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RESEARCH ARTICLE

COST OPTIMIZATION OF ENERGY STORAGE SYSTEMS BASED ON WIND RESOURCES USING GRAVITATIONAL SEARCH ALGORITHM

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Abstract

Proper placement of energy storage system in distributed generation is still a challenging, because of its size and their location. Energy Storage System (ESS) plays a significant role in both the utility and distributed power systems. Among their benefits, the salient features are minimizing the power system cost and improving its voltage profile. Due to improper size and placement of energy storage units leads to undesired power system cost as well as the risk of voltage stability. To solve this problem, Gravitational Search Algorithm (GSA) approach is proposed in this paper to minimize the total system cost and improve the voltage profile of the system by searching the sitting and sizing of storage units. In GSA, every mass attracts towards others due to gravitational field so the heavier mass attains the optimal solution to the problem. Here the optimal solution represents the best location of Energy Storage System (ESS) in wind energy system. The IEEE 30 Bus system is incorporated for the simulation to find out the optimal location and with low operation cost. The presented results with GSA evident that the optimality and reliability of the solution.

Introduction:-

In present scenario, the increased energy consumption and environmental pollution is a serious problem. The renewable energy resource plays an important role to satisfy the need of energy consumption. However, a high penetration of wind energy raises a problem because it's a seasonal one and causes system instability. The best solution to ensure the system stability is the integration of Energy Storage System (ESS).

Generally, distributed generation is defined as the electric power generation within distribution networks, various definitions of DG and environmental impact, location then some of the distribution network issues [1]. As mentioned above due to improper size of ESS. The total expected power system cost increased. The solution to this problem is by placing the best location. It provides many benefits such as improve power quality and power stability thereby reducing the power system cost. The rapid development in ESS technology, preferably large-scale energy storage systems have been come into attention nowadays. Many countries widely used this ESS. The importance of ESS for distributed generation [2]. An economic dispatch and optimal capacity of ESS [3] multi-pass dynamic programming is used to solve the economic dispatch of BES thereby maximizing the fuel cost savings.

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The Net Present Value (NPV) method for the optimal allocation and economic analysis of energy storage system in low voltage Micro-grid system [4]. To find the maximal NPV a matrix real coded genetic algorithm is used. A Genetic Algorithm (GA) [5] based on multiple objective functions. To evaluate the economic impact of energy storage specific cost on net present value of energy storage installations in distribution substations.

A stochastic optimal algorithm [6] is developed for sizing the ESS in an isolated wind-diesel power system. Here wind penetration, ESS efficiency and diesel operating strategy are considered to minimize the cost of supplied energy. A Particle Swarm Optimization (PSO) [7] is employed to achieve optimal dispatch of controllable loads and generators. The effective utilization of ESS in Micro-grid reduces the cost. A new approach of modified particle swarm optimization based on multi-objective optimization algorithm is used to solve the energy storage design problem [8] in distributed systems. In Multi-objective Particle Swarm Optimization (MOPSO) [9] is adopted differential evolution algorithm to optimize the operation of interconnected Micro-grid system. It comprises a variety of distributed energy resources and storage devices to reduce the annual cost of the electricity.

The new technique of probabilistic load flow algorithm [10] uses a linear approximation method to obtain the power distribution of wind. Then a five-point estimation method is solved and IEEE118 bus system has been tested. The economic allocation of Energy Storage System considering the wind distribution using a hybrid method of Multi-objective PSO [11] to reduce the power system cost. Energy Storage System plays a major role to store the power from the generator output. Various types of batteries are used to store the energy [12] the sodium-ion batteries are used for present challenges to become low cost.

The meta-heuristic based Optimization techniques such as Central Force Optimization (CFO), Bacterial Swarm Optimization (BSO), Biogeography Based optimization (BBO), Bat Motivated Optimization (BMO), Ant Colony optimization (ACO) etc. CFO [13] technique it does not use any random parameter for its formulation while GSA is stochastic algorithm. The probabilistic power flow method (Newton Raphson) is used to solve the power flow equations considering the wind distribution. BSO [14] is employed to schedule the thermal generators. Even though BSO is employed to solve the problem, it has complex steps involved to solve the problem. Similarly, the BBO solves and schedules the optimal operation of DG connected to micro grid [15, 16]. Sometimes the BBO algorithm struck in local optima so this algorithm fails. The BMO [17] is tried for optimal placement and sizing of distributed power resources in micro grid, the rational algorithm steps makes the problem solving in a complex manner. The optimal power flow is carried out using ACO [18] with considering ecological emissions; the application of ACO leads the solution to poor.

In this paper, Gravitational Search Algorithm (GSA) [19] is implemented for allocating Energy Storage System to minimize the power system operation cost. When compared to other algorithms GSA is best of its convergence rate. For example, the Particle Swarm Optimization technique simulates the social behavior of birds but GSA inspires by the physical phenomena. Then IEEE 30-bus test system [20] is used to implement the proposed algorithm.

