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Sustaining the Electrical Distribution System Reliability with Solar Photovoltaic Distributed Generations

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--*ABSTRACT*--

Integration of intermittent renewable energy resources onto the power grid provides a means of achieving green-energy supply. Solar power generation poses significant integration challenges due to its nature of intermittency which affects the grid reliability and stability with reference to voltage profile and quality of the grid power. Electrical network reliability is the ability of the power grid to deliver load demand without failure while maintaining the system's constrains. Sizing and siting of solar photovoltaic should be optimized for maximum utilization in a power distribution network. There is power losses and voltage drops in transmission and distribution grid lines due to their resistance and reactance properties. Evolutionary techniques of optimization are applied for optimal placement of solar photovoltaic distributed generations in a power system. Particle Swarm Optimization algorithm for improved system reliability and voltage profile by minimizing power losses in an IEEE 33-bus radial distribution network was used when implemented on MATLAB code, and Genetic Algorithm case study was used to validate the developed model and solution techniques. The total reactive and active loads connected to the network test system are 2.31MVAr and 3.72MW respectively. The solar power conversion was modelled as constant power factor modelling under normal operating conditions with cut-off solar radiation≥ 4kWh/m^2/day. The initial network configuration, RPL and APL obtained are 143.03kVAr and 211.01kW respectively without distributed generation at 0.85pf. Similarly, the line power losses reduce by 61.61% active and 57.97% reactive on integration of solar DG of optimal capacity and location. The voltage profile improvement achieved was 8.45%, and value of network reliability index, ASAI, before integration of solar sourcewas 0.99735p.u. which on installation it improved by 1.82%. The results show minimized power losses while maintaining acceptable voltage profile in a distribution network for sustained reliability.

KEYWORDS; *-Active Power Loss, Electrical Distribution System, Objective Function, PSO, Solar PV*

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I. INTRODUCTION

Practically, the operation of a distributed generation is done at the maximum rated power output; and the power utilities have no direct control over the power injected by it; renewable intermittent sources are unpredictable [1]. The solar energy is available on day time and absolutely unavailable at night. Using the characteristic availability of solar, power supply and quality can be maintained by optimal sizing and placement of the solar DGs. It is noted that all the solutions to distributed energy challenges for technical and regulatory cases must adhere to the golden rule of reliability [2].An increased load in the distribution network leads to more drawing of load current from the source and consequently resulting to increased network power losses and voltage drops. This lowers the performance of distribution networks [2]. An electrical distribution network is responsible for supplying electrical power to the end users in the entire electrical grid network. [3]. A DG represents a small scale power generating unit in the range of 5MW that is installed throughout a power grid network to supply power to local loads. [3]. Generally, electrical loss minimization provides a recommendable way of carrying out reliability assessment for optimally sized and placed DGs. Evolutionary techniques of optimization that are applied for optimal placement of DG provide solutions that are affected by premature convergence and therefore they require enhancement and modifications when applied to solve optimization problem in order to realize feasible solutions for intermittent grid connected renewable energy sources [4].Solar irradiance varies with respect to the time of the day and weather, and thus how the network reliability will be affected by these intermittent energy sources is unclear if a larger share of the electrical energy demand is supplied by them. The determination of capacity and siting SPV is a requisite for their integration in a distribution network system due to the uncertainties associated with its energy harvesting related to solar irradiation [4]. The productivity of solar vary depending on location [5]. The distribution network operation can only be achieved optimally when an exact and reliable prediction of solar power is available for the next hours and days [5]. The study proposes a Particle Swarm Optimization technique for sizing and placement of intermittent renewable energy resources, solar, based on spatial distributed generation.The integration of distributed generation into the grid network enhances its reliability in meeting load demand sustainably and improves voltage profile [6] [7]. The proposed approach provides an optimal distribution network of a standard IEEE configuration, while yielding an optimal site and capacity of the DG with reduction in network power losses and improved voltage profile for sustained system reliability. The network system considered does not have storage units; its restrictions and constraints were neglected, and a 240Wp suniva ART 245-60 solar module characteristics was adopted for the solar DG modeling. A software simulation was used to validate the proposed method to solve the optimization problem in view to keep the utility grid network reliable on intermittent supply source, solar.Studies have indicated that the power grid losses are likely to increase when the intermittent sources are installed at non-optimal locations or have non-optimal capacities. [8]. The proposed algorithm is versatile to incorporate other DG resources. Using PSO-method [3] achieved 51.4% power loss reduction by suitably locating and sizing the DGs in a RDN. When GA method was used by [6], the objective function was reduced to 46.4% for better RDN performance with respect to voltage profile improvement and power loss minimization. Integration of DG units resulted in improved SAIDI and SAIFI reliability indices by 32.27% and 30.71% respectively [9]. Reliability evaluation results are expressed using different reliability indices depending on the application. This study adopted Average system availability index, ASAI $=\frac{Load-hours-service-availability}{Customer-hours-service-demand}$ Whereby customer hours service demand = 8760 annually and the standard target value for this index = 0.99983 [10]; below this value, the supply is not adequate and secure.

