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Improvement of Wind Energy Systems by Optimizing Turbine Sizing and Placement to Enhance System Reliability

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Abstract

Wind energy and its conversion is part of renewable energy resources as cheaper and cleaner energy today even though the initial cost varies from place to place. Most of the government sector always promotes renewable energy with a provision of subsidies as observed worldwide. Wind energy is an actual solution over costlier conventional energy sources. If it is not properly placed and the selection of turbine design is not up to the mark, then investments may require more time to acquire Net Profit Value called as NPV. This research work is focused on the development of mathematical models to optimize the turbine size and locations considering all constraints such as the distance between the turbines, hub height, and investment in internal road and substation cost. Particle-Swarm-Optimization is an intelligent tool to optimize turbine place and size. The database management system is selected as the appropriate data storage platform for before and after optimization simulation. Various plots and excel outputs of .net programming are addressed for the success of optimization algorithms for the purpose of wind turbine placement and WTG design is suggested to manage wind energy such that power system reliability has been improved and the same is monitored through the reliability indices.

KEYWORDS: Reliability, Energy Management, PSO, WTG, Optimization.

I. INTRODUCTION

Combining the cost-advantage version of wind farm [1] and thinking about more than one elements and the version for comparing the advantages of growing the wide variety of wind generators in a wind-farm, a extra whole and powerful Mathematical version has been advanced to decide the most appropriate configuration. Distributed technology primarily based totally at the single-section wind-turbine placement as well as sizing issue is framed as a non-linear integer based optimization problem. The set-up of single-section wind generators in distribution structures is tremendous and calls for most appropriate placement [2]. The potentialities for producing strength from wind are characterized with the aid of using their inexhaustible availability and financial performance. Despite all of the benefits related to wind electricity, there may be a downside within side the shape of low electricity density. Therefore, to generate quantity of strength akin to that of the opposite sources, several windmills are organized in an unmarried wind farm having the trouble of wake interplay among turbine fields, due to which downstream windmills have decreased electricity output.

This drastically reduces the performance of the downstream wind mills and consequently additionally their provider life. Ample work reported in literature has motivated to gain a proper appreciative of post-run interactions by evolving post-run interaction-based models [3].

A new approach to selecting the most suitable wind turbine among several commercially available wind turbines for a given location. Jensen's wake model was adapted to account for the wake effect in [4]. Adjusting turbines in a different wind farm shape is a difficult task as there are multiple factors to consider. Ref. [5] have applied various methods to the wind-farm design problem, transforming it into a single-target optimization problem with two targets at most. The main factor in the location of the turbine is the wake effect, which is resulted in to the loss of kinetic-energy from the wind after a turbine passes over it. Current energy problems are related to technology selection and location issues, the variation in demand for energy services depending on location as well as time of use, along with new purchase options, specifically renewable energy.

Along with these problems, there are significant challenges for today's energy production [6]. Renewable energy sources (RES) are intermittent and highly dependent on a variety of factors, so it is important to use these sources with caution. BONMIN presents and solves an optimal planning model in order to minimize investment and operating costs, considering the construction of wind turbines and feed-ins, in the MATLAB/ YALMIP environment with suitable system used to establish the proposed model [7].

The optimal place and size of distributed generation (DG) is also significant for maximizing network stability. Reference [8] presents continuous power flow (CPF) method for determining the optimal position which is novel one. The tangential vector of the CPF method provides the relationship between differential voltage changes and differential charge changes. The method is also presenting detailed directions for wind analysis considering the most important boundary conditions. The optimal position and size of SVC are realized under the different loading conditions with PSO and TLBO in conjunction with the loading flow. The IEEE 14 bus power system is used [9] to show the applicability and validity of the algorithms. Comparison for simulation results of PSO and TLBO is carried out. The effectiveness of TLBO is shown by comparing the SVC simulation with and without FACTS. In [10] monitoring the condition of wind turbines is considered more and more important, but not yet recognized in the industry due to uncontrolled economic benefit. Most of the research is based on simulation or benchmark data. The amalgamation of hetero-generous data sources in a single NoSQL database-repository, the selection and recovery of varied geo-spatial wind data regions of interest, and the analysis of these data using a Data Mining tool. A graph-based wind power data base management system is discussed in [11].

