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Optimal allocation of wind and solar power based distributed generation: case study

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ABSTRACT

The main goal of the power system is to congregate the power demand within the power grid while maintaining economical operation, system security and minimal environmental impact. Due to the increasing demand for electrical energy, many problems have arisen with the power systems. These problems include excessive load, uneven system performance, unsatisfactory voltage profile, and an increase in network power losses. To address these issues, more generation sources and improved transmission capacity are required. In order to meet increasing electricity demand, it is more efficient to integrate a sufficient number of smaller generation units. Utilities and consumers can get the significant benefit from installation of distributed generation (DG), which reduces power losses, progress voltage profile, increases power quality and reliability, delays system updates, supports local reactive power, standby generation and peak limiting. This article aims to enrich the performance of the entire network through the best possible placement and penetration of wind energy and solar photovoltaic (PV) dispersed generation.

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NOMENCLATURE

DG	: Distributed generation	R_m	: Resistance of the line
RDN	: Radial distribution networks	P_{DGn}	: Real power from generator
LFA	: Load flow analysis	$p.f.$	: Power factor
SLD	: Single line diagram	Q	: Reactive power
n	: Number of nodes	I_{rm}	: Reactive current
p.u.	: Per unit	I_{am}	: Active current
I_{DGn}	: Current supplied by DG	RES	: Renewable energy sources
n/w	: Network	T&D	: Transmission and distribution
V_{min}	: Minimum voltage	V_{max}	: Maximum voltage
P_n	: Total load	P_{loss}	: Line loss
A_n	: Active power	Tol	: Tolerance
PQ	: Load bus	BC	: Base case
WTG	: Wind turbine generator	PV	: Photovoltaic
P_{loss}	: Power loss of the transmission lines	kW	: Kilo-watt

1. INTRODUCTION

Due to the recent sharp increase in energy consumption, study on the safety and reliability of power systems has received more attention [1], [2]. The main goal of energy systems is to meet all electricity demand while maintaining the overall reliability of the grid [3], [4]. The primary energy sources used in the conventional power generation system are hydropower, fossil fuels, and nuclear power [5]. The power is centrally generated in a conventional power grid and distributed to all distributed consumers through a sophisticated T&D infrastructure [6], [7]. Due to rising T&D costs, deregulation trends, exhaustion of conventional energy resources, environmental concerns and technological advances, large-scale centralized power generation is becoming less important in today's world [8], [9].

Developing countries like India face a number of challenges in providing consumers with the quantity and quality of electricity they need [10]. Due to recent industrial growth and expansion in other sectors, the electricity distribution network has expanded and multiplied manifold [11], [12]. In order to meet the increasing demand for electricity, attempts are being made to significantly increase the spread of decentralized energy generation [13]. The expansion of new technologies and a newly deregulated environment are responsible for the increase in connected DG units [14], [15]. The addition of DG to the present distribution network will benefit numerous companies. DG is beneficial in many ways, including reducing peak loads and maintaining power reliability [16], [17].

Figure 1 illustrates the integration of RES into the distribution network [18]. With the depletion of fossil fuels and growing environmental concerns in modern times, RES are becoming increasingly important [19], [20]. In the present power grid solar and wind power generation is essential to increase system reliability, reduce transmission infrastructure costs, and reduce greenhouse gas emissions and power losses [21]–[23].

