IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 4, April 2026

DOI: 10.17148/IJIREEICE.2026.14409

Load Flow Analysis of Grid Connected Wind Farm

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Abstract: Nowadays, the need for electrical energy is increasing day by day, which has made renewable energy sources more important. Among them, wind energy is widely used because it is clean and easily available. In this work, a grid-connected wind farm system is considered and its load flow behaviour is studied. The main aim is to observe how power is distributed in the system and to check voltage levels and losses under normal conditions. The modelling and simulation are carried out using Dig SILENT Power Factory software. The Newton-Raphson method is selected for analysis since it gives faster and reliable results. From the simulation, it can be observed that the system operates within acceptable limits. This kind of study helps in understanding the performance of wind farms and supports better integration with the power grid.

Keywords: Wind Farm, Load Flow Analysis, Power Factory, Newton-Raphson Method, Renewable Energy.

I. INTRODUCTION

The demand for electrical energy has been increasing continuously due to population growth, industrial expansion, and technological development. At the same time, the use of conventional energy sources such as coal and petroleum is becoming a concern because of their limited availability and the environmental issues associated with them. This situation has led to a gradual shift towards renewable energy sources for power generation. Among the available renewable options, wind energy has gained significant importance. One of the main reasons is that wind is naturally available, does not produce harmful emissions, and can be utilized on a large scale. Wind farms are typically installed in areas where wind speed is sufficient, and the generated power is connected to the main electrical grid to supply consumers.

A grid-connected wind farm consists of multiple wind turbines working together to produce electrical energy. Each turbine converts the kinetic energy of wind into mechanical energy, which is then converted into electrical energy using a generator. This generated power is transmitted through transformers and transmission lines before being delivered to the grid. Since these systems are directly connected to the existing power network, their performance has a direct impact on overall system operation. Unlike conventional power plants, wind energy is not constant and depends entirely on wind conditions. Because of this, the power generated by wind turbines keeps changing. These variations can affect important parameters such as voltage levels, power flow, and system stability. In some cases, it may also lead to issues like voltage fluctuation or imbalance in reactive power.

To study and understand these effects, load flow analysis is carried out. Load flow analysis is a basic and essential study in power system engineering that helps in determining how electrical power flows through different parts of the system under steady-state conditions. It provides information about voltage magnitude, phase angle, real power, reactive power, and losses at various buses in the network. By performing load flow analysis, it becomes possible to check whether the system is operating within acceptable limits. It also helps in identifying weak points in the network, such as buses with low voltage or lines carrying excessive load. This is especially important in wind energy systems, where power generation is not stable and varies with time.

In this work, a grid-connected wind farm is considered, and its load flow behaviour is analysed. The modelling and simulation are carried out using Dig SILENT Power Factory software, which is widely used for power system studies. The Newton-Raphson method is used for solving the load flow equations, as it provides faster convergence and reliable results for large systems. The main objective of this study is to understand how the wind farm interacts with the grid and to ensure that the system operates efficiently without violating any limits. The results obtained from this analysis can be useful for improving system performance and planning future expansions.

II. LITERATURE REVIEW

W. Yang et al. (2020) [1] discussed the coordinated planning of grid-connected wind farms along with transmission expansion. In their work, both generation and transmission were considered together instead of separately. This approach helped in reducing the overall cost and improving the reliability of the system. It clearly shows that proper planning is important when integrating large-scale wind energy into the grid.

C. Wang et al. (2022) [2] studied the behaviour of a wind-storage combined system and analysed its impact on power quality. The authors mainly focused on reducing the variations in wind power output by using energy storage. From their results, it was observed that the system becomes more stable and voltage fluctuations are reduced when storage is included.

M. Rosyadi et al. (2014) [3] proposed a simplified model of a wind turbine based on Doubly-Fed Induction Generator (DFIG). This model is mainly used for dynamic analysis of wind farms. Compared to complex models, the proposed approach is easier to use and still provides acceptable accuracy for system studies.

Q. Xia et al. (2017) [4] analysed different power quality issues that arise in wind energy systems. The study mainly discussed problems such as voltage fluctuations, harmonics, and flicker. It was pointed out that these issues are mainly due to the variable nature of wind and need proper control methods to maintain system performance.

Y. Z. Sun et al. (2009) [5] presented a review on the integration of variable speed wind turbines into power systems. The authors explained the challenges related to system stability and control. Their work also highlighted the importance of proper control strategies to ensure smooth operation of wind energy systems.

D. Dragomir et al. (2009) [6] discussed the technical challenges involved in connecting wind turbines to the grid. The paper focused on grid requirements, power quality issues, and control techniques required for stable operation. This study provides a basic understanding of practical issues in wind farm integration.

