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Optimal size and allocation of wind distributed generation in distribution network using particle swarm optimization

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ABSTRACT

The aim of this research is to evaluate the performance of the distribution network by connecting wind distributed generation (DG) and determining the optimal location and size using the particle swarm optimization (PSO) technique, once the wind DG is connected at the optimal location, the output of wind turbines is not constant but varies with changes in wind speed. Wind turbines are designed to generate the energy from the wind. As the output of the wind turbines changes, it influences the power flow and voltage levels in the distribution network. The injection of power from the wind turbines can cause variations in voltages within the distribution network. Additionally, the changing power flow may contribute to power losses in the distribution system. In this paper, the voltages and active power losses are evaluated with the change in wind speed for the IEEE 15 Bus system by conducting load flow analysis in MATLAB. The results reveal optimized solutions that contribute to reduced power losses, increased renewable energy generation, and improved voltage profiles. This research underscores the potential of PSO-based optimization in conforming more efficient and sustainable distribution networks.

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1. INTRODUCTION

The accumulation of renewable energy sources into distribution networks has grown significant attention due to the growing concerns about environmental sustainability and the need to decrease greenhouse gas discharge. Traditional distribution network planning often relies on conventional methods that may not be well-suited for operating the intermittent and variable nature of renewable generation. As a result, there is a growing interest in use advanced optimization techniques to determine the optimal locations and sizes of renewable-based generators within distribution networks. This study focuses specifically on wind turbine generators and employs the particle swarm optimization (PSO) algorithm to memorialize these challenges.

The use of a modified PSO for solving the dispatch optimization problem in micro-grids is an interesting approach with the goal of minimizing both carbon emissions and costs associated with each microgrid [1], [2]. This optimization technique contributes to enhancing the self-reliance of micro-grids while concurrently reducing losses [3], [4]. The use of optimization techniques and adaptive control strategies aligns with the goal of improving the overall efficiency and reliability of the microgrid system [5]-[7]. A novel crow search algorithm is used for the best location and sizing of RDGs [8]. Yang *et al.* [9] and Bernstein *et al.* [10] explained the unbalanced load flow of radial distribution network (DN). The central problem managed in this study is the optimal size and allotment of wind turbine/ generators in a distribution network. The aim is to reduce power losses, improve voltage stability, and boost the utilization of renewable energy sources [11], [12]. The PSO algorithm is employed as an effective optimization tool to find solutions that enhance the performance of distribution networks while absorb renewable energy sources. The optimal location and size of DG using different optimization algorithms are covered in the present literature review. Renewable energy combine in distribution networks is a basic and evolving phase of modern power systems. It involves incorporating renewable energy sources, such as solar, wind, hydro, and biomass, into the existing distribution structure to meet energy demand, reduce carbon emissions, and enhance energy sustainability [13], [14]. This integration presents a series of objection and opportunities that need to be carefully managed to ensure reliable, efficient, and resilient power delivery. The process of renewable energy integration in distribution networks compass various technical, economic, and precept considerations [15], [16]. The Figure 1 shows the multiple DGs connection in DN. When several wind generators are connected, the distribution network's primary issues are voltage stability and performance. These issues are addressed in this paper.