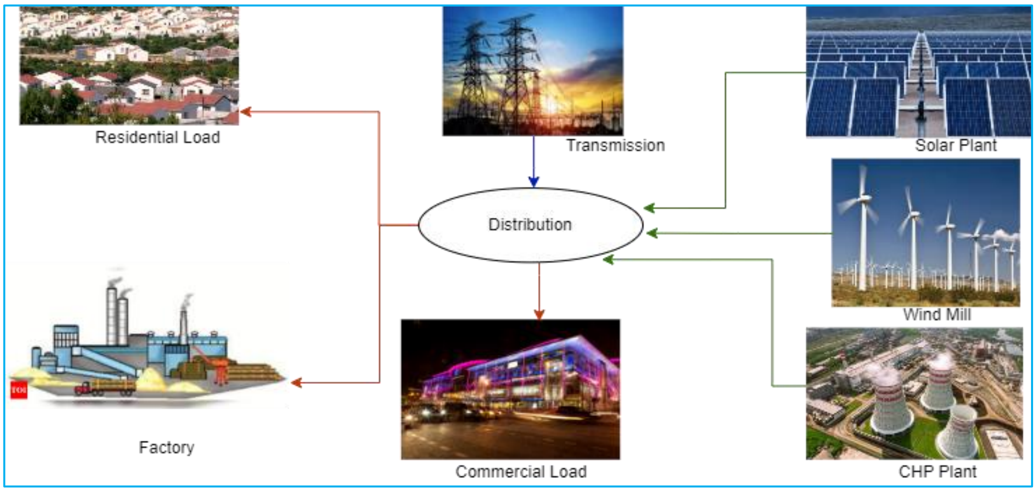

Figure 1. Integration of the RES into the distributed network

2. METHOD

The goal of the problem statement is to reduce the total performance loss of the distributed network, which is computed by (1)-(3).

$$Minimize\ f = Min\ (PT_{loss}^{DG}) \quad (1)$$

Subjected to

$$V_{min} \leq V_n \leq V_{max} \quad (2)$$

$$\sum_{n=1}^{N} PG_n = \sum_{n=1}^{N} P_n + P_{loss\_n} \quad (3)$$

The load flow calculation method known as backward/forward sweep is an iterative process that includes two calculation steps for each iteration. The first set of formulas for calculating power flow across the branches, backwards to the last bus with integrated line and starting at the last line. The second set of equations is used to calculate the voltage magnitude and voltage angle on each bus, starting with the slack bus and continuing to the last bus [24], [25]. In RDN, this approach proves useful because traditional LFA methods were unable to accurately determine the power losses in each branch. Figure 2 illustrates the backward/forward flowchart.

Algorithm 1. Backward/forward sweep algorithm
Step 1. Read node, generator, transmission corridor data and determine the p.u. values
Step 2. Consider a constant value of 1.0 p.u. at every node. From the last node backwards determine every branch current.
Step 3. While revising the constant current magnitudes from the preceding iteration and ensuring the convergence criterion, all node voltages are passed from the source bus to the final node.
Step 4. Verify that the variance between the calculated and specified voltages at the bus is less than the tolerance value, which is 0.0001. If so, move on to the next action. If not, repeat steps two and three
Step 5. Using the currents and voltages derived from the backward and forward sweep methods; calculate the total active and reactive losses of each line.
Step 6. Display the results.