II. METHODOLOGY

The main purpose of the study was to optimize capacity and siting of distributed generations, solar, using Particle Swarm Optimization algorithm for improved system reliability and voltage profile by minimizing power losses in an IEEE 33-bus radial distribution network. Quantification of solar irradiance profiles from data extracted at selected Kenya meteorological department was useful in obtaining primary data. MATLAB coding was developed to compute the expected solar power outputs from the selected sites. Using the PSO test flow chart provided in Fig [2], a PSO algorithm was developed on MATLAB application to optimize capacity and siting of solar DGs integrated on the IEEE 33-bus RDN system for improved voltage profile, power loss minimization and enhanced network reliability. The solar dataset represented a direct normal irradiance, Table [1]. The required network characteristic data included line data and bus data. The standard IEEE 33-bus loading is described in Table [2].

Time (Hours)	Solar irradiance data (W/m^2)
1	0
2	0
3	0
4	0
5	0
6	25.72
7	203.58
8	411.52
9	572.6
10	674.96
11	712.54
12	848.56
13	720.82
14	730.97
15	637.98
16	584.6
17	358.4
18	145.05
19	35.84
20	0
21	0
22	0
23	0
24	0

Table 1: A typical day solar irradiance data: Source KMD – Lodwar station, Kenya

Bn	BP (kW)	BQ (kVAr)
1	0	0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40
Bn - Bus number	BP - Bus Active Power	BQ - Bus Reactive Power

Table 2: The Standard IEEE 33-bus distribution system loading data

The standard IEEE 33 – bus RDN test system

In this study, radial distribution system has been adopted due to being simple, mostly applied to distributed generations and cheap in implementing. The system is assumed to have constant load where apparent power= 100MVAand base voltage 12.66KV.The total load on the system is 3.72MW and 2.31MVAr. The DG's maximum active output was considered to be 5MW. The test system main components include utility grid, buses, loads and branches; 32 branches, 33 buses and 32 loads.

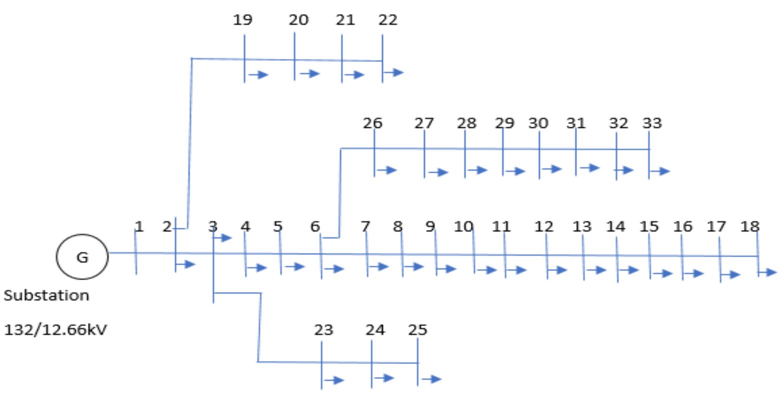

Figure 1: Single line diagram of the standard IEEE 33 – bus RDN test system

PSO finds application in real power dispatch and more important renewable energy source integration in a power system. The search strategy for best solution using PSO technique will be to follow the particle nearest to the optimal solution referred to as global best solution, *g*Best*j*, and using the objective function to compute the fitness of each solution, *p*Best*i*. Fig. [2] provides a flowchart to obtain power loss minimization, voltage profile improvement and network reliability for optimally sized and placedSPV DGs in a RDN system. The optimization results are obtained for solar DG. The PSO parameters are l = 50; population size, m = 2; number of members in a particle and k_{max} = 1000.