The remaining sections of this paper: section-II about the problem formulation based on the distribution of wind power and probabilistic power flow method. Section-III provides a brief description of heuristic algorithms and the principle of GSA. In section-IV, the problem formulation is implemented with GSA. In Section-V the proposed GSA is verified for IEEE 30-bus test system using MATLAB.

Formulation of Economic Energy Storage of Wind Energy Resources:-

The optimal placement and sizing of ESS problem is formulated as constrained non-linear integer optimization problem with both location and sizes of storage devices being discrete. The objective functions are restricted by equality and inequality constraints.

Discretizing Wind Distribution:-

The optimal allocation for ESS by considering the distribution of wind power is taken [21]. The concept of discretizing the wind power is to calculate the first few moments of wind power distribution.

Wind Distribution:-

Wei-bull distribution is the best method to provide the probabilistic description of wind speed. The Wei-bull distribution has more flexibility is defined as follows,

$$f(x/\lambda,k)=\frac{k}{\lambda}\left(\frac{\lambda}{x}\right)^{k\ 1} e^{\left(\frac{x}{\lambda}\right)^{k}} \quad (1)$$

Where

k Shape parameter of wind speed

λ Scale parameter of wind speed

Discretizing Wind Power Distribution:-

Discretization means to group the values of continuous random variable into a finite group. First, the probability of zero power and rated power is computed as follows,

$$P_i = prob\{Y=0\} = prob(X \le V_{ci}) + prob(X > V_{co}) \quad (2)$$

$$P_n = prob\{Y=M\} = prob(V_{no} \le X \le V_{co}) \quad (3)$$

For $V_{ci} \le X \le V_{no}$, the probability density function of Y is defined as simple manner as shown below,

$$\tilde{f}Y(y/\lambda,k) = \frac{\frac{1}{\beta} f\left(\frac{y-\alpha}{\beta} \Big/ \lambda,k\right)}{1-P_i-P_n} \quad (4)$$

$$\int_0^M \tilde{f}Y(y \mid \lambda,k)dy = 1 \quad (5)$$

To Discretization of the continuous component of Y, is defined by

$$\tilde{\mu}Y = \int_0^M y\ \tilde{f}Y(y/\lambda,k)dy \quad (6)$$

$$\tilde{\sigma}^2 Y = \int_0^M \left(y-\tilde{\mu Y}\right)^2 \tilde{f}Y(y \mid \lambda,k)dy \quad (7)$$

$$\lambda_j = \int_0^M \left(\frac{y-\tilde{\mu}}{\tilde{\sigma}Y}\right) \tilde{f}Y(Y/\lambda,k)dy \quad (8)$$

Where

$\tilde{\mu}Y$	Mean of Y
$\tilde{\sigma}Y$	Standard deviation of Y
λ_j	j th central moment of Y
Y	Injected power
X	Actual wind speed
M	Maximum power of wind turbine
α,β	Linear co-efficient
V_{ci}	Cut-in wind speed
V_{co}	Cut-out wind speed
V_{no}	Normal wind speed

The moment equations are given by,

$$\sum_{i=1}^{n} p_i z_i = \lambda_j \qquad \text{for j = 1, 2, 3, 4} \quad (9)$$

Let $z = \left(y - \tilde{\mu}Y / \tilde{\sigma}Y\right)$ is a standard value of Y and p_i is the probability corresponding to z_i.

The above equations are solved by discrete distribution of finite groups are obtained with corresponding locations for $\tilde{f}Y$ .then the estimated point Y_i and associated probabilities P_i is found.

Objective Function:-

The aim of this project is to allocating the ESSs and generator output optimally thereby reducing the total expected system operation cost and improve the voltage profile, by considering the wind power. The multi-objective function is given by

$$\min f_1 = \sum_{i=1}^{5} prob_i - \cos t_i \tag{10}$$

$$\min f_2 = \sum_{k=1}^{n} \left(\frac{v_k - v_k^{spec}}{\Delta v_k^{\max}} \right)^2 \tag{11}$$

Where

n	Total number of bus node;
v_k^{spec}	Expected voltage;
$\Delta v_k^{\max}$	Maximum of voltage deviation;
$prob_i$	Probability of operation cost at the i scenario;
$\cos t_i$	Total operation cost at the *i* scenario (\$/h);

$$\begin{aligned} \cos t_i &= \sum_{j=1}^{NG} C(P_{Gi}) + C_w + C_s \\ &= \sum_{j=1}^{NG} \left(a_j + b_j \cdot P_{Gj} + c_j \cdot P_{Gj}^2 \right) \quad + c^{opw} \cdot P_{wind} + c^{ops} \cdot P_{storage} \end{aligned} \tag{12}$$