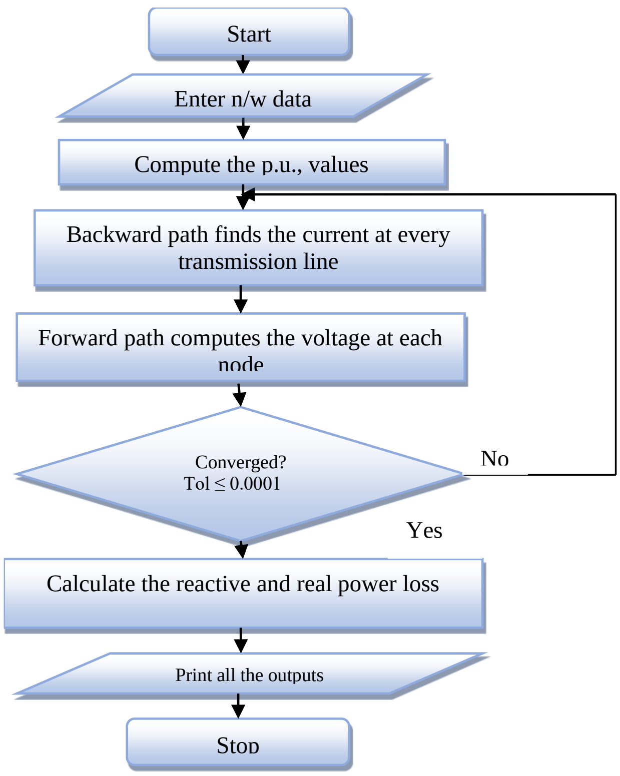

Figure 2. Flow chart of backward/forward LFA for renewable integration

The current introduced by the dispersed generator at node n changes the current flow in the transmission lines fixed between the slack bus and the bus connected to the DG. While the current flow of the remaining branches remains unchanged. The formula (4) and (5) can be used to determine the total power loss on bus n due to DG in terms of both reactive and active power.

$$P_{LDGn} = \sum_{m=1}^{n} [(I_{am} + I_{DGn})^2 * R_m] + \sum_{m=n+1}^{M} [{I_{am}}^2 * R_m] + \sum_{m=1}^{n} [(I_{rm} + A_n * I_{DGn})^2 * R_m] + \sum_{m=n+1}^{N} [{I_{rm}}^2 * R_m] \quad (4)$$

$$I_{DGn} = -\frac{\sum_{m=1}^{n}(I_{an} * R_n)}{\sum_{m=1}^{n} R_m} \quad (5)$$

The sizing of solar PV at node-n is computed by subsequent node voltage values and it is represented by (6),

$$P_{DGn} = I_{DGn} * |V_n| = -|V_n| * \frac{\sum_{m=1}^{n}(I_{an}*R_n)}{\sum_{m=1}^{n} R_m} \quad (6)$$

The sizing of wind power based DG at node-n is computed by subsequent node voltage values and it is represented by (7),

$$P_{DGn} = \frac{\alpha_{nn}(PD_n + A*QD_n) - X_n - A*Y_n}{A^2\alpha_{nn} + \alpha_{nn}} \quad (7)$$

where,

$$\mathrm{A} = tan[cos^{-1}(p.f._{DG})]. \quad (8)$$

3. RESULTS AND DISCUSSION

To improve the voltage profile and reduce power losses, the Hassan power distribution network is used as a test case system. Eleven feeders in the Hassan City, Karnataka, India, distribution network supply the city of Hassan and its surroundings with electricity. One of a total of eleven feeders will be taken into account for the waterworks and used as a test facility. Figure 3 shows the single-line diagram of the Hassan City, Karnataka, India, network. The twenty four branches and loads with a sum of fourty MW of real power and twenty one MVAr of reactive power form the Hassan City, Karnataka, India, network. The complete length of the network is 18.38 km.

