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SUSTAINING THE DISTRIBUTION GRID NETWORK RELIABILITY WITH DISTRIBUTED WIND TURBINE GENERATIONS

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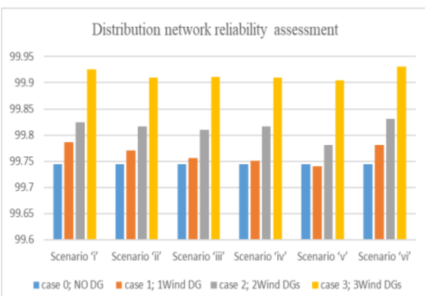
Graphical abstract



Abstract

Distributed generations are practically operated at the rated maximum power output. The locking off and on into the grid network of the intermittent power generating units is on availability basis. There are significant integration challenges posed by wind power generation due to its intermittency nature which seriously affect power grid stability and reliability issues related to grid power quality and voltage profile. Several reliability indices can be established to assess the distribution network reliability; they include ASAI, SAIFI, AENS and EENS. This study had the main purpose of optimizing placement and sizing of wind distributed generations through the application of the Particle Swarm Optimization algorithm to attain voltage profile improvement as well as network reliability enhancement by power loss reduction for radial distribution network - IEEE 33-bus system. The proposed PSO-based algorithm adequacy was investigated using MATLAB simulation on a radial distribution network - IEEE standard 33-bus test system, with a case study of Genetic Algorithm being used for validation of the solution techniques and model developed. The RDN test system is connected to a total of 3.32 MW and 2.71 MVAr; both real and reactive loads respectively. Modelling of the wind power generation considered for grid integration was variable reactive power model. A cut-off wind speed of ≥ 6 m/s on average was considered for power generation. Results from the analysis yield 0.2115 p.u of average active power produced by the wind turbine generator. 206.87 kW and 139.13 kVAr were the APL and RPL initial network configurations obtained respectively at 0.83pf when no DG was integrated. When wind DG is integrated at optimal placement and capacity, the reduction of the overall network power loss is 68.12% and 61.43% for real and reactive power loss accordingly. The voltage profile improved by 8.17% on installation of wind DG. The network ASAI reliability index value before wind DG integration was 0.99743 p.u. which improved by 1.81% after their installation. In general, network power losses are minimized besides acceptable voltage profile being maintained for a sustained distribution system reliability when several wind DGs are integrated.

Keywords: Active Power Loss, Distribution Network, Optimization Function, Reliability index, Wind Turbine

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1.0 INTRODUCTION

There is no direct control by the utility operator over the power injected into the grid network by distributed generations since they operate at their rated maximum power output [1]. Integration of wind energy into the grid has significant challenges posed by its intermittency nature resulting in serious concerns about the network reliability and system stability regarding voltage levels and frequency which ultimately affect the quality of grid power [2,17]. Wind energy is less generated in the day time but more generated at night [21]. The reliability of an electrical distribution network depicts the continuous supply of power to end users without failure as the defined system constraints are maintained; any power supply system is operated to achieve this objective [3,15]. When the power demand in a network increases, the source experiences a high load current drawn from it, causing increased voltage drops and more system power losses which consequently lowers the performance of the distribution networks. This has necessitated the consideration of live distribution networks in system operation and design by installing DG units [8,14].

Network reliability assessment can be achieved through electrical power loss minimization on optimally sized and sited DGs. It is therefore recommended that suitable reliability data for optimally integrated wind DGs is inferred while improving the electrical distribution network reliability. The electrical loads and power line inductances cause voltage fluctuations and power losses in distribution networks. Intermittent renewable energy resources placement and sizing in a power grid need to be optimized for maximum utilization. Optimization evolutionary techniques are applied to achieve wind DGs optimal placement; the techniques require modifications and enhancement since their solutions suffer from premature convergence, so as to achieve practical results for intermittent renewable energy resources that are grid-connected [4,19].

The incorporation of intermittent renewable energy DG resources has been presented with scanty research about distribution system reliability [5,20]. This study aimed at optimizing the siting and sizing of wind energy resource for sustainable grid reliability in an electrical power system. The research suggests a PSO algorithm for optimal placement and sizing of spatially distributed wind turbine generations. The WTG integration into the distribution network improves the voltage profile and thus enhancing its reliability besides supplying end user demand sustainably [12,13,22]. The proposed technique of optimization in this research gives optimal capacity and site of wind DG in a distribution network, a standard IEEE 33 bus RDN configuration, with reduced power losses and better voltage profile for sustained network dependability.

The wind DG modelling was done by neglecting network constraints and restrictions, and adopting the characteristics of the V52-850 kW wind turbine. The proposed approach validation in solving the optimization problem regarding WTG distributed generations integration onto the utility grid to enhance network reliability was attained via program simulation on a IEEE - 33 bus RDN; electrical power end users are supplied by the distribution network in a grid system [9,16]. The versatility of the developed algorithm allows for the incorporation of other intermittent DG sources.