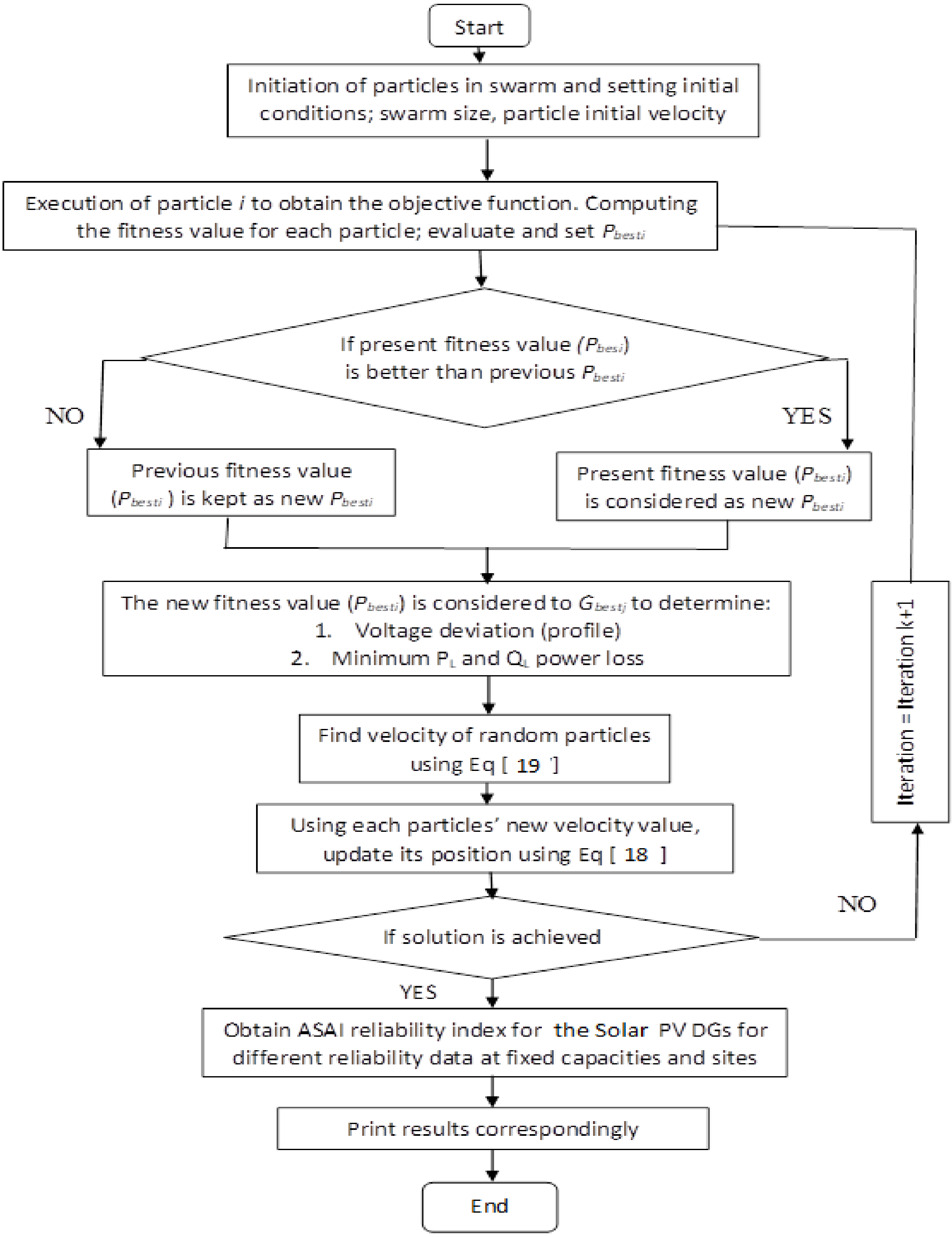

Figure 2: PSO test flow chart using IEEE Standard 33-bus system

Mathematical background of the study

The theoretical reference of the study was based on the principle of power losses and voltage drops in transmission and distribution grid lines due to their resistance and reactance properties.

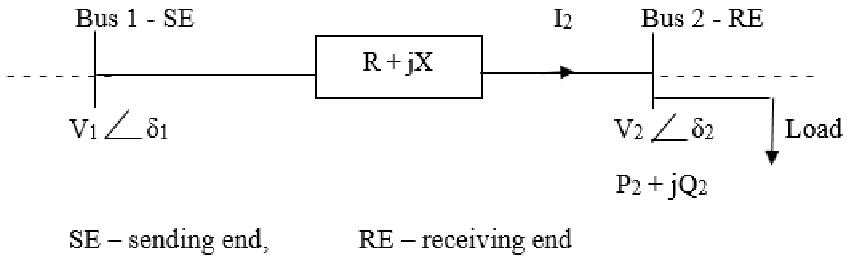

Figure 3: RDN section of two buses

It follows that:

The line impedance (Z), $R + jX$ [eq. 1]

Through power at bus 2, $P_2 + jQ_2$ [eq. 2]

Line voltage drop, between bus 1 and bus 2, $V_d = V_1 \angle \delta_1 - V_2 \angle \delta_2$ [eq. 3]

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

The receiving end power at bus 2 is:

$V_2^2 I_2^* = P_2 + jQ_2 \quad \rightarrow \quad I_2 = (P^2 - jQ^2)/V_2^*$ [eq. 4]

Also;

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

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

This study proposes a PSO algorithm to optimally site and place DG units, solar, in a radial distribution network to minimize power losses, improve voltage profile by minimizing voltage difference between the sending end and receiving end buses to enhance network reliability [3].