Where

NG	Number of generators;
$C(P_{Gi})$	Fuel cost of generator i (\$/h)
C_w	Cost of wind power generator (\$/h)
C_s	Cost of energy storage system (\$/h)
a_i, b_i, c_i	Fuel cost coefficients of generator *i*
c^{opw}	Operation cost of wind power generator (\$/h)
P_{wind}	Power of wind power generator (MW)
c^{ops}	Operation cost of ESS (\$/MWh)
$P_{storage}$	Capacity of installed ESS (mw)

The main objective function is to calculate the total operation cost of the system and thereby by reducing the total expected system cost and optimally allocating the energy storage system. Wind power generation is a renewable one and voltage will fluctuate hence the improvement of voltage profile is the second objective function.

Problem Constraints:-

There are two types of constraints are considered to solve this problem equality and inequality constraints.

Equality constraints:-

The equality constraints are related to non-linear power flow equations. In this paper Newton-Raphson power flow method is used to solve the equality constraints.

$$P_i = V_i \sum_{j=1}^{n} V_j \left(G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij} \right) \tag{13}$$

$$Q_i = V_i \sum_{j=1}^{n} V_j \left(G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij} \right) \quad (14)$$

Where

P_i Real part of v_i (voltage of bus i)

Q_i Imaginary of v_i (voltage of bus i)

Inequality Constraints:-

These are associated with reactive power of generation, tap of transformer and bus voltage are shown below.

$$V_{\min} \le V_i \le V_{\max} \quad (15)$$

$$T_{\min} \le T_i \le T_{\max} \quad (16)$$

$$Q_{G\min} \le Q_{Gi} \le Q_{G\max} \quad (17)$$

Where

V_i Rms value of the bus i voltage

T_i Tap of transformer i

Q_{Gi} Reactive power of generator i

Gravitational Search Algorithm:-

GSA is developed by Esmat Rashedi and Hossein Nezamabadi-pour in 2009. The basic idea behind this algorithm is Newton's law. This algorithm is based on the Newtonian gravity: "Every particle in the universe attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them". Hence, named as Gravitational Search Algorithm.

Principle of GSA:-

In GSA the agents are considered as objects and their performance is measured by their masses. All objects attract each other by a gravity force and this force causes a global movement of all objects towards the object with heavier masses. Thereby those heavier masses are corresponds to good solutions. This principle is detailed and shown in Fig.1. These masses obey the following laws:

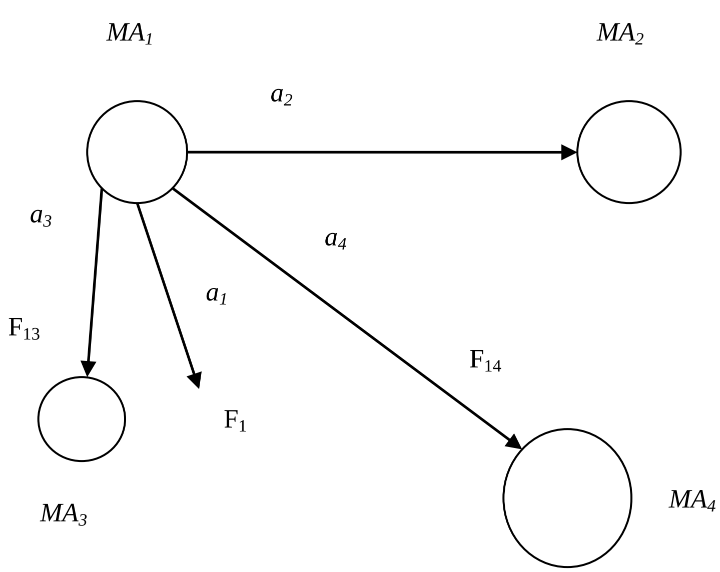

Fig. 1:- Principle of GSA

Law of gravity:-

Each particle attracts every other particle and a gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the distance between them.

Law of motion:-

The current velocity of any mass is equal to the sum of the fraction of its previous velocity and the variation in the velocity. Variation in the velocity or acceleration of any mass is equal to the force acted on the system divided by mass of inertia. The following equations represent the solution to the optimization problem and hence these are considered a system with N agents

$$O_i = \left(O_i^1, \ldots, O_i^d, \ldots, O_i^n\right) \qquad \text{for } i=1, 2, \ldots..S \tag{18}$$

Where X_i^d represents the position of *i*th agent in the *d*th dimension. At some specific time the force acting on from one mass to another mass then is defined as:

$$Force_{ij}^d(t) = G(t)\frac{Mass_{pi}(t) \times Mass_{aj}(t)}{E_{ij}(t) + \varepsilon}\left(O_j^d(t) - O_i^d(t)\right) \tag{19}$$