Results from other studies show that installing distributed generations of non-optimal capacities or at non-optimal locations causes additional increase in system power losses [7,23]. The optimization of DG sizing and placement has continually been studied with various techniques implementation to resolve such optimization problem. A network loss reduction of 53.9% was realized when [24] applied PSO-method to place and size distributed generations in a grid network. Using GA technique [6] achieved 45.7% reduction in the objective function to increase network efficiency by improving voltage drop and minimization of power loss. The reliability indices of SAIDI and SAIFI equally improved by 33.71% and 32.69% respectively [9]. The performance assessment of any power system is appropriately done through RA which is presented as a reliability index. Average system availability index was preferred in this research; The ASAI network reliability index per unity value is intended to be approximated to 0.99983 according to literature [10]; a small value shows that the supply is neither adequate nor secure.

The uniqueness of the proposed PSO algorithm is its capability to obtain consistent results of optimal solutions in a few number of iterations besides being versatile and compatible with weather predictive software for multiple integration of intermittent distributed generation units.

2.0 METHODOLOGY

This study majorly aimed at optimizing capacity and location of wind turbine DGs using PSO algorithm for enhance network reliability besides improving voltage profile through reduction of power loss in a standard IEEE 33-bus RDN system. Wind speed profiles quantification was carried out on primary data obtained from Lodwar meteorological weather station in Kenya. MATLAB program was applied to determine the possible wind power output form the chosen site. Figure 2 shows the PSO test flow chart that guided the development of the PSO algorithm coded in MATLAB to achieve optimal placement and sizing of WTG distributed generations integrated onto an IEEE 33-bus electrical distribution network for better voltage profile as well as enhanced system dependability through minimization of power loss. The dataset used was wind speed shown in Table 2. Line data and load data were the network characteristic data required. Table 1 presents the RDN line data of a standard IEEE 33-bus system.

Table 1 Standard IEEE 33- bus distribution system Line data

L n	s n	r n	r (Ω)	x (Ω)
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	1.7144	1.2351
8	8	9	1.03	0.74
9	9	10	1.044	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

Table 2 Wind speed data of a typical day:Source KMD (Lodwar station, Kenya)

Time (Hours)	Wind speed data (m/s)
1	10
2	5
3	7
4	8
5	10
6	12
7	15
8	18
9	15
10	26
11	20
12	10
13	8
14	10
15	14
16	20
17	25
18	15
19	10
20	8
21	5
22	4
23	4
24	3

2.1 RDN Test System Of The Standard IEEE 33 – Bus Network

This study adopted radial distribution network because it is simple, cheap to implement and more preferred for DGs. A constant load was assumed on the system with base voltage of 12.66 KV and 100 MVA apparent power. The network total load is 3.32 MW and 2.73 MVAr, and the maximum active DG output power considered was 5 MW. The test network has buses, branches, loads and utility grid as the main components; 32 loads, 32 branches and 33 buses.

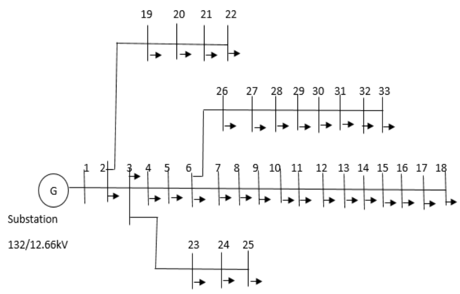

Figure 1 The RDN test system of a standard IEEE 33 – bus network single line diagram

2.2 Test flowchart of the PSO Algorithm

Application of PSO is largely on renewable energy resources integration and active power dispatch in power systems. The best solution is obtained by following the particle closer to the global best resolution, *g*Best, which is the optimal value in a PSO technique search strategy, again the particle's best solution, *p*Best, is computed by applying the objective function; this represents the fitness of every solution. Figure 2 shows the flowchart that was adopted to attain improvement in voltage profile, minimization of power loss as well as enhanced network reliability for optimum capacity and siting of WTG distributed generations in a radial distribution system. Parameters of the PSO include m = 2; number of members in a particle, k_{max} = 1000 and I = 50; population size. They are used to obtain optimization results for wind distributed generations.