To begin, multi-source wind power data is used to extract knowledge graph elements such as entity, relation, and property. These elements are then utilized to create a knowledge-graph of wind related power-data in the existing graph 65 database to complete the process. The profitability of offshore wind farms is dependent on satisfactory wind-conditions compared with onshore locations, which outweigh the additional costs of installation. Therefore, a reliable forecast of wind resources and wave climate is essential for project planning and support, specifically in the event of large-scale projects [12]. The optimal location and size of shunt device for the system has received considerable attention from researchers over the past four decades.

Article [13] presents the reduction of losses in the system using the optimization of the swarm of particles (PSO) When investigating the problem of 75 device configuration, it is necessary to consider single-phase as well as 3-phase available loads with voltage profile, distortion factor, and harmonics constraints.

The indices of reliability in the distribution systems are also improved. Article [14] supplied evaluation of wind electricity primarily based totally on mechanical layout parameters, reliability parameter and attention electric electricity further to Wind Canyon Model. Today, to achieve a high level of security and completeness of the system, reliability indices limit in the electrical system must be closely monitored. Three main limits must be presented in the reliability analysis, namely the customer-compound damage-function, the average load in addition to the failure rate. The modifications in failure rate is used to compute the reliability cost and therefore the objective function is designed. In this work the active tasks of the low voltage alternating current network and the microgrid are examined and planned. In smart-grids, the transmission of various distributed energy resources data and their suitable communication arrangement combine to control the frame with greater probability [15,17]. Then, the control needs and the configurations of the releases are controlled by grids that are designed and simulated.

II. PROBLEM FORMULATION

Mathematical Wind Modeling For Wind Turbine Placement By Using Database Management and it's problem is defined as optimizing wind farm layout for placing an appropriate number of wind turbine generators for maximum and reliable output power. Equation (1) represents the cost function to optimize cost of wind farm layout.

$$Cost_f = \frac{CC \times ES + OC}{FCY} \times P_{out} \times \frac{0.1}{n} \tag{1}$$

Where,
$Cost_f$ – cost of objective function to be evaluated and remaining parameters are explained in section III.

III. MATHEMATICAL MODELLING

Various mathematical equations are designed in this research work and few of them are presented here. Equation (2) is mathematically expressed for computing construction cost inside the wind farm.

$$CC = C_1 \times N + C_s \times \frac{n}{m} \tag{2}$$

Where,
CC – Construction cost
C_1 – Turbine Cost
C_s – Substation cost
n – Number of turbines
m – Turbine /Substation

Economic of scale is an important parameter in wind farming as if to evaluate wind strength and capability of region depending on number of turbines to be selected as imperially formulated in equation (3). In addition to this operating cost is mathematically expressed by equation (4) and wind farm floating capital 110 cost per year has to evaluate as per equation (5).

Output power of a wind farm is an essential commodity needs to use for optimization purpose and calculated here as per equation (6).

$$ES = \frac{2}{3} + \frac{1}{3} \times e^{-0.00174\,n^2} \quad (3)$$

$$OC = C_{om} \times n \quad (4)$$

$$FCY = \frac{1-(1+r)^{-y}}{r} \quad (5)$$

$$P_{out} = \frac{1}{8760 \times P} \quad (6)$$

Where,

ES - Economics of scale
OC - Operating cost
C_{om} - Operating/maintaining cost / turbine
FCY - Floating capital cost in a year
r - Interest rate
y - Life of wind farm in years
P_{out} - output power
P - Farm Energy output

Equation (02) to (05) and (07) to (08) are referred from [16,9] whereas, equation (01), (06) and (07) are developed.