Where

O_i^d	Position of i th agent in the d th dimension
$Mass_{aj}$	Active gravitational mass related to agent j
$Mass_{pi}$	Passive gravitational mass related to agent i
$G(t)$	Gravitational constant at time t
ε	Constant value
$E_{ij}(t)$	Euclidian distance between two agents i and j

The law of motion, the acceleration found. Then the velocity of an agent is considered a fraction of its current velocity added to the old acceleration value. Therefore, its position and its velocity calculated by the following equation:

$$vel_i^d(t+1) = rand_i \times vel_i^d(t) + acc_i^d(t) \tag{20}$$

$$X_i^d(t+1) = X_i^d(t) + vel_i^d(t+1) \tag{21}$$

Gravitational and inertial masses are calculated by the fitness evaluation. Then update the gravitational and inertial masses by the following equations:

$$Mass_{ai} = Mass_{pi} = Mass_{ii} = Mass_i \qquad i=1, 2\ldots S \tag{22}$$

$$mass_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \tag{23}$$

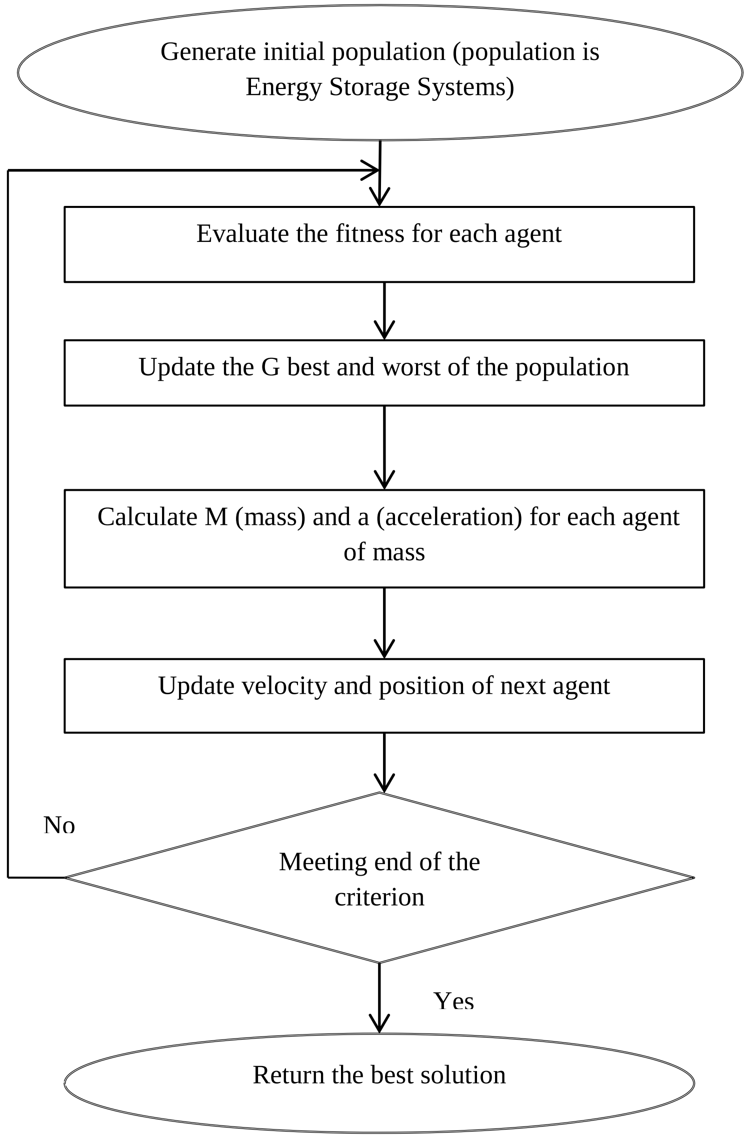

Fig. 2:- Flowchart of Gravitational Search Algorithm

Pseudo code of GSA:-

The flowchart of GSA algorithm presented in Fig. 2. The pseudo code of the proposed algorithm is given below

Step 1: Search the space identification for no of agents.
Step 2: Randomized initialization of each agent (masses).
Step 3: Fitness evaluation of agents.
Step 4: Update G(t), best(t), worst(t) and $Mass_i$ (t) for i = 1, 2, ,S.
Step 5: Calculation of the total force in different directions.
Step 6: Calculation of acceleration and velocity for next agent.
Step 7: Updating agent's position.
Step 8: Repeat steps 3 to 7 until the stop criteria is reached.
Step 9: End.