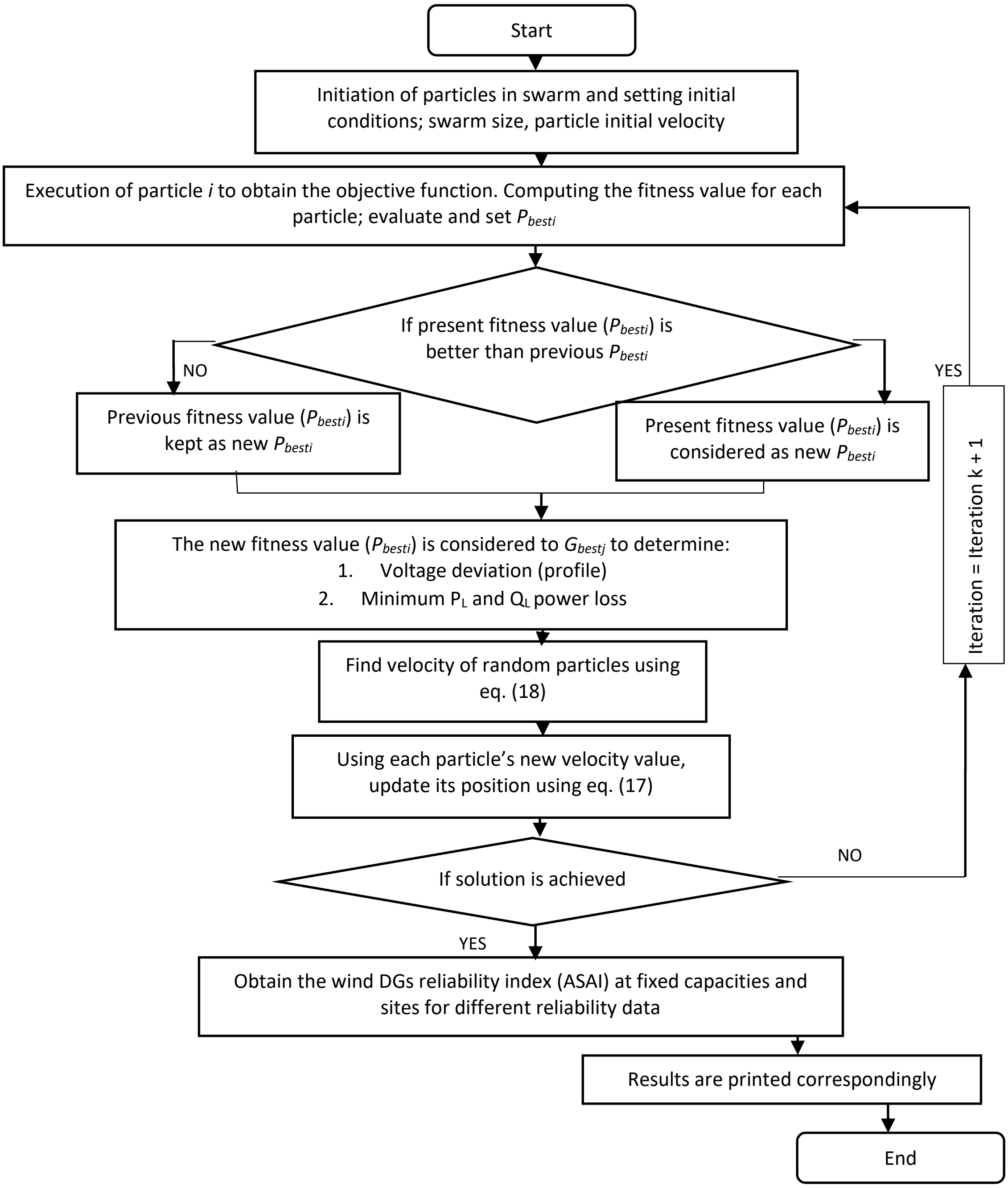

Figure 2 Test flowchart depicting the proposed PSO algorithm on a RDN

2.3 Mathematical Principle Guiding The Study

The research background was informed by the theory of losses in power and reduction in voltage in an electrical grid system caused by network power lines impedance characteristics. Figure 3 shows a two bus section.

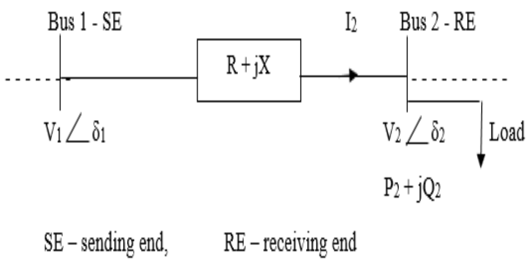

Figure 3 A two bus section of radial distribution network

The network quantities are:

Impedance of the network line (Z), $R + jX$ eq. 1

Power at the receiving end (P_2), $P_2 + jQ_2$ eq. 2

node 1 to node 2 Line voltage drop,

$$V_d = V_1\angle\delta_1 - V_2\angle\delta_2 \quad \text{eq. 3}$$

$$= (R + jX)\, I_2 = Z\, I_2$$

The bus 2 receiving end power is given by:

$$I_2^{*}\, V_2^2 = P_2 + jQ_2 \;\rightarrow\; I_2 = (P^2 - jQ^2)/V_2^{*} \quad \text{eq. 4}$$