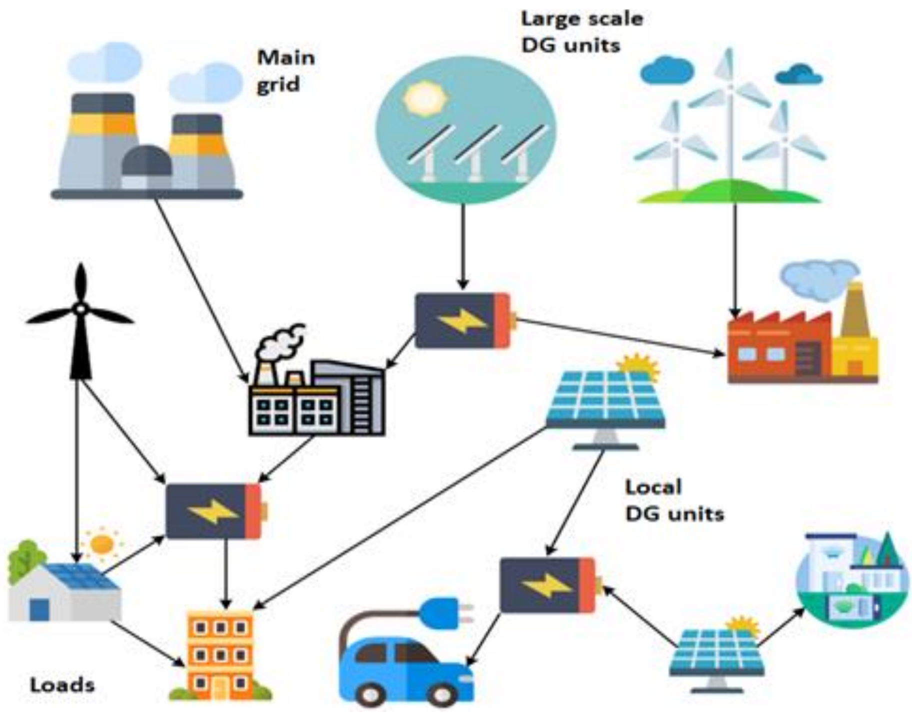

Figure 1. Distribution network with multiple DG units

The necessary steps to resolve this issue are listed below. Section 2: data collection and processing covers the requirements for the distribution network line and load data. Section 3: PSO algorithm covers the PSO technique, which is used to connect and size the wind generators optimally. Section 4: wind power generation discusses the modeling of wing generators. Section 5: results and analysis contains the results and discussion.

2. DATA COLLECTION AND PREPROCESSING

A single-line diagram of IEEE-15 bus radial DN is shown in Figure 2. The line data and load data of the IEEE-15 bus are given in the Table 1. This data could come from field measurements, historical records, replications, or databases. Wind turbine characteristics, such as power curves and efficiency data, are crucial for accurately modeling the renewable-based generator. Data preprocessing is once collected, the data requires preprocessing to ensure its quality and suitability for the PSO algorithm. Data cleaning is identifying and rectifying any inconsistencies, errors, or missing values in the collected data. This is critical to ensure the accuracy and reliability of subsequent analyses. Feature engineering is extracting or transforming features that are relevant for the optimization problem. This could involve converting wind speed data into power generation potential or calculating load profiles based on historical data. Normalization/scaling is scaling numerical data to a common range to prevent certain features from dominating the optimization process. Data integration is combining various datasets, such as load profiles and wind speed data, to create a comprehensive input dataset. Format conversion is ensuring that the data is in a format suitable for the PSO algorithm [17], [18]. This may involve converting data into matrices or arrays that can be efficiently processed. Defining constraints is setting constraints based on system limits, such as generator capacity, voltage limits, power losses and network constraints. Data partitioning is splitting the dataset into training and testing subsets to evaluate the PSO algorithm's performance and validate the obtained solutions [19], [20].