IV. DATA BASE MANAGEMENT STRATEGY

A. Steps in creating WTG Table through mathematical modeling

Step 1: Enlist all turbines and select data such as hub height and air density.
Step 2: Take sample of selected five turbines
Step 3: Draw power curve of selected turbine using appropriate equation.
Step 4: Select appropriate graph related to power curve of WTG
Step 5: Print WTG Table with power curve
Step 6: Proceed to PSO treatment for optimization

B. Farm optimization algorithm

The process shown in Fig. 1 is indicated and considered the cost of reliability by means of improvement in indices. Use of PSO is for optimal solution finding of cost function expressed in equation (1). Many of computation based on remaining equations presented here are followed and finally results are exported with plot and excel table.

Farm optimization was the problem of placing wind turbine since last five decades. Many researchers focused their ideas with suitable constraints. Here a novel-technologies are adopted for selecting the farm location and it’s shape too. A suitable location of a state within the India has proposed with different sizes of land procured. Once a land area is known the algorithm is designed to select for the shape sizes. The options for location shapes are enlisted as circular land, square land and rectangular land.

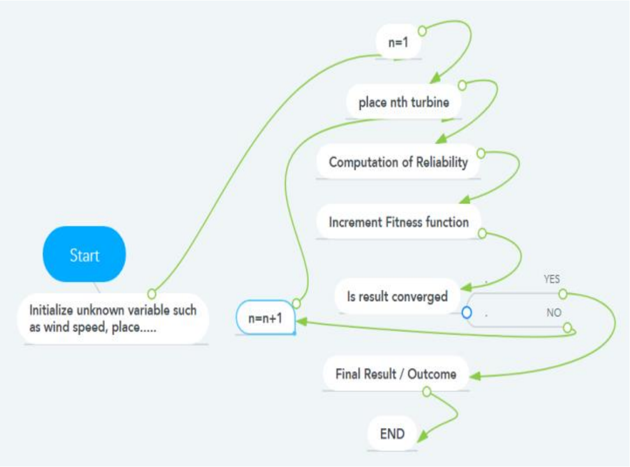


Fig. 1: Farm optimization model considering reliability cost using PSO

In case of circular land the placement of Wind turbines are with the technologies of circle in circle and circle in line methods are developed and implemented here to observe that which method may suitable to generate more wind energy from the selected turbines. Number of maximum possible turbines and available turbines are computed with distance between the turbine tower as constraint. Possible many options from the set is selected for computation of objective function where maximum energy produced in the available land shape is observed and for the best solution among all available solutions are selected with the help of PSO.

Fitness Function for the objective cost function represented in equation (1) is developed with PSO considering velocity and position are developed with PSOFEED data and shown in equation (7) , (8) and (9). IF FFE is denoted for Fitness function Error, then

$$FFE = A.x^5 + B.x^4 + C.x^3 + D.x^2 + E.x^1 + F \quad (7)$$

Equation 8 and 9 are generalized equations of PSO tool to update velocity and position of all particles as given in the PSO tool by selecting PSO parameters. Velocity modified is

$$V^1 = (0.5 + \frac{r}{2})V^0 + r(P_b - x_i) + 2r\left(P_g - x_i\right) \quad (8)$$

Similarly, position of particle updated/modified as

$$X^{new} = X^{old} + V^1 \quad (9)$$

Parameters specially relates in equation (7)-(9) are used in PSO tool, where A, B, C, D, E and F are from the PSOFEED Table for the PSO tool operation. V^1 is the modified velocity of particle, V^0 is the old or previous velocity of particle, r is the random number in between 0 to 1, P_b is the local best particle position, P_g is the global best particle, X^{new} is the modified particle position and X^{old} is the previous particle position.