In which;

$$I_2 = V_d / Z \;\rightarrow\; \frac{V_1\angle\delta_1 - V_2\angle\delta_2}{R + jX} \quad \text{eq. 5}$$

$$\delta_2 = \delta_1 - \tan^{-1}[(P_2X - Q_2R) / (V_2^{\,2} + P_2R + Q_2X)] \quad \text{eq. 6}$$

$$|V_2| = [\{(P_2R + Q_2X - |0.5|V_1^{\,2})^2 - (R^2 + X^2)(P^2 + Q^2)\} - (P_2R + Q_2X - 0.5|V_1^{\,2}|)] \quad \text{eq. 7}$$

The receiving end bus voltage in eq. 7 is required to be improved for safe voltage and quality in a power system supply network. The proposed PSO algorithm in this research optimizes size and site for wind DGs in a RDN to attain improved voltage profile through reduction of the voltage drop between the source bus and the load bus, in addition of lowering the network power losses to enhance the grid reliability [3]. Modelling of the WTG was based on the variable reactive power model for network integration [22]. Classification of intermittent wind speeds applicable in power production include Class IV (6 – 6.5m/s), Class III (6.5 – 7.5m/s), Class II (7.5 – 8.5m/s) as well as Class I (> 8.5m/s); any wind speed < 6.0m/s isn't recommendable for power production [21]. In this research, bus voltage, DG type, power loss, network reliability, DG location and size parameters were considered. Figure 4 shows the DG technologies classification [5]. This study considered WTGs only.

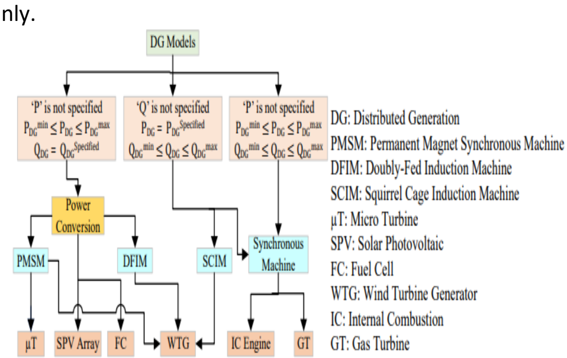

Figure 4 models of DG technologies

2.4 Variable Reactive Power PQ Modelling

Energy conversion in WTG is accomplished via an induction generator. Such generator does act as a source of reactive power. Real power output calculation in a wind farm is achieved by applying power curves that relate to the wind generator model. The unit reactive power output is a function of the generator impedance, active power output and bus voltage. Or else, the power output computation for wind turbine is a solution of a quadratic function involving its active power, which is given as:

$$Q_0 + Q_1P_{i,\,WTG} + Q_2P_{2i,\,WTG} = -Q_{i,WTG} \quad \text{eq. 8}$$

Q_0, Q_1 and Q_2 are determined through measurements.

2.5 Modelling of the Wind Power

A wind turbine power output is related to the swept area by rotor, wind speed, kinetic energy, and air density. The wind speeds are categorized as cut-out, cut-in and rated wind speeds with ideal values of 25m/s, 3.5m/s and 15m/s accordingly for a Vestas-52 turbine rotor. WTG manufacturers provide data-sheet detailing the restraint values of a specific turbine rotor model.

The power output of a wind turbine rotor is expressed as:

$$P(t)_{\text{wind power DG}} = \alpha\rho(t)A\upsilon(t)^3 * 0.5 \quad \text{eq. 9}$$

In which;

- α - power coefficiency; Albert Betz constant (0.593)
- ρ - density of air (Kg/m^3)
- A - swept area by the wind turbine rotor (m^2)
- $\upsilon(t)$ - speed of the wind (m/s)

Generation of wind power is usually done at utmost rated amount within the day at time intervals on wind speed availability. Determination of the wind station maximum power rating is attained by obtaining the calculated wind power total day's averages using eq. 9. Modelling of the wind distributed generation considered VESTAS V52-55m WTG; a Vestas company manufactured wind turbine, whose output power rating and other specifications are given in Table 3.

Table 3 specifications of the VESTAS V52-55m Wind Turbine

Parameters	Unit of rating
Rated output power	5.10 MW
$V_{c\text{-}in}$; Cut-in Speed	3.50 m/s
$V_{c\text{-}out}$; Cut-out Speed	25.0 m/s
Temp	-20.0 ^{0}C to 45.0 ^{0}C
Diameter	52.0 m
Area swept by rotor	2124 m^2
Frequency	60/50 Hz
Height of hub	56.0 m

Table 2 shows a 24 hours' wind speed data averaged annually. Application of eq. 9 for every wind speed level yields to the power generated. The average wind farm real power generated in this analysis was computed as 0.2115 p.u.