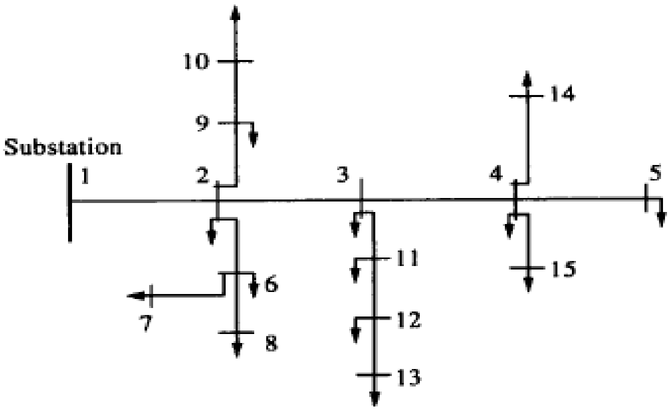

Figure 2. IEEE-15-Bus radial distribution network

Table 1. Line and load data for IEEE 15 bus radial distribution system

Branch number	Sending end node	Receiving end node	R (ohm)	X (ohm)	kVA
1	1	2	1.35309	1.32349	63.0
2	2	3	1.17024	1.14464	100.0
3	3	4	0.84111	0.82271	200.0
4	4	5	1.52348	1.0276	63.0
5	2	9	2.01317	1.3579	200.0
6	9	10	1.68671	1.1377	200.0
7	2	6	2.55727	1.7249	100.0
8	6	7	1.0882	0.734	100.0
9	6	8	1.25143	0.8441	63.0
10	3	11	1.79553	1.2111	200.0
11	11	12	2.44845	1.6515	100.0
12	12	13	2.01317	1.3579	63.0
13	4	14	2.23081	1.5047	100.0
14	4	15	1.19702	0.8074	200.0

3. PSO ALGORITHM

The PSO algorithm is a nature-inspired optimization technique that replicates the social behavior of birds or particles in a swarm to solve complicate development problems. In PSO, each possible by iteratively updating particle positions according to their historical best and the best solution found by the entire swarm, PSO strongly explores the solution space to meet towards excellent or near-optimal solutions. This collective movement and knowledge sharing among particles copy the social interactions in natural swarms and enable PSO to efficiently solve a wide range of development challenges, including those found in engineering, economics, and power systems, among others.

The flow chart of PSO is shown in Figure 3. The PSO process involves replicating the behavior of a swarm of particles to solve development problems fitness. The fitness indicates how well each particle's solution performs in the given problem. Velocity update is the velocity of each particle using a combination of its current velocity, its intellectual component (based on P best), and its social component (based on Gbest) [21], [22]. The new velocity guides the particle's movement in the solution space. Position update is the position of each particle using its new velocity. The position change reflects the particle's movement towards potentially better solutions. Check for combining conditions, such as reaching a maximum number of iterations or achieving a satisfactory solution quality. If the combining criteria are met, the process stops.

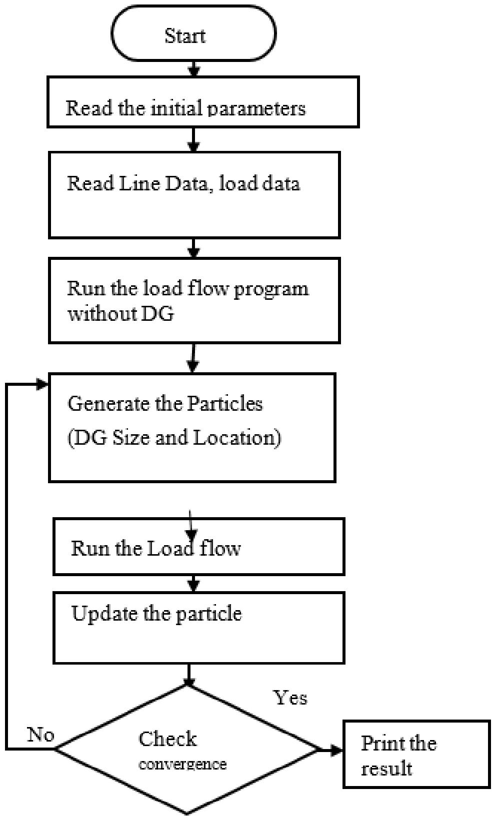

Figure 3. PSO flow chart

4. WIND POWER GENERATION

Wind is the result of the uneven heating of the Earth's surface by the sun. Variations in solar radiation absorption due to different land and water formations cause differential heating. The curvature of the earth also contributes to uneven heating and creates differences in atmospheric temperature and pressure.