The modelling of the solar generating units in this study is on the basis of constant - p.f. model. The cut-off solar radiation for power generation on average is considered to be ≥ 4kWh/m^2/day [11]. The study considered power loss, bus voltage, reliability, DG type and DG capacities and siting parameters. DG technologies are classified, as illustrated in Fig [4] [4]. This study considers SPV DGs only.

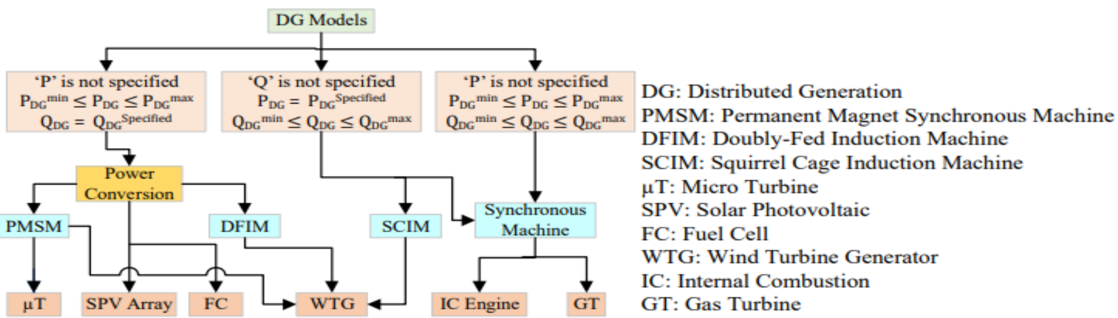

Figure 4: DG technologies models

Constant power factor modelling of PQ type

In this case, p.f and real power values are specified. Calculations of current injection equivalent and reactive power is accomplished by applying expressions [7] and [8] respectively.

Equivalent injected current: $I_{i,\,source} = \frac{P_{i,source} + jQ_{i,source}}{V_{i.source}}$ [eq. 7]

Reactive power: $Q_{i,\,source} = P_{i,\,source} \tan[\cos^{-1}(p.f_{i,\,source})]$ [eq. 8]

Solar Power Modelling

Solar power generation units produce electrical energy from solar energy conversion with direct current power output; this output is changed to alternating current power for grid compatibility through grid-tie inverters. A solar PV module has an output that depends on solar irradiance, surface area of the module as well as the module efficiency. The maximum output power of the solar module at time instant *t* expression is:

$$P(t)_{\text{solar power DG}} = \mu(t)A\beta \qquad \text{[eq. 9]}$$

In which;

μ - solar radiation intensity (W/m^2) β - module efficiency

A - module surface area (m^2)

Normally, solar power is generated at maximum rated capacity within time interval of the day. The SPV module power output into the distribution grid network is expressed in eq. [10] when implementing the proposed PSO algorithm, in which:

SPV – AC output power to grid = Maximum SPV power out x Inverter efficiency, at time instant *t*.

$$P_{SPV(AC)}(t) = P_{SPV(\max\ output)}(t) \times \eta_{inverter} \qquad \text{[eq. 10]}$$

Solar farm maximum power rating is determined by getting the total day averages of calculated solar powers using eq. [9]. In modelling the solar DG unit, Table [3] shows the basic features and specifications of the solar PV module considered in this study, with a module efficiency of 14.75%. The BYD240P6-30, solar PV module, manufactured by Suniva BYD company is adopted for its output power rating. The module cell is rated $1000W/m^2$, cell temperature of 25^0C and A.M 1.5 global with its performance being proportional to solar energy falling on its surface perpendicularly on standard test conditions.

Parameter	Rating (unit)	Parameter	Rating (unit)
Nominal power (P_{nom})	240Wp	Maximum series fuse	25 A
Tolerance of power	±3/0%	Temperature	-40 ^{0}C to 85 ^{0}C
Efficiency	14.75%	Power temperature coefficient	-0.34%/^{0}C
Rated voltage	27.84 V	Voltage temperature coefficient	-0.28%/^{0}C
Rated current	8.12 A	Current temperature coefficient	0.06%/^{0}C
Open circuit voltage (V_{oc})	37.54 V	Weight	21.5 kg
Short circuit current(I_{sc})	8.9 A	Solar cells	Monocrystalline
Maximum system voltage (*IEC*)	1500 V	L x B x H mm^2	2362x1092x35

Table 3: Suniva BYD Solar Panel (BYD240P6-30) specifications

The solar irradiance data over 24 hours, averaged annually, is shown in Table [1]. Using equation [9], the power generated for every solar irradiance level is computed. Calculations in this analysis yield average real power generated by solar farm as 1.0268 p.u.