2.6 The Electrical Distribution System Optimization Objective Function Formulation

The PSO algorithm is initiated by the random particles' X_i positions in an electrical power network system while searching for the best position to attain an optimum solution with regards to the formulated objective function, and the swarm is expressed as multidimensional variable(s) with respect to the designated number of variables in the network. Thus, the particles X_i and velocities V_i sets are related to a number of *m* particles as well as a number of *n* variables that are expressed using eq. 10,11 respectively.

$$V_i = \begin{bmatrix} v_{1,1} v_{1,2} \ldots v_{1,n} \\ v_{2,1} v_{2,2} \ldots v_{2,n} \\ v_{3,1} v_{3,2} \ldots v_{3,n} \\ . \\ . \\ . \\ v_{m,1} v_{m,2} \ldots v_{m,n} \end{bmatrix} \quad \text{eq.10}$$

$$X_i = \begin{bmatrix} x_{1,1} x_{1,2} \ldots x_{1,n} \\ x_{2,1} x_{2,2} \ldots x_{2,n} \\ x_{3,1} x_{3,2} \ldots x_{3,n} \\ . \\ . \\ . \\ x_{m,1} x_{m,2} \ldots x_{m,n} \end{bmatrix} \quad \text{eq. 11}$$

The individual's particle own knowledge gained over time is utilized to attain $P_{best,}$ particle position, while the neighboring particles' cognition gained over time yields to $G_{best,}$ Global position, in order to vary their positions to adopt the best position they and their neighbours have encountered [18]. Three variables were considered in this study, namely; bus voltage restraint V_n, bus loading S_n and network impedance $Z_{l,}$ when integrating spatially dispersed wind DGs onto the electrical distribution system for voltage profile improvement, minimization of power line losses and enhancement of network reliability for an RDN system. The bus voltage matrix is provided in eq. 12, whereby Z_{bus} is the system impedance matrix, I_{bus} represents the injecting matrix of the bus, while n_{bus} is the bus numbers.

$$[Z_{bus}]_{nbusx\ nbus} * [I_{bus}]_{nbusx1} = [V_{bus}]_{nbusx1} \quad \text{eq. 12}$$

The power received by the distribution network from the substation must be greater than that from the distributed wind generations.

$$0.83\sum_{i=1}^{Nbus} AP_{di} + AP_L \geq \sum_{i=1}^{Ndg} AP_{dgi} \quad \text{eq. 13}$$

$$0.83\sum_{i=1}^{Nbus} RP_{di} + RP_L \geq \sum_{i=1}^{Ndg} RP_{dgi} \quad \text{eq. 14}$$

Gross power loss, $G_{loss(RDN)} = \sum_{i=1}^{n} P_{i,\,loss} + j\sum_{i=1}^{n} Q_{i,\,loss}$ eq. 15

The aim of the objective function is to minimize the total network power loss and increase operation efficiency of the RDN;

$$T_{loss(RDN),optimized} = \min\left(\sum_{i=1}^{n} P_{i,loss}\right) + \min\left(j\sum_{i=1}^{n} Q_{i,\,loss}\right) \quad \text{eq. 16}$$

About 13% power losses has been noted on distribution network systems, being part of the total power injected into the grid system [10]. The continued growth in energy demand leads to more grid network loading, which has necessitated further research on distributed generations to offer solutions to the increased power demand, besides wind power being a variable DG that require to be optimally sized and placed in a radial distributed network for reduced active power losses. The final solutions quality performance measure presented by the proposed PSO algorithm in this research was applied to assess the procedure in comparison to other conventional methods inexistence. The voltage profile, power losses and the algorithm termination guide used were the statistical measures considered to appraise the performance of the PSO algorithm; this was based on the average population fitness ratio. There is little improvement expected when the ratio nears unity whereby all the results in losses are almost identical, and the variance between the fitness measure of all the members is less than a small tolerance value. The optimal solution is provided by the best performing candidate on termination.

A PSO algorithm to establish the optimal solutions of WTG DGs is proposed in this study. The movement of the particle depends both on their own occurrence and occurrence from the other swarm particles; P_{best} and Q_{best} accordingly. The new position X_i^{k+1} and velocity V_i^{k+1} for the particle are updated by applying eq. 17,18 accordingly, and in regard to P_{best} and G_{best}. Thus, the particles' updating is carried out in every iteration for the best two solutions linking the cognitive factor-personal best value as well as social factor-global best value as traced by the PSO.