From the above studies, it can be understood that wind energy integration introduces several challenges related to stability and power quality. Even though different methods have been suggested by researchers, analysing the steady-state behaviour of the system is still important. In this work, load flow analysis is carried out to study the performance of a grid-connected wind farm.

III. GRID CONNECTED WIND FARMS

A grid-connected wind farm is an interconnected collection of wind turbines designed to generate electricity and supply it directly to the main electrical power grid. Unlike isolated wind turbines that might serve local loads, grid-connected wind farms are integrated into the larger utility infrastructure, allowing for widespread distribution and utilization of the generated power.

KEY COMPONENTS

A. Wind Turbines

These are the primary energy conversion units, consisting of blades, a rotor, a nacelle (housing the gearbox and generator), and a tower. They Observe the kinetic energy from the wind and convert it into rotational mechanical energy..

B. Generators

Most modern wind turbines use Fixed Speed Induction Generators (FSIG) which convert mechanical energy into electrical energy. These generators are often coupled with power electronic converters to allow for variable-speed operation and grid integration.

C. Transformers

Individual wind turbines often have step-up transformers at their base or within the nacelle to raise the voltage of the generated electricity to a collection voltage level. Additional step-up transformers are typically found at the substation to increase the voltage further for transmission.

D. Grid

It consists of cables and feeders that connect individual wind turbines to a central substation. It ensures that power from all turbines is gathered and transferred efficiently.

E. Substation

The wind farm substation serves as the crucial interface between the wind farm and the main transmission grid. It houses step-up transformers to increase the voltage from the collection system level to the transmission voltage level. It includes the components like switchgear, circuit breakers, protective relays, and control equipment.

F. Transmission Lines

High-voltage transmission lines connect the wind farm substation to the existing national or regional electrical power grid.

IV. LOAD FLOW ANALYSIS

LOAD FLOW STUDY

It is a steady state analysis of a power system network. Its primary goal is to determine the following steady-state operating conditions of the system under a given set of load and generation conditions:

1) Bus Voltages: Magnitude (p.u. or kV) and phase angle (degrees or radians) at each busbar in the system.
2) Power Flows: Active (P) and reactive (Q) power flowing through all transmission lines, cables, transformers, and other network elements.
3) Generator Outputs: The active and reactive power being supplied by each generator.
4) Transformer Tap Settings: The tap positions of transformers, especially those with on-load tap changers, which are often adjusted to regulate voltage.
5) Losses: Active and reactive power losses in transmission lines, transformers, and other components.

STEPS TO PERFORM LOAD FLOW

a) Data Collection and System Modelling: Gather all necessary data, including:

Bus data: Classification of buses (Slack, PV, PQ), specified real and reactive power for load buses (PQ), specified real power and voltage magnitude for generator buses (PV), and specified voltage magnitude and angle for the slack bus.

Line and Transformer data: Impedances and shunt admittances of transmission lines and transformers, often represented by their equivalent π-models.

b) Generator data: Capability limits and other characteristics.

Solving Load Flow Equation: Iterative numerical techniques are employed to solve these equations by the Newton-Raphson Method. The most efficient and widely used load flow algorithm for large and complex systems. It uses partial derivatives (Jacobian matrix) to solve the non-linear equations.

c) Result Analysis: Once the solution converges, the results (voltage magnitudes and angles, power flows, losses) are analysed to identify any issues and to make informed decisions for system optimization (e.g., reconfiguring the network, installing reactive power compensation devices)

V. SIMULATION AND RESULTS

1.LAYOUT OF THE SYSTEM

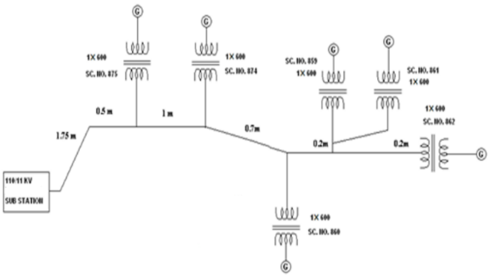


Fig. V. 1 Layout of the system

Figure. V. 1 shows the layout of the substation It consists of six wind generator each with capacity 600 kW at 690 V is taken for the analysis. The total capacity of this wind farm is 3.6 MW. The shaded part in the layout indicates the

DOI: 10.17148/IJIREEICE.2026.14409

wind generator under erection work. Each wind turbine is connected to an 11 kV bus bar. The induction generators, soft-starters and the capacitor banks for reactive power compensation and step up transformer are placed at the foot of wind turbine. The control of active and reactive power is based on the measured reactive power at the point of common coupling. The wind turbine controller must be able to adjust the production of wind turbine, according to the demands imposed by the system operator. In normal operating conditions, the wind turbine has to produce maximum power. In power limited operation mode, the wind turbine has to limit its production to the rated power for wind speed greater than rated values.