C. *PSO Algorithm*

Understanding of PSO is based on two equations of velocity and position of particle. Objective function must be multi-dimensional one and having multiple best solutions. Local and Global best may be differ or remain same considering various constraints as shown in Fig.2.

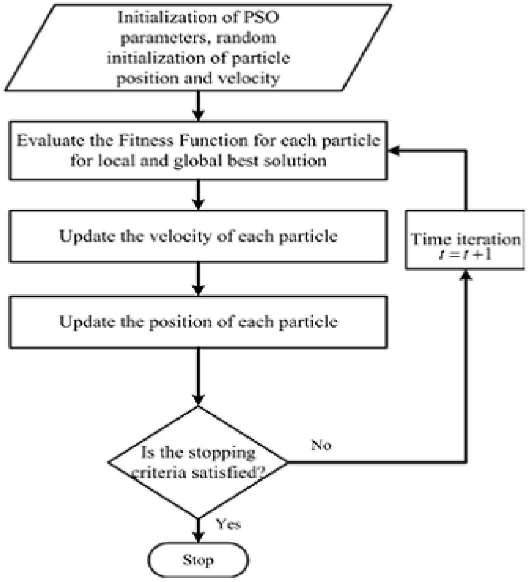


Fig. 2: PSO algorithm.

D. *Data Base Management*

Data base management system is an approach here used in addition to dot net programming framework. Insert and Select query is utilized many times for successive data mining and storing purpose during the analysis of optimization algorithms as discussed in this research work for wind placement problem.

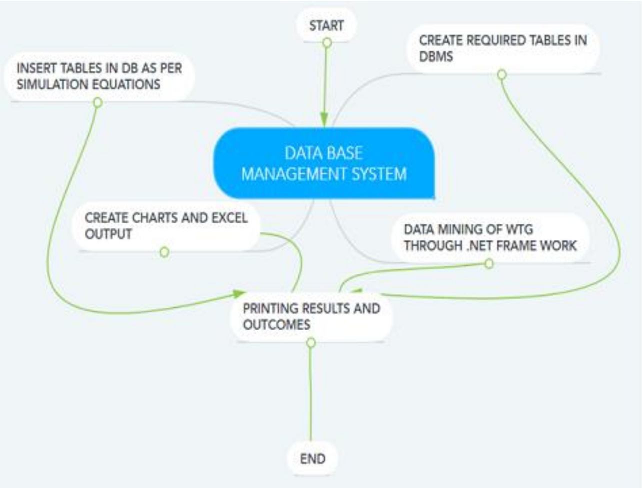
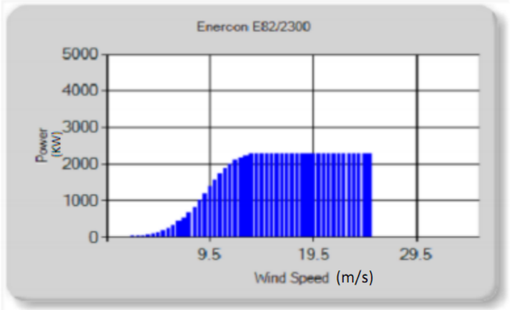
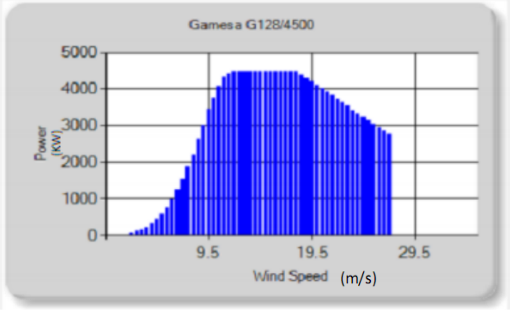