$X_i^{k+1} = X_i^k + V_i^{k+1}$, $j = 1, 2,\ldots m$ (swarm) and $i = 1, 2,\ldots l$ (particle) eq. 17

$V_i^{k+1} = (P_{besti} - X_i^k) * C_1 * rand_1 + (G_{bestj} - X_i^k) * C_2 * rand_2 + \omega V_i^k$ eq. 18

whereby the particle's *i* current searching position and velocity are X_i^k and V_i^k at iteration *k,* with $rand_2$ and $rand_1$ representing random values within the range 0 to 1, on equal distribution. G_{best} is the fitness function best value attained by particle so far; which represent the particles' global best position in the swarm, among all particles, prior to iteration *k* while P_{best} is the fitness function finest value realized by particle *i*; best position of particle's *i* prior to iteration *k*. The random positive acceleration terms C_1 and C_2 are weighting factor constants whose values are within the space of 1 to 2, though it is preferred to adopt 2 in most cases [10]; hence the constants are ordinarily set to 2.0. X_i^{k+1} is the particle *i* position updating while V_i^{k+1} is the updated velocity. *l* is the number of particles in a group and *m* represents the number of members in a particle. Ideally, the particle *i* velocity weight function; the inertia weight *ω*, setting is done with respect to the equation below [11]:

$$\omega(k+1) = \omega_{max} - \left[\frac{-\omega_{\min} + \omega_{\max}}{k_{\max}}\right] * k \quad \text{eq. 19}$$

in this case, the current iteration number is *k* while k_{max} represents the number of maximum iterations. The inertia weights lowest and highest values are ω_{min} and ω_{max} respectively, and 0.4 and 0.9 are their preferred values accordingly. The accomplishment of the system reliability assessment is done after getting the reduced system's power loss and improved bus voltage. Performance analysis of the chosen distribution network is performed and then the network's RA is computed with the WTG DGs integrated and without. The standard IEEE number 1366-2012 guided the distribution network reliability assessment; it provides the requirements of analyzing EDS reliability indices [12].

2.7 The PSO Algorithm Extract

```
clc;
clear;
format short;
tic
m=load('loaddata33bus.m');
l=load('linedata33bus.m');
disp('%-----Wind Based DG------%')
% m=load('loaddata33bus.m');
% l=load('linedata33bus.m');
.
.

  % --Position of Swarms---
  for uu=1:Swarms;
    Swarm(uu,1)=Swarm(uu,1)+Swarm(uu,5)/1.2, % update u Position
    Swarm(uu,2)=Swarm(uu,2)+Swarm(uu,6)/1.2, % update v position
.
.

        % ---updating velocity vectors
        for vv=1:Swarms
                    Swarms(vv,5)=rand*inertia*Swarm(vv,5)+Correction_factor*rand*(Swarm(vv,3)...
                        -Swarm(vv,1))+Correction_factor*rand*(Swarm(qbest,3)-Swarm(vv,1));      %      u      velocity
                        parameters
                         Swarm(vv,6)=rand*inertia*Swarm(vv,6)+Correction_factor*rand*(Swarm(vv,4)...
                        -Swarm(vv,2))+Correction_factor*rand*(Swarm(qbest,4)-Swarm(vv,2));      %      v      velocity
                        parameters
.
.
Sprintf('Power-Loss=%d KW, Power-Loss=%d KVAr',PL,QL')
Sprintf('DG Location=%d, DG Power=%d KVA',DG_Location, DG_Size')
```

3.0 RESULTS AND DISCUSSION

The reduction of power loss, betterment of voltage profile and RDN network reliability enhancement are analysed for the standard IEEE 33-bus network in Figure 1. The test system population size is 50 with 0.001 being the set convergence value. 95% and 105% are the set minimum and maximum voltages respectively; per-unit system is adopted in all the calculations.

There were four cases investigated.

Case-0: Network with NO Wind DGs
Case-1: Network with 1WTG DG
Case-2: Network with 2WTG DGs
Case-3: Network with 3WTG DGs

The procedure adhered to in obtaining the results were:

Step 1: Optimal placement and capacity evalution of the WTG for ELM putting into consideration the technical ratings given in Table 3.

Step 2: Computation of the network's APL, RPL and bus voltages after integrating of 1WTG, 2WTGs and 3WTGs so as to evaluate the outcome of step 1.

Step 3: Estimation of the system reliability index, ASAI, when the wind DG's reliability data provided in Table 4
is adopted, and more specific the application of λ_p and RT values for six scenarios; scenario *'i'* to scenario *'vi'*.

Table 4 Reliability data for IEEE 33-bus distribustion system

Feeder, Bus, et al.	Reliability Data for all Feeders, Substations, DGs and Loads	
	λ_p (f/yr)	**RT (h)**
Loading at 4	0.321	11.04
Load at (25-28, 18-22, 30, 29, 16, 14, 7-12, 5)	0.301	11.44
Load at (15, 13)	0.314	11.17
Load at (24, 23, 17)	0.208	1.75
Load at (31-33)	0.327	10.96
Substation	0.1	5
Feeder (6, 3, 2)	0.2	3
Distributed Generation	0.2	12

3.1 Real and Reactive Power Loss Results

The real and reactive power loss reduction in an EDS is obtained on optimal sizing and location of WTG distributed generations integrated in the electrical distribution system. On determining the values of RPL, APL and VP, the network reliability assessment is then done to establish the optimal placement and capacities of the DGs at enhanced voltage profile and minimal power losses.

