table 2 and Table. 15 which shows the power flow in various lines for

TABLE 20. OPF for IEEE-57 bus under HSO.

Branch	From_ Bus	To_ Bus	Pl_{ij}^{max} (MW)	Pl_{ij}^{base} (MW)	Pl_{ij}^{ALI} (MW)	Pl_{ij}^{dg} (MW)
1	1	2	0	102.08	655.65	1.3189
2	2	3	0	97.772	616.62	7.1937
5	4	6	0	14.156	167.64	88.439
6	6	7	0	17.778	63.691	18.390
8	8	9	0	178.02	125.63	127.25
13	13	14	0	10.354	137.34	13.018
14	13	15	0	48.892	241.18	25.508
16	1	16	0	79.247	392.37	129.64
21	5	6	0	0.6681	84.271	48.314
22	7	8	0	77.935	43.987	29.277
27	12	17	0	48.461	247.73	59.545
28	14	15	0	68.835	270.66	31.115
29	18	19	0	4.6343	13.836	2.9465
32	21	22	0	1.0790	1.3371	9.9159
38	26	27	0	10.536	6.9473	16.206
40	28	29	0	24.901	37.797	11.302
41	7	29	62	60.090	106.82	50.945
42	25	30	0	7.5590	15.404	5.0899
45	32	33	0	3.8078	7.6610	4.3693
52	36	40	0	3.4647	8.2019	6.5068
54	11	41	0	9.1869	18.020	11.806
57	38	44	0	24.345	78.524	43.794
59	14	46	0	47.894	105.82	82.268
65	10	51	0	29.642	51.351	24.114
67	29	52	0	17.916	33.829	8.9967
70	54	55	0	11.824	27.285	10.580
71	11	43	0	13.594	26.763	19.160
74	56	41	0	5.4294	10.185	5.2003
77	57	56	0	2.8473	4.8575	1.2011
80	9	55	0	18.93	42.470	2.9949

TABLE 21. Lines violating the power flow limit after load increment and power flow improvement after placement of DG for IEEE-57 setup under HSO.

Branch	From_ Bus	To_Bus	PF_Orig (MW)	PF_Ali (MW)	PF_DG (MW)
41	7	29	62	106.82	50.945

TABLE 22. Optimal scheduling of generators for IEEE-57 for efficient congestion management under HSO.

Gen_1 (MW)	Gen_2 (MW)	Gen_3 (MW)	Gen_4 (MW)	Gen_5 (MW)	Gen_6 (MW)	Gen_7 (MW)
222.49	46.927	92.665	34.629	33.924	60.018	92.348

the base case, after load increment and after placement of optimum sized DG implementing PSO which clearly shows that improvement in power flow alleviates congestion plus rendering scope for further accommodation of load as per requirements.

TABLE 23. Optimal size of DG by HSO in IEEE-57 bus.

Bus Location	DG No.	Best Optimal Size (MW) Round 26	Worst Optimal Size (MW) Round 37
27	DG1	2.96	193.701
7	DG2	62.09	200
54	DG3	62.46	200
55	DG4	0	0
	Total Cumulative Sizing	127.51	593.701

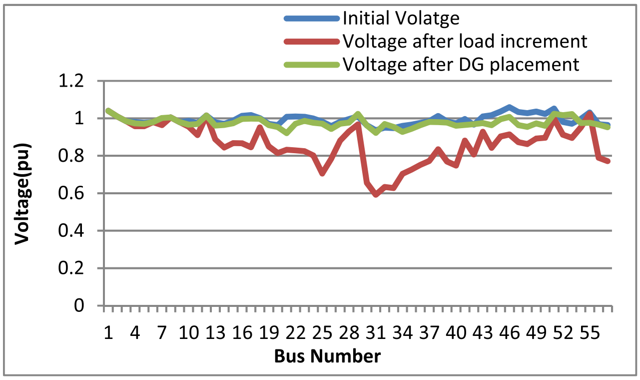

FIGURE 9. Voltage profile enhancement after placement of DG under HSO in IEEE-57 bus.

TABLE 24. Power loss reduction after placement of DG in IEEE-57 setup under HSO.

P_{loss}^{0} (MW)	P_{loss}^{ALI} (MW)	P_{loss}^{dg} (MW)	
27.86	629.413	Round 26	Round 37(worst)
		118.85	172.41

TABLE 25. Comparison of total power loss after placement of DG for IEEE-57 setup.

Type of Technique	Pl_{loss}^{dg} Total Power Loss(MW)	
	Best Results during optimization	Worst Results during optimization
Hybrid Swarm Optimization	118.85	172.41
PSO	129.56	147.12

TABLE 26. Comparison of effective total DG size for management of congestion for IEEE-57 setup.