The turbine's shaft, connected to the rotor with blades, is linked to a generator. To match the generator's required speed with the rotor's operational speed, a gearbox is used. Wind turbine blades typically have a lift design, similar to axial flow fans. Adjusting the pitch of the blades controls the turbine's operation, much like the aerodynamics of an airplane wing. Wind turbines have minimum operational speeds; below this, the rotor is locked to prevent damage. The ideal maximum mechanical power output (P) is given by (1).

$$\boldsymbol{p = \frac{1}{2} \times \rho \times A \times V^3} \quad (1)$$

Where ρ is the air density, A is the swept area, and V is wind velocity.

4.1. Modelling and simulation of wind turbine

Load demand profiles represent the fleeting modification of electricity consumption within a specific area or power distribution network over a given period. These profiles provide critical vision into the patterns of energy usage and help in designing, planning, and optimizing distribution systems. Load demand profiles are usually obtained through historical data analysis, dimensions, or simulations. They are often categorized into peak, off-peak, and intermediate periods. Peaks occur during high-demand hours, such as mornings and evenings, while off-peak times experience lower consumption. Median periods bridge these extremes. Understanding load demand profiles is essential for various intension, including network design, capacity planning, and renewable integration [23], [24]. For instance, precise load profiles enable the optimal sizing and placement of distributed generators, like wind turbines, by aligning generation with peak demand periods, enhancing grid solidity, and minimizing energy costs [25]. These profiles are premium inputs for optimization algorithms like PSO, guiding them to make logical decisions that align with actual devouring patterns and overall system effectiveness. The wind turbine design is shown in Figures 4 and 5. The output power of wind turbine is 177.7 kW at a wind speed of 12 m/s.