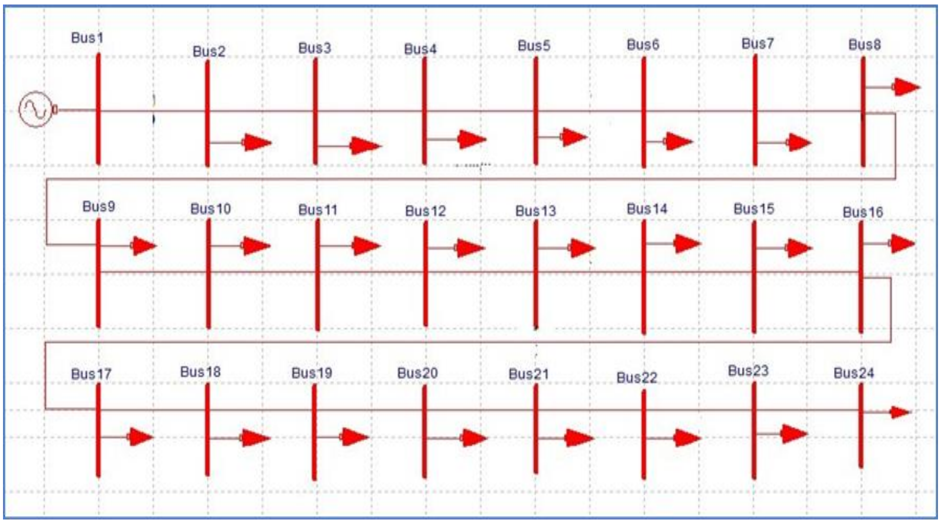

Figure 3. SLD twenty four RDN

The PQ nodes are considered for placing the decentralized generator. The slack bus, referred to as node-1 in the Hassan city, Karnataka, India, network, has a voltage of 1 p.u., For the purposes of this test and all future tests, each node in the system is considered a candidate bus. With each subsequent test, the node voltages and total losses are calculated. After connecting DG to each candidate bus, twenty three LFA results are acquired for the best possible placement of dispersed generator in Hassan city, Karnataka, India, twenty four node systems. The best location for DG is opted based on the overall reduction in network power loss and noteworthy boost in the voltage profile. The power loss on node nineteen with the existing DG was 490.1 kW. Therefore, node nineteen is the best place for the first DG. Figure 4 demonstrates the diverse voltage levels before and after installing a DG.

From the exhaustive LFA node-19 is the best location. The 5.84 MW solar PV generator sizing is carried using (6) i.e., Solar PV generators produces only the active power. Suppose all loads are connected in the network having unity power factor, in that case solar PV generators are more effective in efficient operation of the networks. In twenty four node network integration of solar PV at node suppresses the power loss 893 to 490 kW. Single solar PV helps to diminish the more than 40% of the power loss in the network. Similarly, the size of the WTG is also carried out by (7). The wind generator supplies both reactive and active power. The amalgamation of single wind power plant at node-19 improves the voltage profile with shrinks the total loss to 396.2 kW. Wind power plants also plays vital role in significant energy loss declination in the system. The efficient use of wind and solar generating units helps to reduce the dependency on the thermal power plant by reducing the emission of the greenhouse gases. This will helps to efficient, clean and sustainable operation of the distribution systems. Figure 5 shows SLD of twenty four node network with solar PV generation.

The comprehensive LFA is conducted for allocation of the second decentralized generator. In the presence of 5.8 MW DG at node 19, the second decentralized generator allocation is performed for every PQ node with a fixed DG size of 2 MW on all candidate nodes. All nodes are believed as a candidate node in the test and in all succeeding tests. Among all the test results, only a few selected results are illustrated in Table 1. The DG at node 13 shows a better voltage profile compared to the candidate nodes. Figure 6 shows integration of WTG in twenty-four node networks.

At node-13 the sizing of the solar and wind generation is carried out by (6) and (7). The second DG is placed at node-19 with the first DG at node 13, further dip in the power loss is observed followed by commendable progress in the voltage values. The integration of solar and wind DG shrinks the power loss from 893.6 to 348.2 kW and 316 kW respectively. In both the renewable generators condenses the power loss more than 50%. Figure 7 shows the power loss comparison of base case with RES in the network.