Implementation of Gravitational Search Algorithm to Energy Storage System on Wind Resources:-
The following steps solve the implementation of gravitational search algorithm with the IEEE-30 bus system. The number of agents is considered as ESS. The Euclidian distance is the distance between bus 1 and bus 2. Force is considered as an actual wind speed. The following steps are shown below,
Step-1:- Consider the system with N agents and define the position of its i^{th} agent by the following formula,

$$O_i = \left(O_i^1, \ldots, O_i^d, \ldots, O_i^n\right) \qquad \text{for } i=1, 2, \ldots S. \tag{24}$$

Step-2:- Define the force acting on from one mass to another mass at specific time *t***,** it should be calculated by,

$$Force_{ij}^d(t) = G(t)\frac{Mass_{pi}(t) \times Mass_{aj}(t)}{E_{ij}(t) + \varepsilon}\left(O_j^d(t) - O_i^d(t)\right) \tag{25}$$

Step-3:- Total force acts on the agent in dimension are randomly weighted and acceleration of this agent at time *t* is calculated. To find acceleration this formula should be used,

$$acc_i^d(t) = \left(\frac{force_i^d(t)}{mass_{ii}(t)}\right) \tag{26}$$

Step-4:- Next velocity of a new agent is considered and its current velocity added to its acceleration. Therefore, position and velocity is calculated.

$$vel_i^d(t+1) = rand_i \times vel_i^d(t) + acc_i^d(t) \tag{27}$$

$$O_i^d(t+1) = O_i^d(t) + vel_i^d(t+1) \tag{28}$$

Step-5:- Gravitational constant initialized in the beginning will reduced with time to control the search accuracy. Then update the gravitational and inertial mass.

$$Mass_{ai} = Mass_{pi} = Mass_{ii} = Mass_i \qquad i=1, 2\ldots S \tag{29}$$

Results and Discussion:-
The proposed GSA has been applied to standard IEEE 30-bus system shown in Fig. 3 is selected to perform the three cases. The system consists of 20 loads and 5 generations where bus-1 is the slack bus. Bus 5, 8, 11, 13 are PV buses and remaining buses are PQ bus.

Case 1:- The regular load flow analysis for the system considering the wind power without ESS installed. The resultant bus voltages, operation cost, and losses of Case 1 are listed in Table 1. When the wind power increases automatically the system operation cost and power loss reduced.

The total operation cost varies from 10 626.5 $/hr to 8577.0 $/hr according to the changes of wind power from 0 to 113 MW. In addition to that, the system experiences both low and high voltage problems. When the wind power is less than 55.79 MW, the voltage at the wind generator bus experiences a low-voltage problem. For instance, the voltage drops to 0.976 p.u. when the wind power is 0 MW.

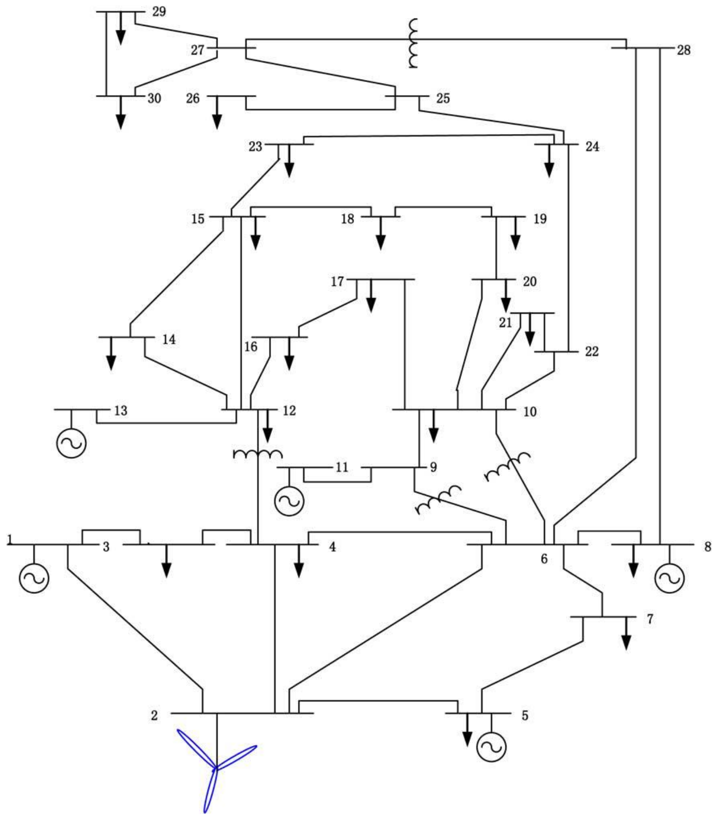

Fig. 3:- IEEE 30-Bus System

Under this condition, even if the voltages at the generator buses 11 and 13 are increased to 1.082 and 1.071 p.u. respectively, the low voltages still appear at buses 2, 4, 29 and 30.

Table1:- Voltage Profile and Power Loss data for Case-1 Incorporating without ESS Installation.