Type of Technique	Total Cumulative DG Size (MW)	
	Best Results during optimization	Worst Results during optimization
Hybrid Swarm Optimization	127.51	593.701
PSO	137.85	593.70

Table.3 and Table.16 show lines violating the power flow limit after load increment and effective power flow management after placement of DG implementing PSO for IEEE-30

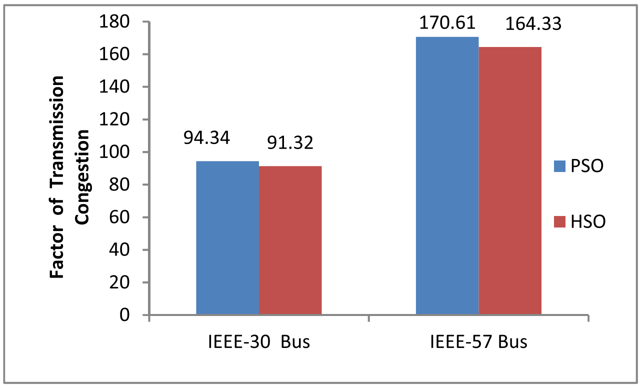

FIGURE 10. Comparison of factor of transmission congestion.

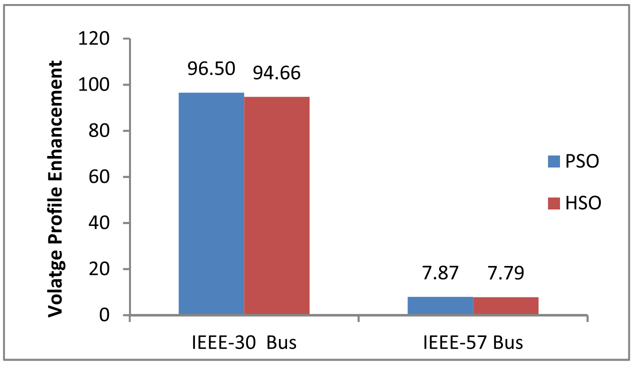

FIGURE 11. Comparison of voltage profile enhancement.

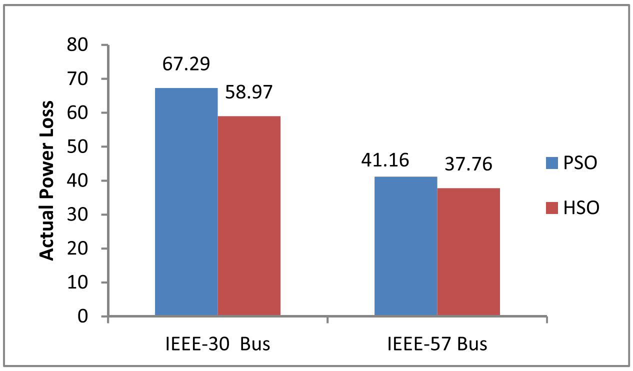

FIGURE 12. Comparison of active power loss.

and 57 bus systems. Table 4 and Table 17 show the Optimal Scheduling of Generators by PSO for Efficient Congestion Management. Table 5 and Table.18 show the Optimal Sizing of DG by PSO for placement at optimal locations of buses for effective management of congested Lines for the two networks. Table 6 & Table.19 shows total power loss in lines in the base case, after load increment and after placement of optimal sixed DG which gets effectively reduced by implementing PSO methodology. Figure.5 & Figure.8 shows the voltage profile of buses in the base case, after load increment, and after placement of DG resulting in improvement in the profile of voltage by optimal positioning & sizing of DG

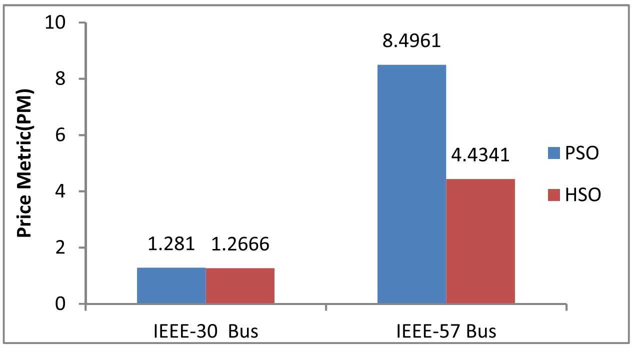

FIGURE 13. Comparison of Price Metric (PM).

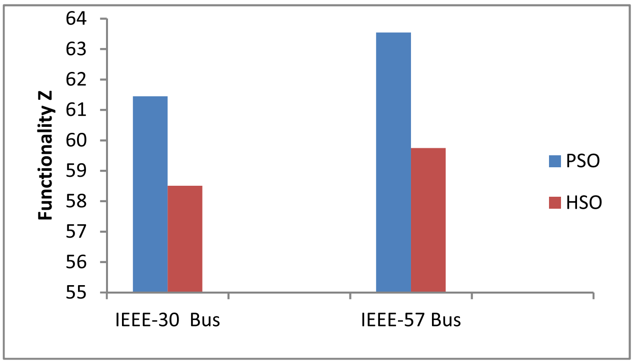

FIGURE 14. Functionality Z comparison for PSO & HSO.