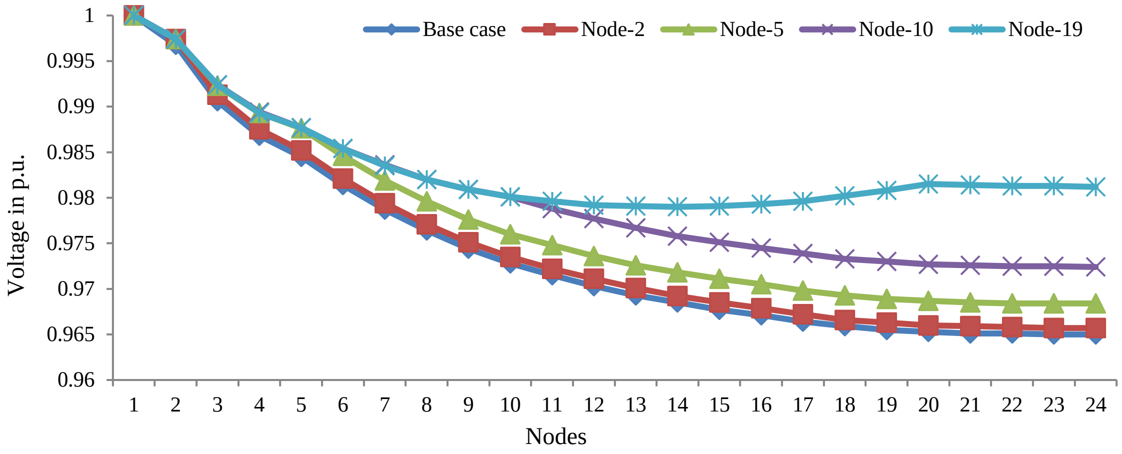

Figure 4. Voltage comparison

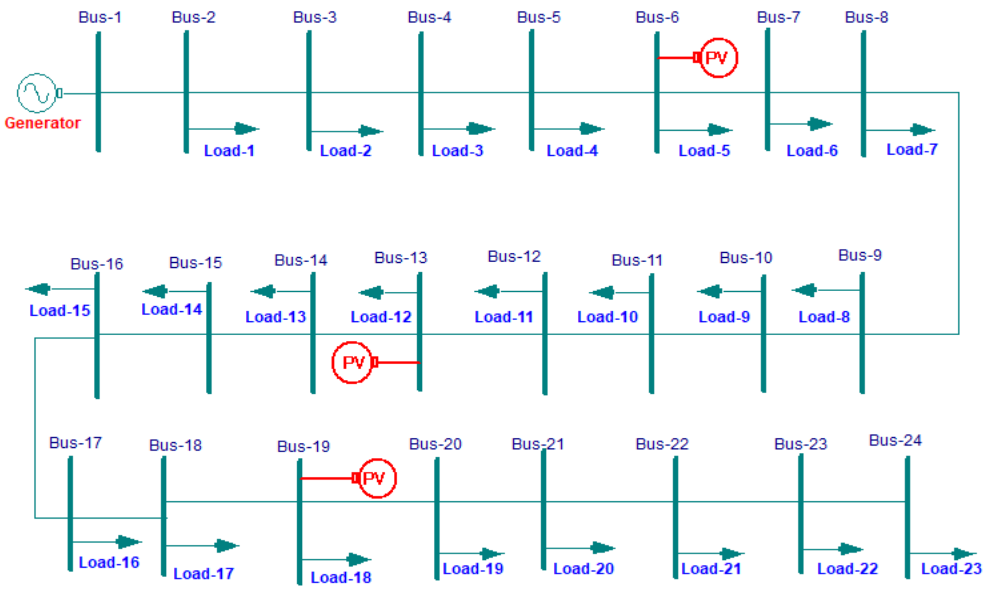

Figure 5. Twenty four node network with solar PV dispersed generator

Table 1. Comparison of voltage profile in the presence of second DG

Node No	Node-2	Node-4	Node-7	Node-11	Node-13	Node-20	Node-24
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9976	0.9977	0.9977	0.9977	0.9977	0.9977	0.9977
3	0.9928	0.9931	0.9931	0.9931	0.9931	0.9931	0.9931
4	0.9899	0.9904	0.9904	0.9904	0.9904	0.9904	0.9904
5	0.9883	0.9888	0.9890	0.9890	0.9890	0.9890	0.9890
6	0.9862	0.9867	0.9870	0.9870	0.9871	0.9870	0.9870
7	0.9845	0.9850	0.9855	0.9855	0.9855	0.9855	0.9855
8	0.9831	0.9836	0.9841	0.9843	0.9843	0.9843	0.9843
9	0.9821	0.9826	0.9831	0.9835	0.9835	0.9835	0.9835
10	0.9814	0.9819	0.9824	0.9831	0.9830	0.9830	0.9831
11	0.9811	0.9816	0.9821	0.9829	0.9829	0.9829	0.9829
12	0.9809	0.9814	0.9819	0.9827	0.9829	0.9829	0.9829
13	0.9808	0.9813	0.9819	0.9827	0.9830	0.9831	0.9831
14	0.9809	0.9814	0.9820	0.9828	0.9833	0.9834	0.9832
15	0.9811	0.9816	0.9822	0.9830	0.9836	0.9838	0.9834
16	0.9815	0.9820	0.9825	0.9833	0.9841	0.9843	0.9836
17	0.9821	0.9826	0.9831	0.9839	0.9849	0.9852	0.9844
18	0.9828	0.9833	0.9838	0.9846	0.9860	0.9862	0.9852
19	0.9837	0.9842	0.9847	0.9855	0.9871	0.9874	0.9859