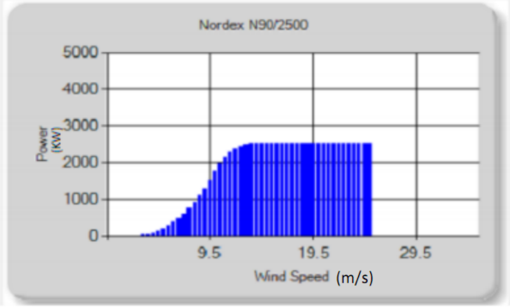
Fig. 3: Data Base management system for WTG as data storage and mining



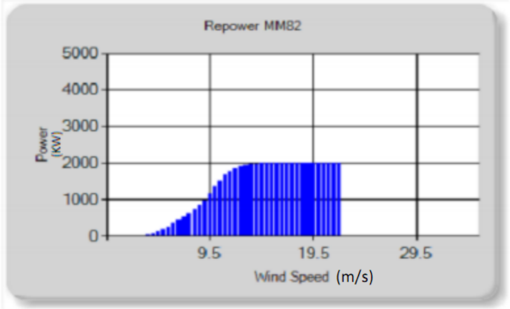
(a) Enercon E82/2300 WTG



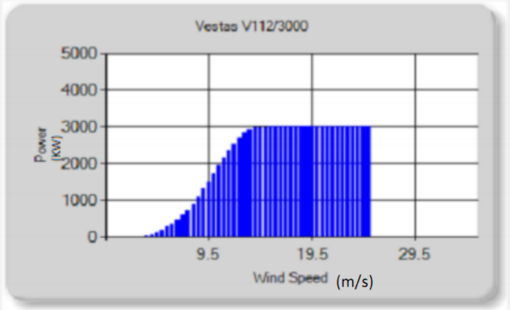
(b) Gamesa G128/4500 WTG



(c) Nordex N90/2500 WTG



(d) Repower MM82



(e) Vestas V112/3000 WTG

Fig. 4: Power curve of selected WTG such as (a) Enercon E82/2300 WTG, (b) Gamesa G128/4500 WTG, (c) Nordex N90/2500 WTG, (d) Repower MM82, (e) Vestas V112/3000 WTG.

Data base management was always the question of storage data in wind field. Herein the research work as shown in Fig.3, many of the system data was generated in many mathematical treatments such as wind velocity and it’s forecasting data, available turbine data among all WTG manufacturer such as power generated by the turbine in different wind velocity conditions as well as direction etc. MS chart and plot system is adopted to realize the system behavior during the research work such as power plots, reliability indices, wind pattern as per selected locations. Stored data of before and after optimization is also required for comparison purposes. Required query is written to generate the essential data output in the form of excel. All the data in this simulation process is handled with the use of DBMS systems.

TABLE I
WTG Power Data for Wind Speed Vs Power (KW)

Wind Speed (m/s)	Enercon P(KW)	Gamesa P(KW)	Nordex P(KW)	Repower P(KW)	Vestas P(KW)
2	3	75	0	0	0
3	25	165	5	0	0
4	82	300	62	66	76
5	174	600	188	192	192
6	321	967	363	343	346
7	532	1533	599	519	584
8	815	2200	912	711	890
9	1180	3018	1299	959	1306
10	1580	3774	1744	1355	1722
11	1890	4314	2149	1681	2162
12	2100	4490	2389	1861	2542
13	2240	4500	2492	1947	2860
14	2300	4500	2500	1987	2970
15	2300	4500	2500	2000	2995
16	2300	4500	2500	2000	3000
17	2300	4500	2500	2000	3000
18	2300	4500	2500	2000	3000
19	2300	4306	2500	2000	3000
20	2300	4113	2500	2000	3000
21	2300	3919	2500	2000	3000
22	2300	3725	2500	2000	3000
23	2300	3532	2500	0	3000
24	2300	3339	2500	0	3000
25	2300	3145	2500	0	3000
26	0	2950	0	0	0
27	0	2758	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0

Wind speed data for selected wind turbines with the power output in kilowatts are tabulated in Table I. and also plotted in Fig. 4.