Wind Power	**0 (MW)**	**55.79 (MW)**	**113(MW)**
Bus	**Voltage (p.u)**	**Voltage (p.u)**	**Voltage (p.u)**
1	1.060	1.068	1.065
2	0.976	0.982	1.013
3	1.007	1.007	1.013
4	0.987	0.996	1.003
5	1.018	1.019	1.018
6	0.996	1.018	1.015
7	0.994	0.997	0.999
8	1.014	1.012	1.013
9	1.042	1.045	1.047
10	1.035	1.038	1.041
11	1.082	1.082	1.082
12	1.048	1.051	1.054
13	1.071	1.071	1.071
14	1.033	1.034	1.039
15	1.028	1.021	1.034
16	1.035	1.038	1.042
17	1.035	1.033	1.036
18	1.018	1.021	1.024
19	1.015	1.019	1.022

Wind Power	0 (MW)	55.79 (MW)	113(MW)
Bus	**Voltage (p.u)**	**Voltage (p.u)**	**Voltage (p.u)**
20	1.019	1.023	1.026
21	1.022	1.023	1.032
22	1.023	1.024	1.033
23	1.017	1.018	1.023
24	1.011	1.012	1.017
25	0.988	1.008	1.007
26	0.988	0.989	0.999
27	1.011	1.015	1.018
28	0.996	0.999	1.001
29	0.991	0.998	0.987
30	0.980	0.981	0.987
Operation Cost ($/hr)	10626.5	9344.1	8577.0
Total real power loss (MW)	43.092	29.188	19.585

Case 2:- The optimal load flow analysis used to find the ESS allocation under zero wind power. In this case, the optimal load flow analysis is implemented to determine the locations and the corresponding sizes of ESS under the zero wind power situations. The system with the obtained ESS is then applied by the same three scenarios and system conditions as in Case 1.

In this case, buses 6, 19, 22, and 28is found to be the best places to install ESS with sizes of 2.5, 18.2, 5.6, and 16 MW, respectively. The system is operated under the three different wind power situations with the given allocation of ESS. Comparing with Case 1, the total operation cost and real power loss is reduced. The fuel co-efficient are shown in Table 2.

Table 2:- IEEE 30-Bus Cost Coefficients of Generator.

Generator	a	b	c
1	0	20	0.3843
5	0	40	0.01
8	0	40	0.01
11	0	40	0.01
13	0	40	0.01

The voltages at PV buses are buses 5, 8, 11, and 13 and load areas are buses 26–30 are optimized and improved within the voltage constraints. The fuel cost coefficients given in Table 2, the expected operation cost in case 2 is equal to 9104.1 $/hr

Table 3:- Voltage Profile and Power Loss Data for Case-2 Incorporating with ESS Installation on Power Flow Method.

Wind Power	0 (MW)	55.79 (MW)	113 (MW)
Bus	**Voltage(p.u)**	**Voltage(p.u)**	**Voltage(p.u)**
1	1.065	1.063	1.064
2	1.013	1.009	1.022
3	1.004	0.997	1.013
4	0.985	0.993	1.003
5	1.001	0.992	1.017
6	0.996	0.979	1.010
7	0.994	1.054	0.999
8	1.015	1.029	1.015
9	1.042	1.066	1.047
10	1.035	1.018	1.041

Wind Power	0 (MW)	55.79 (MW)	113 (MW)
Bus	**Voltage(p.u)**	**Voltage(p.u)**	**Voltage(p.u)**
11	1.065	1.016	1.067
12	1.048	1.005	1.084
13	1.067	1.005	1.0675
14	1.033	1.013	1.039
15	1.028	1.007	1.034
16	1.035	1.011	1.042
17	1.036	1.013	1.036
18	1.018	1.026	1.024
19	1.015	1.019	1.022
20	1.019	1.013	1.026
21	1.022	1.009	1.032
22	1.023	1.015	1.033
23	1.017	0.998	1.023
24	1.011	0.996	1.017
25	0.988	0.995	1.007
26	0.988	0.977	0.999
27	1.011	1.003	1.018
28	0.909	0.993	0.989
29	0.999	0.983	0.989
30	0.988	0.971	0.978
Operation Cost ($/hr)	9451.5	9059.1	8927.0
Total real power loss (MW)	14.063	10.827	8.163
Allocation of ESS (MW)	Bus-6	Bus-22	Bus-28
	2.5	5.6	16
Total size of ESS (MW)	24.1		

Case 3:- GSA with Energy Storage System considers the entire wind power. In this case, the optimal ESS allocation considers the entire wind distribution. Due to the uncertainty in wind power, the optimal power flow used in the case 2 cannot be applied here. At the end, the size of ESSs at some buses becomes zero, which means that these buses do not need to install any ESS.