20	0.9834	0.9839	0.9844	0.9852	0.9871	0.9874	0.9856
21	0.9833	0.9838	0.9843	0.9851	0.9873	0.9873	0.9855
22	0.9832	0.9837	0.9842	0.9850	0.9874	0.9872	0.9854
23	0.9832	0.9837	0.9841	0.9850	0.9877	0.9872	0.9854
24	0.9831	0.9837	0.9841	0.9849	0.9879	0.9872	0.9853

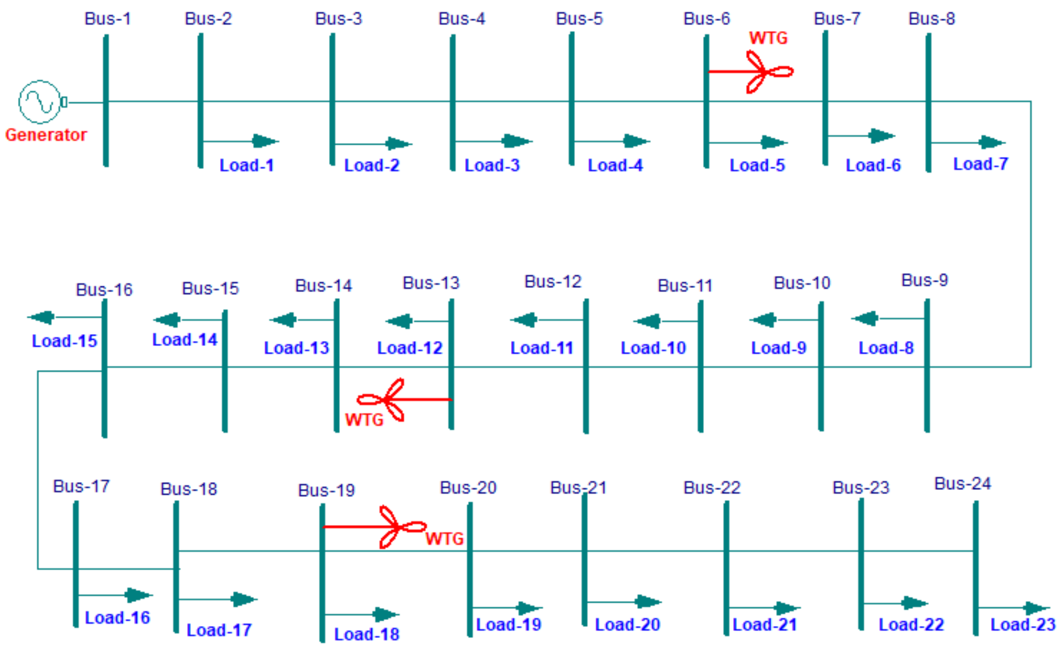

Figure 6. Twenty four node network with wind power dispersed generator

The amalgamation of solar PV DG gives the power loss declination of 45% for single DG placement, 61% for two dispersed generators with 3% to 5% perk up in the voltage throughout the network. Also, the incorporation of wind power DG gives the 55% of power diminution for one DG connection, 65% for two dispersed generators with 4% to 6% progress in the voltage profile is shown in Figure 8. Consequently wind energy can be used as best DG for the presented Hassan network. Hence incorporation of wind power DG the power loss condenses in between 55% to 65%, with 4%-8% enrichment the voltage values for single dg and two DG. So, it can be preferred as most advantageous type of DG for possible power loss reduction in the system. Likewise, solar PV dispersed generator trim downs the power loss from 45% to 61%, with 3% to 7% boost in the voltage values. Thus it can be preferred for second precedence for the decentralized generator placement.