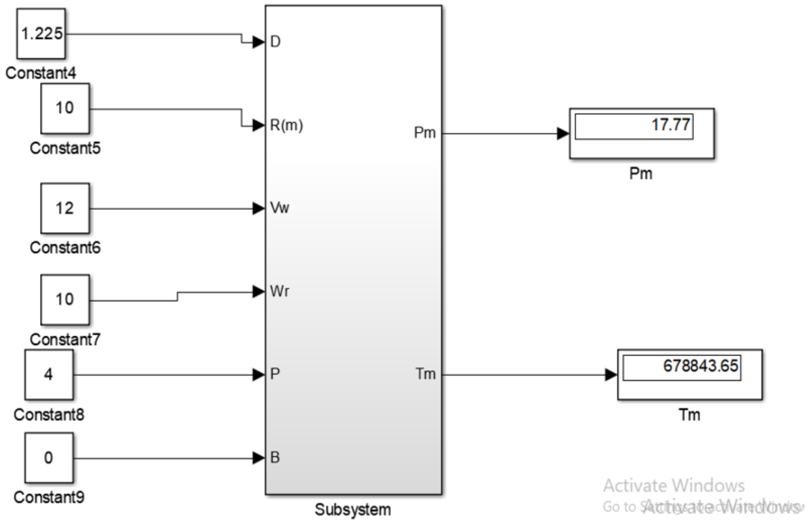

Figure 4. Wind turbine outer circuit diagram

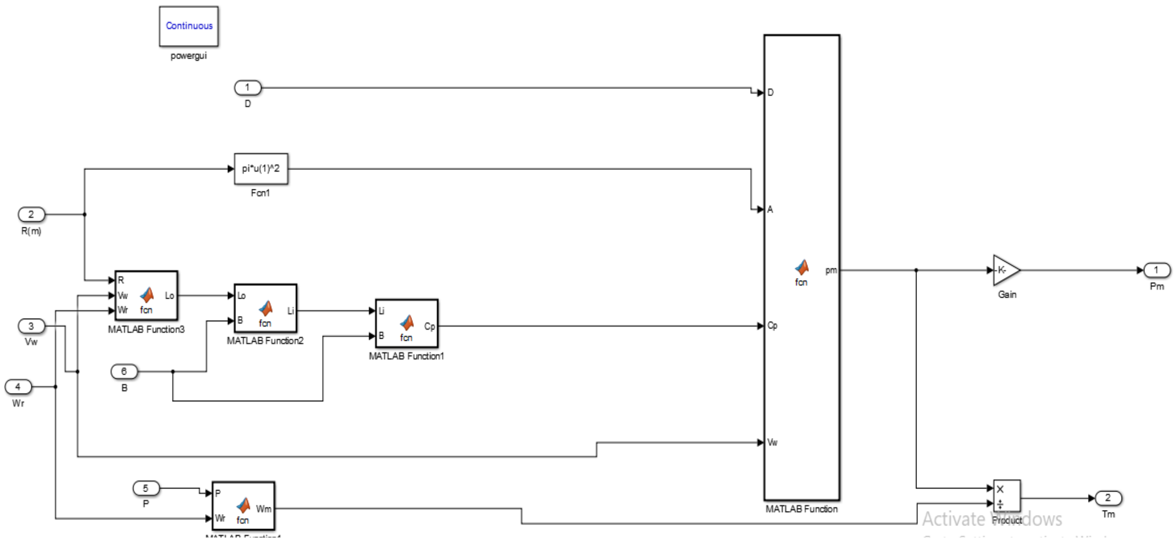

Figure 5. Wind turbine inner circuit diagram

5. RESULTS AND ANALYSIS

The performance of the distribution network is evaluated and explained with different case studies as follows.

5.1. Case study 1: without DG connection

The load flow has been implemented on the IEEE-15 bus distribution network. The per unit voltages at each bus are given in Table 2. Buses at nodes with voltage values less than 0.95 p.u. may experience a significant drop, which could lead to voltage instability issues. It can result in increased active and reactive power losses in the distribution system. In the above 15 bus system bus voltages at 12, and 13 have voltage values below 0.95 p.u., suggesting that these nodes are experiencing a voltage drop. The active loss is 60.06 kW and reactive loss is 55.62 kVAR.

Table 2. Per unit voltages at 15 buses

Bus no	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Voltage (p.u)	1.000	0.972	0.958	0.953	0.952	0.959	0.957	0.958	0.969	0.968	0.951	0.947	0.946	0.950	0.950

5.2. Case study 2: generator 1 is connected in distribution network using PSO

The PSO algorithm is applied on IEEE-15 bus distribution network for optimal location and sizing of wind DG. From the PSO results, the best location is at bus 12 and the DG size is 197.59 kW. Figure 6 shows Bus 1 has a reference voltage of 1.00 p.u., which is expected as it serves as the reference bus. Buses 2 to 15 have voltage magnitudes less than 1.00 p.u., indicating a voltage drop from the reference bus. There is a decreasing trend in voltage magnitudes from Bus 2 to Bus 15. The voltage magnitudes are relatively close for Buses 11 to 15, suggesting a relatively uniform voltage drop in this range. Buses with lower voltage magnitudes may be prone to voltage instability, especially if they approach or go below acceptable lower limits. If the voltage magnitudes are close to the lower limit, there may be opportunities to improve voltage stability by adjusting system parameters or introducing reactive power support. Before connecting wind DG, it's important to assess the impact on the voltage profile. Wind DG at bus 12 can influence voltage levels, and its integration may lead to changes in the voltage magnitudes at different buses. Evaluated the minimum active and reactive power losses by conducting load flow analysis. The minimum active power loss is 46.638 kW and the reactive power loss is 42.648 kVAR.