The remaining ESSs converge to their optimal allocations. Table 3 lists optimization results for three scenarios. Similar to Case 2, the total operation cost and power loss is reduced, and voltage profiles are improved, compared with Case 1. It should be noted that the expected operation cost which is 9033.9 $/hr in case 3 is much less than that in case 2. This result demonstrates that the allocation of ESS selected by the proposed algorithm GSA is much better than using the worst-case scenario.

Supposing that the system operated in one year (360 days), the operation cost will save $606,528 per year compared to the conventional optimization, which is determined by the worst case. Furthermore, even though the total size of ESS in case 3 is less than that in case 2, the voltage profile is improved more with less voltage fluctuation. This is because only the zero wind power is considered in case 2.

The calculated ESS allocations in case 2 tend to over compensate the voltage when apply to the entire wind distribution. The results also show that cases 1 and 2 have the higher voltage fluctuation. The time to operate the algorithm in case 3 once is 1.08s, which is 0.26 s less than that in case 2.

Table 4:- Voltage Profile and Power Loss Data for Case-3 Incorporating ESS Installation with GSA.

Wind Power	**0 (MW)**	**55.79 (MW)**	**113 (MW)**
Bus	**Voltage (p.u)**	**Voltage (p.u)**	**Voltage (p.u)**
1	1.065	1.068	1.063
2	1.006	1.033	1.035
3	1.002	1.007	1.013
4	0.994	0.996	1.003
5	1.002	1.012	1.017
6	0.997	1.098	1.010
7	0.993	0.997	0.999
8	1.004	1.015	1.016
9	1.024	1.029	1.042
10	1.025	1.038	1.041
11	1.037	1.029	1.018
12	1.032	1.059	1.084
13	1.042	1.014	1.057
14	1.017	1.034	1.039
15	1.013	1.021	1.034
16	1.024	1.038	1.042
17	1.016	1.033	1.036
18	1.003	1.026	1.024
19	1.000	0.978	1.020
20	1.005	0.952	1.026
21	1.008	0.968	1.020
22	1.009	0.956	1.033
23	1.003	0.997	1.023
24	0.999	0.988	1.017
25	1.001	0.994	1.007
26	0.983	0.985	0.999
27	1.010	1.006	1.018
28	0.996	0.996	0.989
29	0.998	0.993	1.016
30	0.994	0.989	1.012
Operation Cost ($/hr)	9481.5	9025.1	8599.02
Allocation of ESS (MW)	Bus-7	Bus-16	Bus-30
	12.1	9.6	7.4
Total size of ESS (MW)	29.1		

Moreover, the price of ESS is always changing and different prices will lead to various operations cost and different sizes of ESS. When the price of ESS ranges from 45 to 26 $/MWh, the operation cost decreases from 9084.0 to 7756.2 $/MW and the total installed size of ESS increases from 0 to 124.7 MW. The price of ESS rises to 44.8 $/MWh, which is much higher than the other source such as wind power or fossil energy and evident from Table 4.

Table 5:- Optimal Result Comparison of 30 Bus System (three considered Cases) with and without ESS Installation.

Parameters	**Operation Cost ($/hr)**	**Total Power Loss (MW)**	**Total Size of ESS (MW)**
System Without ESS Installation	10626.5	43.092	-
Load Flow Analysis With ESS Installation	9451.3	15.063	42.3
HMOPSO With ESS Installation	9280.8	14.019	29.2
GSA With ESS Installation	**8809.3**	**13.023**	**27.1**

The installation expense of ESS plays an important role in order to reduce the total operational cost of the system. It is clear from the above table, that the operation cost of 30 Bus systems at zero wind power is higher (10625.5 $/hr). When solved with load flow analysis, the operational cost reduced to 9451.4 $/hr, also the power loss reduced to about 65%, when compared without considering ESS installation. It is evident from the Table 5 that the proposed GSA reduces the operational cost to 17.1006 $/hr. In the same manner, the total size of ESS reduced to about 29.1 MW.

When compared with HMOPSO, the operational cost reduced to 9280.8 $/hr, also the power loss reduced to about 69% when compared with power flow analysis with ESS installation. It is evident from the Table 5 that the proposed GSA reduces the operational cost to 5.0808 $/hr. In the same manner, the total size of ESS reduced to 27.1 MW.

Conclusion:-

This paper proposes the method of improving the voltage stability and reducing the total expected system cost in Distributed Generation. The voltage at several buses is found by the power flow method and then the objective functions are subjected to some constraints. Based on the overall expected system cost calculation for optimal placement of ESS in distributed generation, the gravitational search algorithm (GSA) technique is employed for optimal allocation and the results were compared with HMOPSO technique. The IEEE 30-bus test system is considered for calculating the voltage and its result is verified by GSA using MATLAB software. The results show that the proposed GSA is able to find proper placement and size of ESS as well as minimize the total operation cost and improve voltage profiles than the other optimization technique. Further this implementation leads to the idea of implementing ESS with DG in Future Indian Power System.