Formulate the optimization objective function of the electrical distribution system

The objective function is subjected to a set of constraints. Often, a mathematical expression of a mono-objective optimization problem is given as:

$$\text{Optimize [F(x)], under constraints: } \begin{cases} g(x) = 0 \\ h(x) \leq 0 \\ x_i^{min} \leq x \leq x_i^{max} \\ x = \{x_1, x_{2,\ldots\ldots\ldots}x_n\} \end{cases}$$

In which; mono-objective function is F(x) to be optimized, problem parameters to be optimized isvector x having n variables, h(x) and g(x) represent set of constraints of inequality and equality respectively, while x_i^{max} and x_i^{min} are constraints domains [8]. The system's attributes improvements are obtained by establishing total power loss, distributed energy resources siting and capacity, voltage profile, conductor maximum MVA capacity and network reliability, through a multi-objective optimization process for these sub-problems. The SPV array optimum capacities and sites are observed for voltage deviation and electrical loss reduction, in this optimization method. The distribution network system has been noted to consist of about 13% power losses from the total power generated into the grid network [12]. This fact necessitated the undertaking of this study as the power demand increases with more loading of the grid network; distributed generations are

offering a solution to the increased power demand although solar is an intermittent DG that need to be suitably sited and sized in a RDN to reduce the real power losses
The line current is computed as:

$$I_i = \left[\frac{Pi+Qi}{Vi}\right] \quad \text{[eq. 11]}$$

Both the reactive and active network power losses are given by the expression:

Reactive power, $Q_{loss} = \left[\frac{P_{i+1}^2 + Q_{i+1}^2}{V_i^2}\right] X_i$ [eq. 12]

Active power, $P_{loss} = \left[\frac{P_{i+1}^2 + Q_{i+1}^2}{V_i^2}\right] R_i$ [eq. 13]

MVA Capacity index, $C_I = max_{j=1}^{nl}[\frac{Sj}{SCj}]$ [eq. 14]

Voltage profile index, $V_{PI} = max_{i=2}^{n} [\frac{V1-Vi}{V1}]$ [eq. 15]

With;

- n - being the number of buses in the grid
- V_1 - the reference voltage; substation bus voltage
- V_i - the i[th] bus voltage

The OF in this study is aimed at achieving network power loss minimization, for both APL and RPL. Evaluation of ASAI reliability is then carried out by fixing the optimal sites and capacities of SPV DGs in the proposed PSO algorithm. Any OPF on electrical networks has the principle purpose to minimize the system active power losses.

The general objective optimization is expressed as:

$$OF=W_a * \frac{Tploss;with\ IRES}{Tploss;without\ IRES} + W_b * \frac{Tqloss;with\ IRES}{Tqloss;without\ IRES} + W_c * max_{j=1}^{nl}[\frac{Sj}{SCj}] + W_d * max_{i=2}^{n}[\frac{V1-Vi}{V1}]$$

$$OF = [W_a.R_{PLI} + W_b.Q_{PLI} + W_c.C_I + W_d.V_{PI}] \quad \text{[eq. 16]}$$

The weights in this research are considered to be $W_a = 0.4$, $W_b = 0.2$, $W_c = 0.25$, $W_d = 0.15$. The constraints to be observed was:

$$\sum_{x=1}^{4} W_x = 1 \quad [eq. 17]$$

In which W_x is in the space of [0,1].
After defining the optimization problem, application of optimization algorithms follows to establish an optimal or near-optimal solution to the problem.

The algorithm proposed applies Particle Swam Optimization technique to compute the optimal solutions. The particle movement will depend both on their own experience and experience from the other particles in the swarm; P_{besti} and Q_{bestj} respectively. The new position and velocity; X_i^{k+1} and $V_i k^{+1}$ for the particle will be updated according to equations [18] and [19] respectively and in relation to P_{besti} and G_{bestj}.

Therefore, the updating of the particles is done in every iteration for the two best solutions that links cognitive factor-personal best value, and the social factor-global best value as tracked by the PSO.

$$X_i^k + V_i^{k+1} = X_i^{k+1}, \quad i= 1, 2,....l \text{ (particle) and } j = 1, 2,...m \text{ (swarm)} \quad \text{[eq. 18]}$$

$$\omega V_i^k + C_1*rand_1*(P_{besti} - X_i^k) + C_2*rand_2*(G_{bestj} - X_i^k) = V_i^{k+1} \quad \text{[eq. 19]}$$

; in which particle's i current searching position and velocity are X_i^k and V_i^k at iteration k, $rand_2$ and $rand_1$ represent random values in the range 0 to 1, on uniform distribution. The fitness function finest value that particle i has achieved is P_{besti}; the particle's i best position before iteration k, while the fitness function best value that any particle has achieved so far is G_{bestj}; the particles' global best position among all particles in the swarm before iteration k. C_2 and C_1 are weighting factor constants of the random positive acceleration terms and their values range between 1 to 2, but 2 is preferred in most cases [12]; hence they are normally set to 2.0.