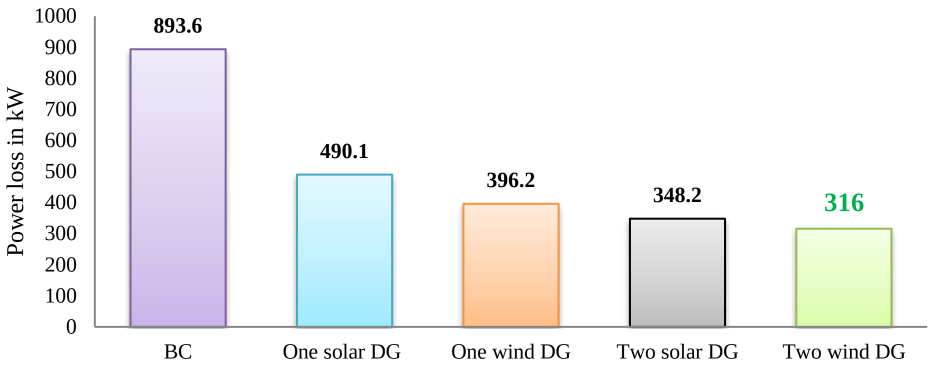

Figure 7. Power loss comparisons of base case with RES

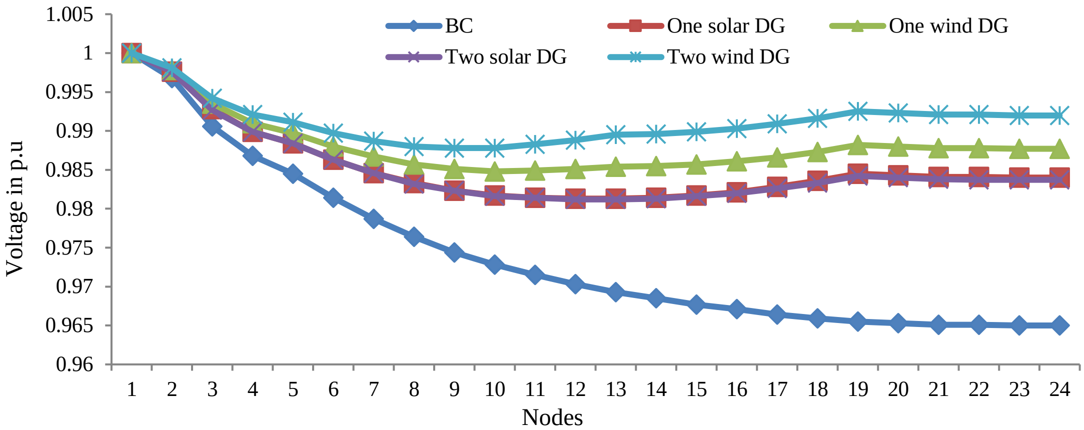

Figure 8. Voltage comparisons of base case with RES

4. CONCLUSION

To get better the voltage profile and reduce the overall power loss, distribution networks must be planned and operated with the most favorable position of DG within the current network. By integrating DG into the network, progressed voltage profiles at the load side and lower distribution losses in the line can be achieved. DG can supply part of the reactive and active power to the demand at on site, assisting to normalize the ampacity factor along the distribution line. The allocation of wind and solar DG plays key role in declining the emission of greenhouse gases. The intended methodology can be applied for any large network for RES integration. The combination of wind and solar DG can be considered for the future work with diverse loading condition.

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