Operating the system at 0.83 pf with NO DGs, the gross power loss; real and reactive, is 206.86 kW and 139.12 kVAr respectively. On integrating the wind DG at optimum location and size, the overall network power loss is reduced by 66.14% and 59.45% for real and reactive power losses accordingly. Additionally, the network power loss reduces by 77.59% real and 76.05% reactive after integrating 2WTG DGs of optimal placement and size. Similarly, integration of 3WTG DGs onto the RDN grid, the network power loss reduces additionally by 85.95% and 83.77% for APL and RPL respectively, Table 5. The graphical representations will show the network power losses when with NO WTG DGs and with WTG DGs integrated, while the network is operated at upf and 0.83 pf respectively.

Table 5 Network Power losses before and after integration of the WTG DGs at 0.83 pf

Testing system	With NO DG power loss		On wind DG installation power loss		power loss reduction (%)		Optimal site	Wind DG Capacity *10kW/ *10kVAr
	P_{loss} (*10kW)	Q_{loss} (*10kVAr)	P_{loss} (*10kW)	Q_{loss} (*10kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)		
With NO DG	20.686	13.912						
1Wind DG			6.80	5.503	66.14	59.45	6	40.32
2Wind DGs			4.43	3.194	77.59	76.05	13	64.983
3Wind DGs			2.701	2.118	85.95	83.77	30	257.645

When the system is operated at upf with NO DGs, the gross power loss; real and reactive, is 207.2 kW and 132.5 kVAr respectively. On integrating the wind DG at optimum location and size, the overall network power loss is reduced by 47.99% and 39.82% for real and reactive power losses accordingly. Similarly, the network power loss reduces by 58.51% real and 55.03% reactive after integrating 2WTG DGs of optimal placement and size. Additionally, integration of 3WTG DGs onto the RDN grid, the network power loss reduces further by 66.02% and 61.54% for APL and RPL respectively, Table 6.

Table 6 Power loss before and after WTG DG integration at unity pf

Testing system	With NO DG integrated power loss		On DG integration power loss		power loss reduction (%)		Optimal site	Wind DG Capacity *10kW/ *10kVAr
	P_{loss} (*10kW)	Q_{loss} (*10kVAr)	P_{loss} (*10kW)	Q_{loss} (*10kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)		
Without DG	20.72	13.25						
1Wind DG			10.57	7.842	47.99	39.82	6	40.32
2Wind DGs			8.390	5.827	58.51	55.03	13	64.983
3Wind DGs			6.835	4.964	66.02	61.54	30	257.645

The PSO technique application on case 3, 2, 1 and 0 at 0.83 pf yields to improved power loss from 206.86 kW to 67.1 kW; which is approximately 66.14% reduction for case-1. A similar study [6] applied GA technique on the test network, and a less improvement in power loss of 16.22% (202.3 kW to 174.7 kW) was achieved. Hence, the advanced PSO algorithm in this research yields to a better improvement in system power loss as in comparison to GA method; giving an overall improvement of 85.95% for case-3. Again, the proposed PSO algorithm provides a preferable performance when compared to the conventional techniques and obtains faster solutions, making it a more superior approach to configure WTG distributed generation in an RDN system.

3.2 Improvement of Bus Voltages

The improvement system voltage profile was achieved on operating the RDN with optimally sized and sited WTG DGs after integration onto the network. The bus voltages change according to the EDS network reactive and real power losses. Figure 5 shows the results that indicate the improvement in voltage profile on optimal size and siting of the WTG DGs installed into the electrical distribution system as attained by the application of the proposed PSO algorithm. Operating the distribution network at a higher reactive power support, at 0.83 pf, there is great improvement of the network buses' VP at the junctions.

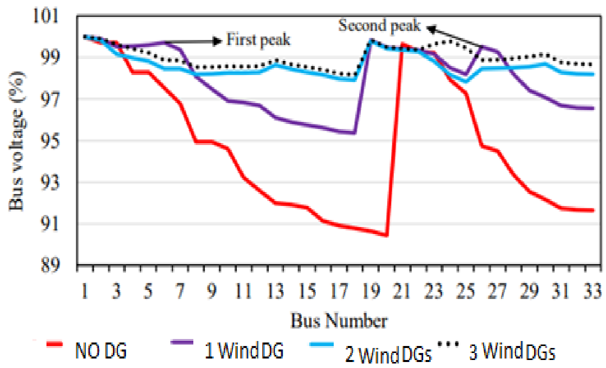

Figure 5 Improvement of voltage profile for 33-bus distribution network on WTG DGs at 0.83 pf