The updated position of the particle i is X_i^{k+1} while V_i^{k+1} is the updated velocity. Number of particles in a group is l and number of members in a particle is m. Typically, the inertia weight ω; velocity weight function of particle i, is set according to the equation below [6]:

$$\omega_{max} - \left[\frac{\omega \max - \omega min}{kmax}\right] * k = \omega(k+1) \quad \text{[eq. 20]}$$

; whereby *k* represents the current iteration number and the maximum number of iterations is k_{max}. ω_{min} and ω_{max} are the inertia weights minimum and maximum values respectively, and their preferred values is 0.4 and 0.9 accordingly.

The network reliability assessment is accomplished after obtaining the improved bus voltage and reduced system's power loss. The selected distribution network performance analysis is done and then the system's RA is carried out without and with the SPV DGs integration. The distribution network reliability assessment is guided by the IEEE standard number 1366-2012 which provide the requirements on analyzing the different reliability indices of an EDS [4].

III. RESULTS & DISCUSSION

Four cases were considered.

Case 0: The system without Solar DGs

Case 1: The system with ONESolar DG

Case 2: The system with TWO Solar DGs

Case 3: The system with THREE Solar DGs

Reactive Power Loss and Active Power Loss results

The RPL and APL minimization in a distribution network is realized on optimal siting and sizing of SPV DGs integration in the RDN system. The system's reliability analysis is carried out after estimating the VP, RPL and APL values. The system's reliability analysis is therefore done at optimal capacities and sites of the DG, and with better voltage profile and minimum power losses.

When the RDN is operated without DGs at 0.85 pf, the total power loss, active and reactive, is 211.01kWand 143.03kVAr respectively. On integration of solar DG of optimal size and location, the overall line power loss reduces by 61.61% and 57.97% for active and reactive power losses respectively. Similarly, the line power losses reduce by 72.42% active and 69.45% reactive on integration of TWO solar DGs of optimal size and location. When THREE SPV DGs are integrated into the RDN system, the line power losses reduce further by 86.73% and 84.55% for APL and RPL respectively. Fig [5] and [6] aregraphical representations of the line power losses with solar DGs and without solar DG integration at 0.85 pf and upf respectively.

Test system	Without DG power loss		On DG integration power loss		% power loss reduction		Optimal site	DG Capacity *100kW/ *100kVAr
	Ploss (*100kW)	Qloss (*100kVAr)	Ploss (*100kW)	Qloss (*100kVAr)	Ploss (kW)	Qloss (kVAr)		
WithoutDG	2.1101	1.4303						
ONE Solar DG			0.812	0.6012	61.61	57.97	6	4.0320
TWO Solar DGs			0.582	0.4369	72.42	69.45	13	6.4983
THREE Solar DGs			0.280	0.221	86.73	84.55	24	25.7645

Table 4: Power loss before and after SPV installation at 0.85 pf

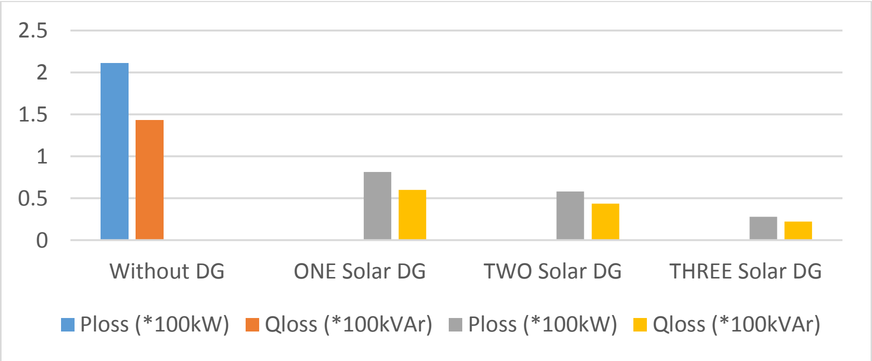

Figure 5: Reactive and Active power losses at 0.85 pf

Test system	Without DG power loss		On DG integration power loss		% power loss reduction		Optimal site	DG Capacity *100kW/ *100kVAr
	Ploss (*100kW)	Qloss (*100kVAr)	Ploss (*100kW)	Qloss (*100kVAr)	Ploss (kW)	Qloss (kVAr)		
Without DG	2.027	1.352						
ONE Solar DG			1.075	0.7824	46.97	42.13	6	4.032
TWO Solar DGs			0.8309	0.5872	59.01	56.57	13	6.4983
THREE Solar DGs			0.6853	0.4946	66.19	63.42	24	25.7645