The voltage generated by the squirrel cage generator is directly connected to LV side of a transformer rated at 800 kVA, 690 V/11 kV. The HV side of the transformer is connected to 11 kV common feeder using underground cable at voltage level of 11 kV. The 11 kV substation is connected to 110 kV substation through a transformer rated at 16 MVA.

2. OVERVIEW OF SIMULATION

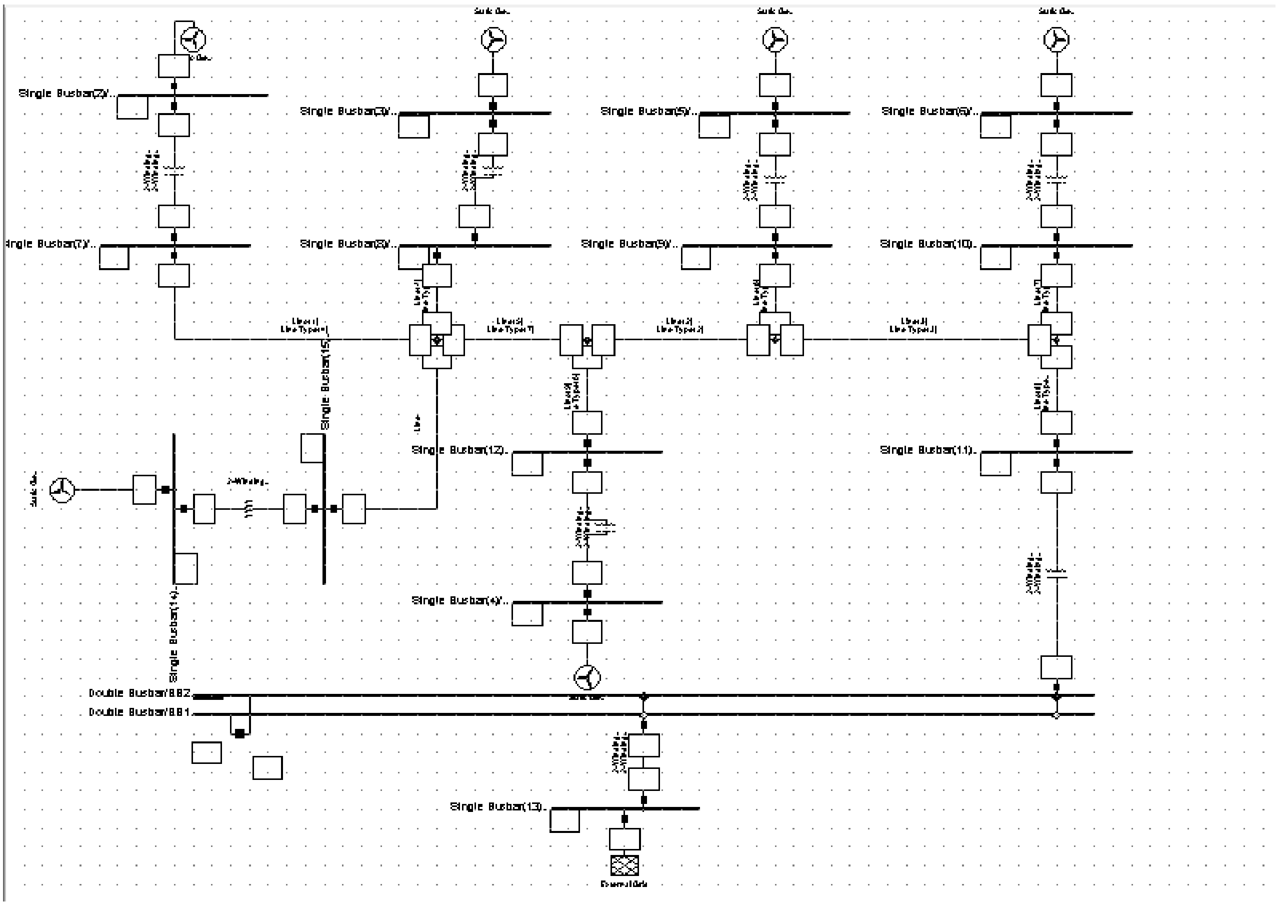


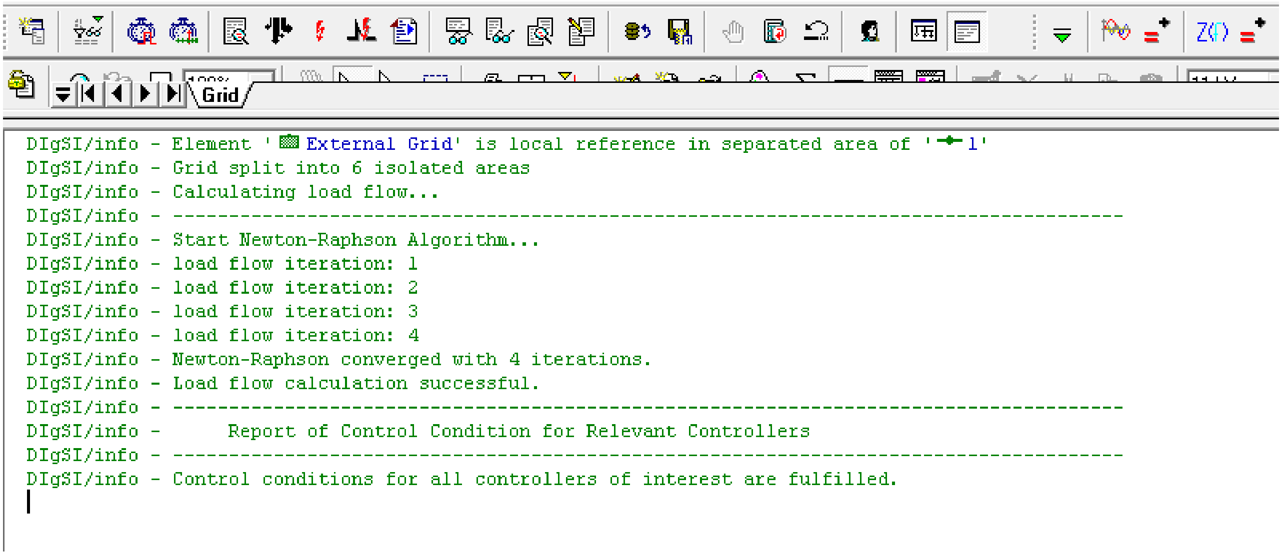
Fig. V. 2 Simulation in Dig Silent software

Figure.V.2. Shows the simulattion model built in DIgSILENT Powerfactory. The DIgSILENT has the ability to simulate load flow, RMS fluctuations and transient events in the same software environment. It provides different levels of the detailing of the system. It combines the models of electromagnetic transient simulations of the instantaneous values with the models of the electromechanical simulations of RMS values. This makes the models useful for the studies of grid fault, the power quality and control issues.

3.RESULTS AND DISCUSSION

Results for Load flow analysis were obtained using DIgSILENT software, providing detailed insights into system performance of the substation has been given in the following Figures. The load flow analysis was carried under the Newton-Raphson method in DIgSILENT PowerFactory software. During this process, the calculations were performed step by step. The algorithm started and completed the iterations within a few cycles, indicating good convergence. The results show that the load flow calculation was successful, and all the conditions were satisfied.