At bus 7 and 26, voltage peaks are observed since the two buses link directly to bus 6 at which the WTG DG is optimally located as indicated in Table 5. The effect of installing the DGs at low voltage buses; 18, 22, 25 and 33, is noticed with the voltage improvement rate decreasing when the number of connected distributed generations is increased. At these low voltage buses, the voltage magnitude is below the acceptable restraint before the optimal capacity and location of the WTG DGs, while after their installation all the nodes are subjected to a voltage within the permissible restraint. The highest and lowest bus voltage limits are 105% and 95% respectively in relation to the reference bus voltage. Table 7 shows that bus 18 has a base case voltage of 0.9073 p.u.; such value is lower than the acceptable distribution system limit of 0.95 p.u. Integrating wind DGs of optimal site and capacity results to improvement of this under-voltage; an improvement of 8.17%. in voltage profile is achieved on installation of the WTG DGs into the electrical distribution system.

Table 7 Minimum p.u. voltage at unity pf, 0.83 pf

p.u. minimum voltage				
	Testing system			
pf	Without DG	1Wind DG	2Wind DGs	3Wind DGs
unity		0.9451	0.9687	0.9667
0.83	0.9073	0.9589	0.9813	0.9814

3.3 Assessment of the Network Reliability

Computation of the electrical distribution test system reliability index was accomplished by the use of MATLAB application with consideration of the reliability data referred from the reliability library. There were four cases simulated to establish the improvement in ASAI reliability index. Without the wind DGs installation, the ASAI value was 0.99754 p.u. while after their integration it improved by 1.81%.

A better improvement in network reliability is obtained when $\lambda_{p,\ failure\ rate}$, is 0.2 and RT, $_{repair\ time}$, is 12h.

Scenario i: 0.2f/yr and 12h Scenario ii: 0.4f/yr and 12h

Scenario iii: 0.6f/yr and 12h Scenario iv: 0.2f/yr and 24h

Scenario v: 0.2f/yr and 48h Scenario vi: No failure

The ASAI index values are determined by inputting these values of relaibility data manually into the proposed PSO algorithm to achieve the system's reliability improvement.

Table 8 Computation of the % ASAI reliability index for the six scenerios for an IEEE 33-bus RDN grid

System configuration	Scenario 'i'	Scenario 'ii'	Scenario 'iii'	Scenario 'iv'	Scenario 'v'	Scenario 'vi'
case 0; NO DG	99.744	99.744	99.744	99.744	99.744	99.744
case 1; 1Wind DG	99.786	99.771	99.756	99.751	99.741	99.781
case 2; 2Wind DGs	99.824	99.816	99.810	99.816	99.781	99.831
case 3; 3Wind DGs	99.926	99.910	99.911	99.910	99.905	99.931

It is noted that the distribution network reliability improves as the ASAI index increases, and especially with integration of 3WTG DGs onto the RDN. An increase in repair time and failure rate decreases the network realiability index; it is therefore recommended for the DGs to have lower RT and λ_p adopted.

All the network loads experience increased electrical power service availability when there is multiple integration of DGs onto a ditribution network. It is therefore desired to have a high value of ASAI for a better network relaibility.

4.0 CONCLUSION

There is voltage drop, network power losses and low network reliability experienced by an electrical distribution system. Improvement of the network reliability was significantly achieved in this study through placement and sizing optimization of wind energy sources, by the application of PSO algorithm. Consideration of VESTAS V52-55m Wind turbine generator model characteristics was applied to carry out the results analysis. Further considerations of WTG unpredictability in their reliability data, and more so the repair time and failure rate yields to better RA results. The betterment in voltage profile of the buses and power loss reduction in the radial distribition network was realized by optimally sizing and placing the wind turbine generator DGs for their installation, in contrast to a system with no DGs. Integration of several wind DGs provided better results than a single integration. The active network power loss reduced by 0.00139 MW on integration of 1WTG, it lowered further by 0.00181 MW when 3WTGs were integrated at upf, in comparison to GA reasults. There was 7.06% improvement in bus voltage minimum value at upf for 3WTGs installed, as compared to when NO DG was integrated. At 0.83 p.u., further improvement of 8.17 % was attained. Scenario 'i' with 3WTGs installated provided a more satisfactory improvement in system's reliability; consideration of such case is more preferred since it gives an ASAI network reliability index of 0.99937; a value that is almost to the 0.99983 preferred from literature. The advanced PSO algorithm has the ability of computing near optimal feasible or practical solutions on few iterations, and is easy to implement. In addition to the reliability improvement, a better power quality delivery is promoted by the minimization of active network power loss through distributed generations integration onto the power grid. Only wind intermittent renewable energy resources were considered in this study; more research is recommended to incorporate the other intermittent renewable energy resources onto the electrical distribution network power mix for a sustainable system reliability.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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