implementing PSO for IEEE-30 and IEEE-57 bus systems. Table.7 and Table.20 show the optimal power flow solution for IEEE 30 and IEEE-57 bus Systems which clearly shows improvement in power transmission capability of lines following load increment and after placement of optimal sized DG using the Hybrid swarm optimization Approach. Table.8 and Table.21 show lines violating the power flow limit after load increment and power flow management after placement of optimally sized DG under HSO for the two networks under consideration rendering further scope of addition of new load if required. Table.9 and Table.22 present optimal Scheduling of generators by a Hybrid Approach for efficient congestion management. Table 10 and Table.23 give the Optimal Sizing of DG by Hybrid Approach for placement at optimal locations of buses for IEEE-30 and IEEE-57 buses for effective management of congested lines. Table.11 and Table.24 show the total power loss of lines during the base case, after load increment, and after the placement of DG implementing the Hybrid methodology. Figure.6 and Figure.9 represent the voltage profile in the base case; after load increment and after placement of DG using the Hybrid Approach leading to enhancement in voltage profile. The comparison of different parameters like total power loss reduction and selection of optimal DG size between hybrid approach and PSO is shown in Table.12 & Table.13 for IEEE-30 bus and in Table.25 & Table.26 for IEEE-57 bus systems. Although both PSO and HSO provide significant improvement for both systems, the

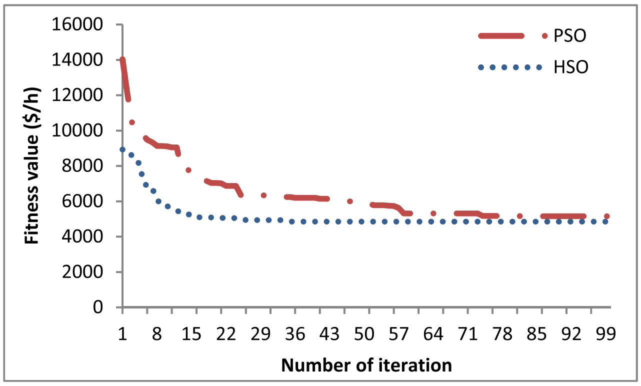

FIGURE 15. Convergence characteristic for IEEE 30 bus system.

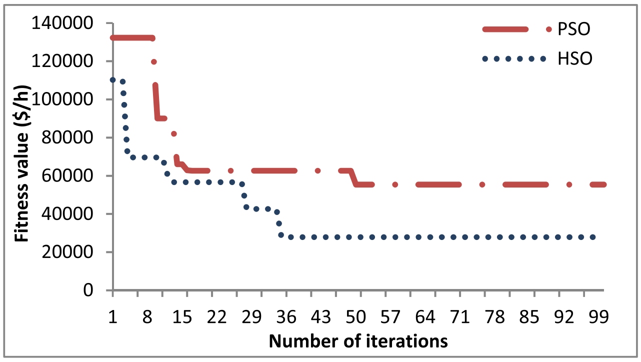

FIGURE 16. Convergence characteristic for IEEE 57 bus system.

HSO outplays the PSO in terms of reduction of power loss and also in terms of determining optimal cumulative DG size for effective congestion management. Also, from Figure.10 to Figure. 14; it can be analyzed that HSO performs better than PSO in order to improve the technological and economic performance of the two networks under consideration. The performance of the HSO is also compared with PSO in terms of its ability to converge for the fitness function. The convergence characteristics of PSO and HSO for IEEE-30 and IEEE-57 bus systems are shown in Figure.15 and Figure.16 respectively. From both the figures, it can be revealed that the HSO algorithm converges more rapidly than the PSO algorithm for both systems. For the IEEE-30 bus system, the HSO converges in 27 iterations while the PSO converges in 58 iterations. Similarly, for the IEEE-57-bus system, the HSO converges in 35 iterations while PSO converges in 51 iterations. Also, HSO gives a more optimized value of the fitness function as compared to PSO for both systems.

VIII. CONCLUSION

This article shows a congestion management methodology based on utilizing the optimal capabilities of distributed generators. TCC based on LMP is used for finding the optimal location for the placement of DG. The article also proposed a new algorithm called hybrid swarm optimization (HSO) demonstrating the efficacy of the implemented currently pbest-r mutation methodology in HSO which simply selects more favorable solutions with a higher probability for the determination of optimal sizing of DG along with optimal rescheduling of conventional generators and compared the results with PSO algorithm which is already a well-established state of art methodology in optimization techniques compared to other existing techniques in the literature. The results obtained show that the proposed hybrid technique of HSO is far more effective in alleviating congestion throughout the network during overloading conditions by efficiently determining the size of DG in comparison to PSO. Also, the scope for the accommodation of future load in case of expansion activities along with improvement in power flow, minimization of line losses, and voltage profile improvement utilizing optimal capabilities of DG is estimated effectively. In addition to achieving optimal congestion management in terms of the economy of the system apart from technological aspects, it is revealed from the results that HSO gives better performance in terms of minimization of line losses and estimation of cumulative DG size as compared to PSO to fulfill the load demand. Thus, the alleviation of congestion throughout the network is achieved with the proposed algorithm effectively with enhancement in technological and economic performance which leads to minimization in investment expenditure in comparison to PSO.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this research article and any relevant information related to the current study are available from the corresponding authors upon reasonable request.

COMPETING INTERESTS

The authors have no conflicts of interest to declare.

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