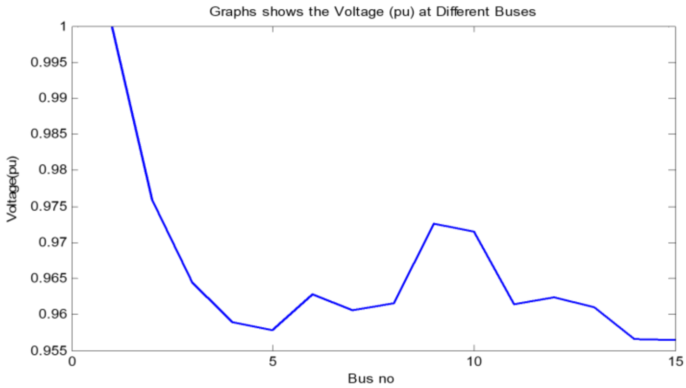

Figure 6. Voltages (p.u) at 15 buses when DG is connected

5.3. Case study 3: generator 1 connected at Bus no: 12, wind speed at 10 m/s, the output power of DG is 81.80 kW

Figure 7 shows the per unit voltages at 15 buses when wind DG supplies 81.80 kW at a wind speed of 10 m/s. Explore control strategies for the wind DG to optimize its contribution to the system while ensuring stability. Buses with lower voltage magnitudes (e.g., Buses 14 and 15) may be more susceptible to voltage instability. Voltage magnitudes close to or below 0.95 p.u. may indicate potential stability issues. The wind DG is injecting power into the system, influencing the voltage profile. The specific impact depends on the location, capacity, and control strategies of the wind DG. By conducting load flow analysis, the minimum active and reactive power loss analysis to comprehensively assess the system's performance with the integrated wind DG. The minimum active power loss is 53.572 kW and the minimum reactive power loss is 49.683 kVAR.

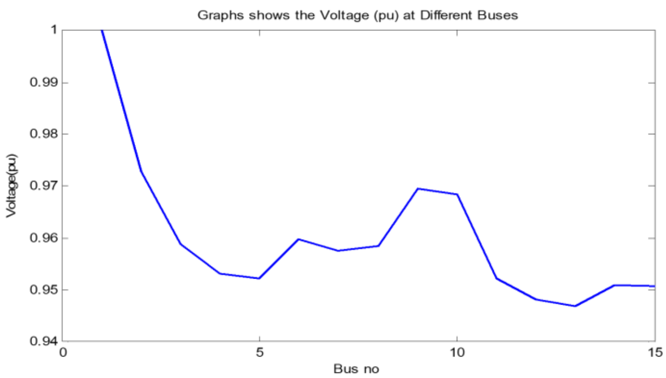

Figure 7. Voltages (p.u) at 15 buses when wind speed is 10 m/s

5.4. Case study 4: generator 1 connected at Bus no: 12, wind speed at 12 m/s. The output power of DG is 177.7 kW

The output power of the wind DG at a wind speed of 12 m/s, along with the minimum active and reactive power losses. Influenced the voltage profile, resulting in decreased voltage drop across the system as shown in Figure 8. Bus voltage at 12, and 13 buses has been improved and the minimum active and reactive power losses are calculated. The minimum active power loss is 47.058 kW. The minimum reactive power loss is 43.584 kVAR.

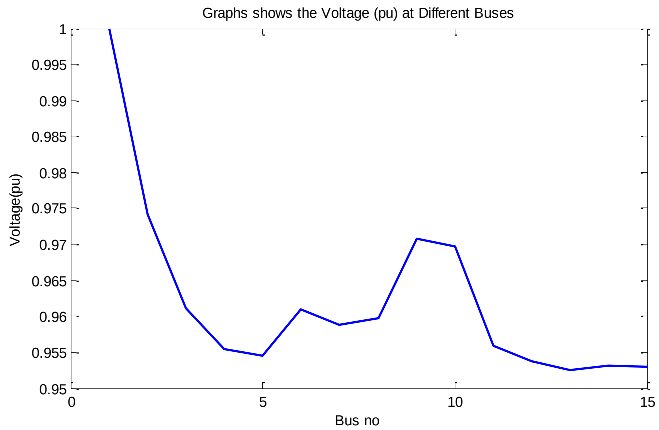

Figure 8. Voltages (p.u) at 15 buses when wind speed is 12 m/s

5.5. Case study 5: generator 1 connected at Bus no: 12, wind speed at 14 m/s, The output power of DG is 274.1 kW

The integration of a generator (generator 1) at Bus 12, along with its size and the wind speed at 14 m/s, resulted in an output power of 274.1 kW. The per-unit voltages are shown in Figure 9. Compare the system losses and efficiency with previous wind speeds (10 m/s and 12 m/s). by the addition of the generator at Bus 12 has affected the minimum active and reactive power losses. By conducting load flow analysis, the minimum active and reactive power losses are calculated. The minimum active power loss is 41.67 kW. The minimum reactive power loss is 38.380 kVAR.