E. *Power curve of selected WTG*

Power curve of selected turbine model has been proposed for the wind farm placement purpose. The curve shows various wind speed versus power output of a given selected turbine for the purchase purpose.

Worldwide almost eleven hundred turbines are manufactured by around thirty-five manufacturers. Fig. 4 indicates the most demanded turbines in the world with their power output Vs wind speed. These are five in number considered here as a test cases. We are supposed to select any one from the turbine available in this list and number of turbines are evaluated as per the land space and shape available. Turbine related cost such as turbine cost, operating cost, maintenance cost, roads and transformer cost along with the revenue generated through the wind power within the farm in different conditions. Power curve is always useful for consideration to evaluate foretasted energy generation probabilities in the due course.

It is also helpful to evaluate recovery period of the wind energy power plant and NPV calculations to understand the project is cost effective or not through the cost-benefit calculations based on NPV. If O_{CI} is the overall capital investments in power plant, R is the discount per year in percentage, y is period in years and ANI is annual net income based on revenue generated by selling wind power and investments in operating and maintaining power plant, then NPV of wind power plant is computed by mathematical equation (10) and NPV results are graphically shown in fig.5.

$$NPV = \left(\sum_{y}^{20} \frac{ANI}{(1+R)^{p}}\right) - O_{CI} \qquad (10)$$

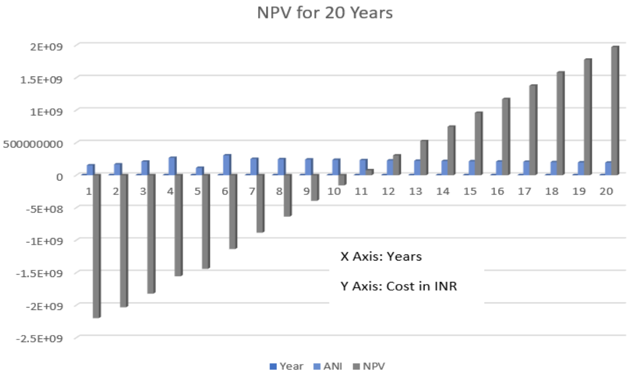


Fig. 5: NPV for 20 Years along with ANI Results.

F. *Wind Turbine Placement Results*

Wind turbine placement is carried out through PSO algorithm. Shape of land is selected with either circular or rectangular as tabulated in Table II. Results shows satisfactory in Local mode operation for turbine placement. Considered distance between two turbines is 0.5 km as constraint with maximum power output.

TABLE II
WIND TURBINE PLACEMENT (AREA=5 SQMTR)

Wind Farm Location	Shape	PSO Mode	No of Turbines Placed
Jodhapur	Circular (r=1.26)	Local	19
		Global	17
	Rectangular (1 X 5)	Local	24
		Global	23
Ratlam	Circular (r=1.26)	Local	19
		Global	17
	Rectangular (1 X 5)	Local	24
		Global	23
Ahmadnagar	Circular (r=1.26)	Local	19
		Global	17
	Rectangular (1 X 5)	Local	24
		Global	23

V. CONCLUSIONS

Proposed mathematical models in a given research paper is a novel development of optimization tool with the help of particle swarm optimization for the purpose of appropriate turbine size, turbine locations, land selections, land shape etc. are addressed here. Cost function is so developed considering substation cost, road cost, turbine unit cost, overall power generation cost and all other investments in this project such as to maximize the profits. A tool PSO is so popular now a days and used here with advanced version for selecting appropriate solutions among the many which are best suitable considering local as well as global optimum. PSO FEED Table is generated for the designated power curves and simulated accordingly. Results indicate that the maximum benefits achieved and the method of placement is succeeded. All mathematical equations are verified and observed with concluding remarks as best possible mathematical models. Various plots and excel outputs of .net programming are addressed for the success of optimization algorithms with determination of wind turbine placement and WTG design. All results are satisfactory and proven.

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CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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