Table 5: Power loss before and after SPV DG installation at upf

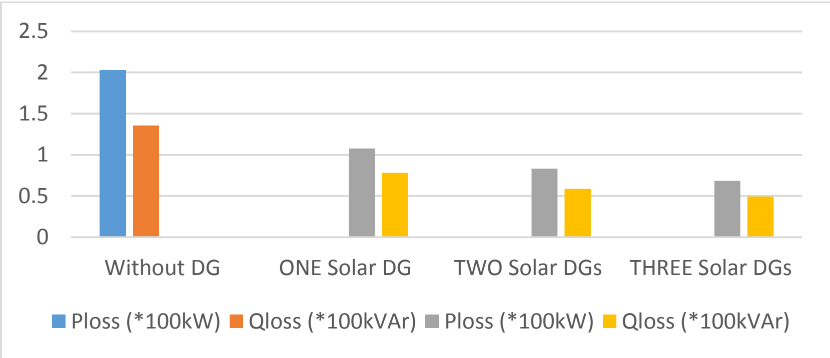

Figure 6: Reactive and Active power losses at upf

When the PSO method is applied in case 0, 1, 2 and 3 at 0.85 pf,the amount of power loss was improved from 211.01kW to 81.2kW; approximated to be 61.61% reduction for case 1. It is observed that the same application carried out on GA approach yields to lower power loss improvement of 12.71% (202.2kW to 176.5kW). In comparison, the proposed PSO-approach in this study results to a more improved network power loss when compared to GA approach; with an overall improvement of 86.73% for case 3. The PSO technique proves to give faster solutions and has better performance than the conventional methods. In this regards, it is therefore a superior technique in configuring solar DG processes in a distribution network.

Bus voltages improvement

The improvement in network voltage profile is achieved when the RDN system is operated on optimally sited and sized SPV DGs on their integration. The bus voltages vary with respect to the reactive power loss and real power loss in the network distribution system.These results are illustrated in Fig [7] which depict the results of improved voltage profile on placement and sizing of solar DGs in the radial distribution network achieved by the proposed PSO algorithm.The system buses' VP at the nodes can further be improved at higher reactive power support; when the distribution network is operated at 0.85 pf.

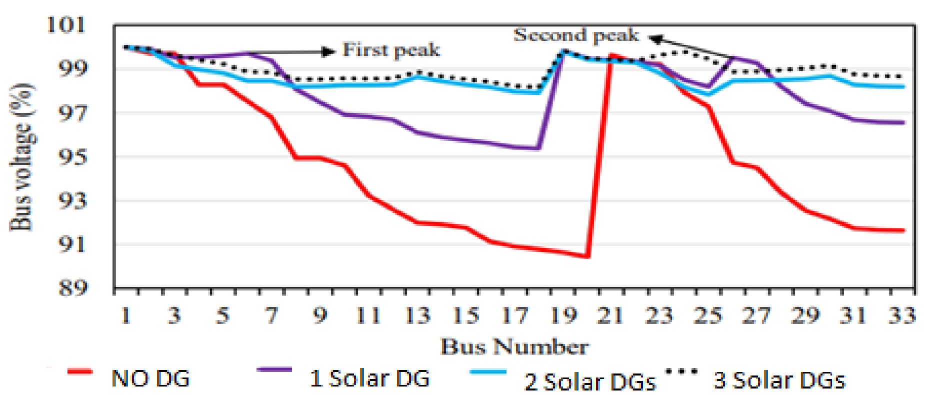

Figure 7: Voltage profile improvement for 33-bus RDN system on SPV DGs at 0.85 pf

Observation is made that there are voltage peaks at bus 7 and 26 because the two buses connect directly to bus 6 where there is optimal placement of the SPV, Table [4]. The effect of distributed generation integration at low voltage buses; 33, 18, 22 and 25, is notably observed with the voltage improvement rate decreasing with an increase in the number of distributed generations connected. The voltage at the low voltage buses was below the allowable limit before the optimal siting and sizing of the solar DGs while after integration of the DGs, the voltage at all the nodes is within the permissible limits.The distribution network bus voltages must be maintained within maximum and minimum limits. The upper and lower bus voltage limits are set at 105% and 95% respective with reference to the nominal bus voltage. It is observed from Table [6] that the base case voltage across bus 18 is 0.9037 p.u. which is less than the permissible distribution network limit of 0.95 p.u.Integration of solar DGs of optimal capacity and site improves this under-voltage; solar integration into the network has a voltage profile improvement of 8.45%.

% minimum voltage				
pf	Test system			
	No DG	ONE Solar DG	TWO Solar DGs	THREE Solar DGs
unity		94.15	96.78	96.76
0.85	90.37	95.63	98.01	98.10

Table 6: Minimum % voltage at upf, 0.85 pf

Reliability Assessment

The reliability index of the RDN test system was computed using the MATLAB application with reliability data inferred from the reliability library. Simulation of four cases was carried out to observe improvement of ASAI reliability index. The value of ASAI before integration of the solar DGs was 0.99735p.u. and after their installation it improves by 1.82%.