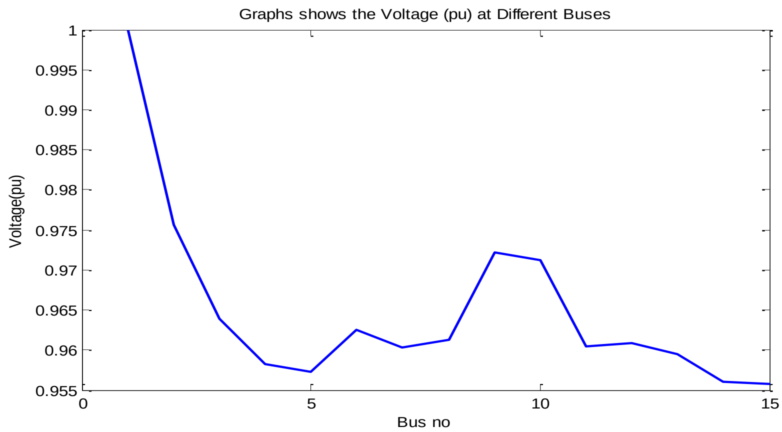

Figure 9. Voltages (p.u) at 15 buses when wind speed is 14 m/s

5.6. Case study 6: generator 1 connected at Bus no: 12, wind speed at 16 m/s, the output power of DG is 356 kW

The wind DG output power has increased from 274.1 kW (at 14 m/s) to 356 kW (at 16 m/s). The minimum active power loss has decreased from 41.677782 kW to 38.002348 kW. The minimum reactive power loss has also decreased from 38.380055 kVA to 34.669412 kVA. The increased wind speed and subsequent higher wind DG output power have resulted in lower minimum active and reactive power losses. The per unit voltages at each bus also more compare with other case studies as shown in Figure 10. The higher wind DG output power may contribute to better overall system efficiency.

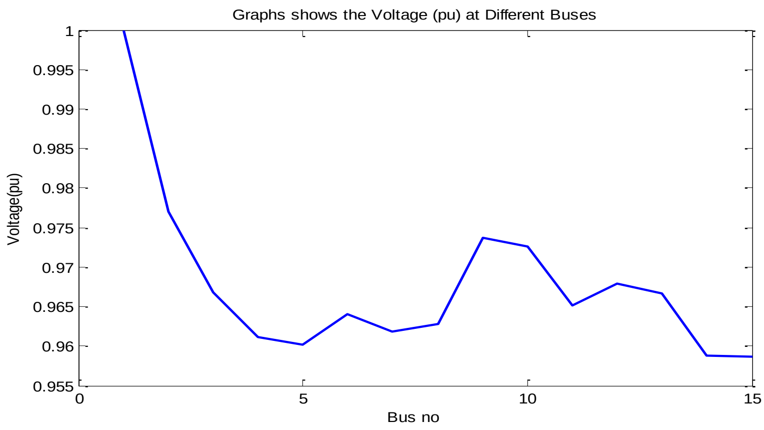

Figure 10. Voltages (p.u) at 15 buses when wind speed is 16 m/s

6. CONCLUSION

The PSO method has been implemented on the IEEE-15 bus distribution network for optimal placement and size of wind DG. After connecting wind DG, the output power of DG is changed with the change in wind speed. The distribution network voltages and power losses are changed with the change in wind DG power supply. When wind speed increased, the wind DG power generation also increased. The distribution network is operated stable when wind speed is more than 10 m/s because all the voltages are within the boundary limits.

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