References:-

1. T. Ackermann, G. Andersson and L. Soder, "Distributed Generation," a definition of Electric Power Syst Res, vol. 57, pp. 195–204, 2001.
2. Qiang Fu, Luis F. Montoya, Ashish Solanki, Adel Nasiri and David C. Yu, "Microgrid Generation Capacity Design With Renewable and Energy Storage Addressing Power Quality and Surety," IEEE Transactions on Smart Grid, vol. 3, no. 4, pp. 2019-2027, 2012.
3. Chin H. Lo and Max D. Anderson, "Economic Dispatch and optimal sizing of Battery Energy Storage Systems in Utility Load Leveling Operations," IEEE transactions on energy conversions, vol. 14, no. 3, pp. 824-829, 1999.
4. C. Chen, S. Duan, T. Cai and B. Liu, "Optimal Allocation and Economic Analysis of Energy Storage System in Micro-grids," IEEE Transactions on Power Electronics, vol. 26, no. 10, pp. 2762-2773, 2011.
5. F. Chacra, P. Bastard, G. Fleury and R. Clavreul, "Impact of Energy Storage Costs on Economic Performance in a Distribution Substation," IEEE Transactions on Power Systems, vol. 24, no. 2, pp. 684-691, 2005.
6. Abbey and G. Joos, "A Stochastic Optimization Approach to Rating of Energy Storage Systems in Wind-Diesel Isolated Grids," IEEE Transactions on power systems, vol. 24, no. 1, pp. 418-426, 2009.
7. E. Sortomme and M. A. El-Sharkawi, "Optimal Power Flow for a System of Microgrids with Controllable Loads and Battery Storage," in proc. IEEE/PES power system, pp. 1-5, 2009.
8. Y. Xu and C. Singh, "Multi-Objective Design of Energy Storage in Distribution Systems Based on Modified Particle Swarm Optimization," In proc IEEE Power and Energy Society, pp. 1-8, 2012.
9. Yasser Moustafa Atwa and E. F. El-Saadany, "Optimal Allocation of ESS in Distribution Systems with a High Penetration of Wind Energy," IEEE Transactions on Power Systems, vol. 25, no. 4, pp. 1815-1822, 2010.
10. Q. Fu and D. Yu, "Probabilistic Load Flow Analysis for Power Systems with Multi-correlated Wind Sources," in proc. IEEE Power and Energy Soc, pp.1-6, 2011.
11. Shuli Wen, Hai Lan and Qiang Fu, "Economic Allocation for Energy Storage System Considering Wind Power Distribution," IEEE Transactions on Power Systems, vol. 30, no. 2, pp. 644-652, 2015.
12. V. Palomares, P. Serras Irune Villaluenga and Karina B. Hueso, "Na-ion batteries, recent advances and present challenges to become low cost energy storage systems," in Energy and Environmental Science, 2011.
13. R. A. Formato, "Central Force Optimization", progress in Electromagnetic Research77, pp. 425-491, 2007.
14. R. Vijay and C. Subramanian Ravichandran, "Scheduling practical generating system using an improved bacterial swarm optimization," Tehnicki vjesnik, vol. 23, no. 5, pp. 1307-1315, 2016.
15. R. Vijay, "Optimal and reliable operation of micro grid using enriched Biogeography Based Optimization algorithm," Journal of Electrical Engineering, 2017. (Accepted for Publication)

16. R. Vijay and C.S Ravichandran, "Enriched biogeography-based optimization algorithm to solve economic power dispatch problem," In Proceedings of fifth international conference on soft computing for problem solving, Springer Singapore, pp. 875-888, 2016.
17. R. Vijay and C.S. Ravichandran, "Optimal placement and sizing of distributed power sources in microgrid for power loss minimization using bat motivated optimization algorithm," Asian Journal of Research in Social Sciences and Humanities, vol. 6, no. 8, pp. 252-266, 2016.
18. R. Vijay and R.C Subramanian, "Enhanced ant colony optimization to solve the optimal power flow with ecological emission," International Journal of System Assurance Engineering and Management, Springer, pp. 1-8, 2016.
19. E. Rashedi, H. Nezamabadi-pour and S. Saryazdi, "GSA: A Gravitational Search Algorithm," Electric Power Syst Res. vol. 179, pp. 2232-2248, 2009.
20. "30 Bus Power Flow Test Case" Univ. Washington [online] Available: http:/www.ee.washington.edu/research.htm.
21. C. R. Eberhart and Y. Shi, "Particle Swarm Optimization: Developments, Applications and Resources," in proc IEEE/PES Congress on Evol. Computation, Korea, pp. 81-86, 2009.