The network reliability improvemnent is best achieved when RT, $_{\text{repair time}}$, is 12h and $\lambda_{p,\ \text{failure rate,}}$ is 0.2.

Scenerio a: 12h and 0.2*f*/yr
Scenerio b: 12h and 0.4*f*/yr
Scenerio c: 12h and 0.6*f*/yr
Scenerio d: 24h and 0.2*f*/yr
Scenerio e: 48h and 0.2*f*/yr
Scenerio f: No failure

These relaibility data values are manually fed into the PSO algorithm to determine the ASAI index values which establish the network's reliability improvement.

System configuration	Scenerio 'a'	Scenerio 'b'	Scenerio 'c'	Scenerio 'd'	Scenerio 'e'	Scenerio 'f'
NO DG case	0.99735	0.99735	0.99735	0.99735	0.99735	0.99735
ONE Solar DG – case 1	0.99777	0.99762	0.99747	0.99762	0.99732	0.99792
TWO Solar DGs – case 2	0.99815	0.99807	0.99801	0.99807	0.99792	0.99822
THREE Solar DGs – case 3	0.99917	0.99909	0.99902	0.99909	0.99896	0.99924

Table 7: Computation of p.u. ASAI index for the six scenerios

It is observed that the ASAI index increases, and thus the network reliability improves, when THREE SPV DGs are integrated into the distribution network. Its value decreases with increase in failure rate and repair time; therefore the DGs should have lower RT and λ_p considered. Consequenlty, there is increased electrical power service availability to all the network loads, with multiple DGs integration. More importantly, to enhance the network relaibility, increasing the value of ASAI is desired.

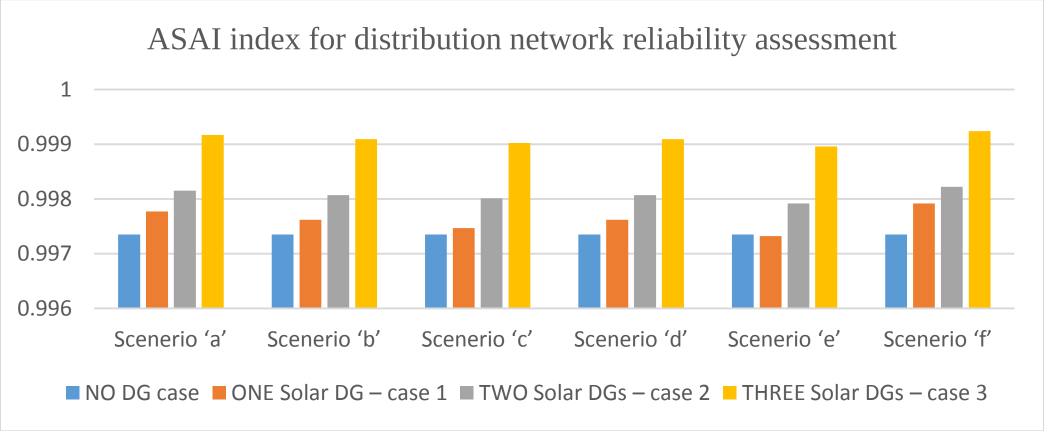

Figure 8: IEEE 33-bus RDN system ASAI reliability indices

IV. CONCLUSION

In a RDN system, there is voltage drop, reliability and line power loss issues.The RDN reliability was significantly improved by optimizing sizing and placement of solar energy sources, using PSO technique. The Suniva BYD SPV Panel - BYD240P6-30power output was considered to perform the analysis of the results.In order to obtain better results for RA, further analysis considered SPV uncertainties in their reliability data, specifically the repair time (RT) and failure rate (λ_p).The distribition network bus voltage profile and power loss reduction were enhanced by optimally siting and sizing the SPV DGs for their integration, as compared to a network without the distributed generations. A multile installation of the DGs provide a better result compared to a single installation.At upf, observation is made that the APL value reduces by 0.00179MW for ONE SPV and 0.00127MW for THREE SPV cases, when compared to GA results [4]. At upf, the bus voltage minimum value improved by 7.07% for THREE SPV case, in comparison to NO DG case. Further improvement is achieved at 0.85 p.u. to yield 8.45%. An acceptable network's reliability improvement is achieved on scenario 'a' with THREE SPV case; which is more favoured for consideration; it yields ASAI reliability index of 0.99917, which is ~ 0.99983 recommended by literature [10]. The implementation of the proposed algorithm is easy and possess the strength of being capable to find optimal or near optimal feasible solutions with few iterations.A similar research can be undertaken in future on large RDN systems; IEEE 118-bus or IEEE 69-bus distribution networks on aspects related to carbon emission and network reconfiguration to evaluate the system's reliability.

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