This confirms that the system is operating under the given conditions without any major issues.



```
DIgSI/info - Element '▦External Grid' is local reference in separated area of '1'
DIgSI/info - Grid split into 6 isolated areas
DIgSI/info - Calculating load flow...
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - load flow iteration: 3
DIgSI/info - load flow iteration: 4
DIgSI/info - Newton-Raphson converged with 4 iterations.
DIgSI/info - Load flow calculation successful.
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info -      Report of Control Condition for Relevant Controllers
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info - Control conditions for all controllers of interest are fulfilled.
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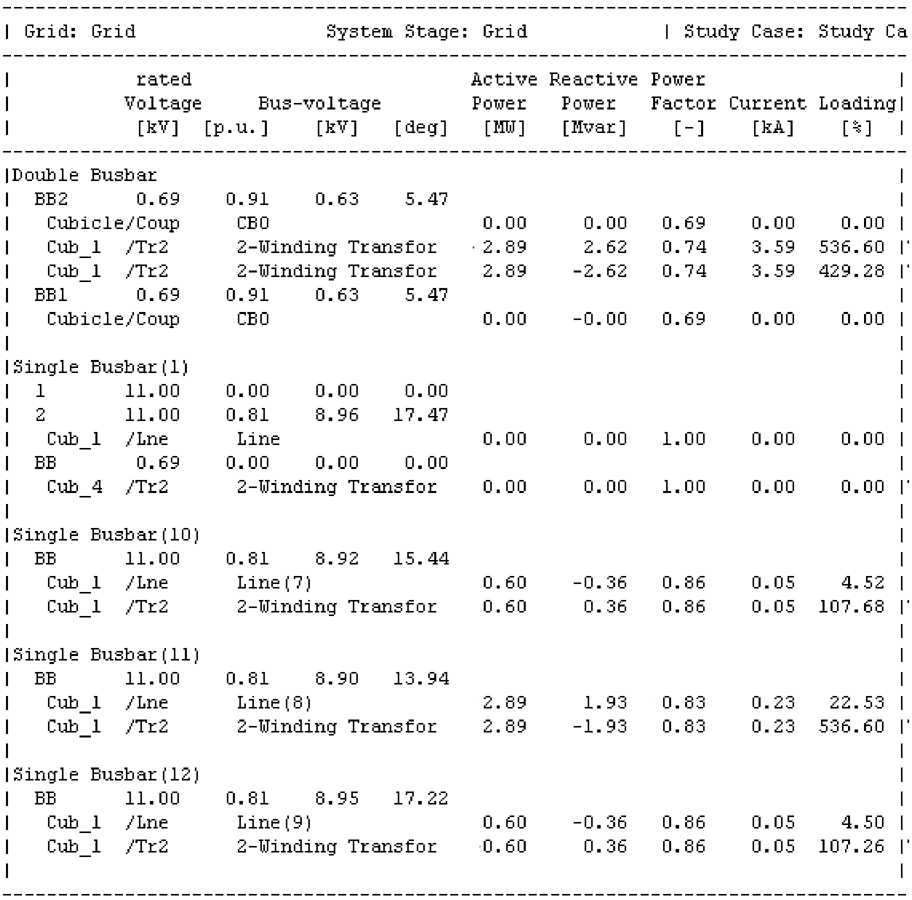
Fig. V. 3 Output of Load flow Analysis



```
--------------------------------------------------------------------------------
| Grid: Grid                 System Stage: Grid            | Study Case: Study Ca
--------------------------------------------------------------------------------
|           rated                        Active Reactive Power                 |
|          Voltage     Bus-voltage       Power   Power   Factor Current Loading|
|           [kV]  [p.u.]    [kV]   [deg]  [MW]  [Mvar]    [-]     [kA]    [%]  |
--------------------------------------------------------------------------------
|Double Busbar                                                                 |
|  BB2      0.69    0.91    0.63    5.47                                       |
|   Cubicle/Coup     CB0                  0.00    0.00    0.69    0.00    0.00 |
|   Cub_1  /Tr2      2-Winding Transfor   2.89    2.62    0.74    3.59  536.60 |'
|   Cub_1  /Tr2      2-Winding Transfor   2.89   -2.62    0.74    3.59  429.28 |'
|  BB1      0.69    0.91    0.63    5.47                                       |
|   Cubicle/Coup     CB0                  0.00   -0.00    0.69    0.00    0.00 |
|                                                                              |
|Single Busbar(1)                                                              |
|  1       11.00    0.00    0.00    0.00                                       |
|  2       11.00    0.81    8.96   17.47                                       |
|   Cub_1  /Lne      Line                 0.00    0.00    1.00    0.00    0.00 |
|  BB       0.69    0.00    0.00    0.00                                       |
|   Cub_4  /Tr2      2-Winding Transfor   0.00    0.00    1.00    0.00    0.00 |'
|                                                                              |
|Single Busbar(10)                                                             |
|  BB      11.00    0.81    8.92   15.44                                       |
|   Cub_1  /Lne      Line(7)              0.60   -0.36    0.86    0.05    4.52 |
|   Cub_1  /Tr2      2-Winding Transfor   0.60    0.36    0.86    0.05  107.68 |'
|                                                                              |
|Single Busbar(11)                                                             |
|  BB      11.00    0.81    8.90   13.94                                       |
|   Cub_1  /Lne      Line(8)              2.89    1.93    0.83    0.23   22.53 |
|   Cub_1  /Tr2      2-Winding Transfor   2.89   -1.93    0.83    0.23  536.60 |'
|                                                                              |
|Single Busbar(12)                                                             |
|  BB      11.00    0.81    8.95   17.22                                       |
|   Cub_1  /Lne      Line(9)              0.60   -0.36    0.86    0.05    4.50 |
|   Cub_1  /Tr2      2-Winding Transfor   0.60    0.36    0.86    0.05  107.26 |'
|                                                                              |
--------------------------------------------------------------------------------
```

Fig. V. 3.1 Load flow Result

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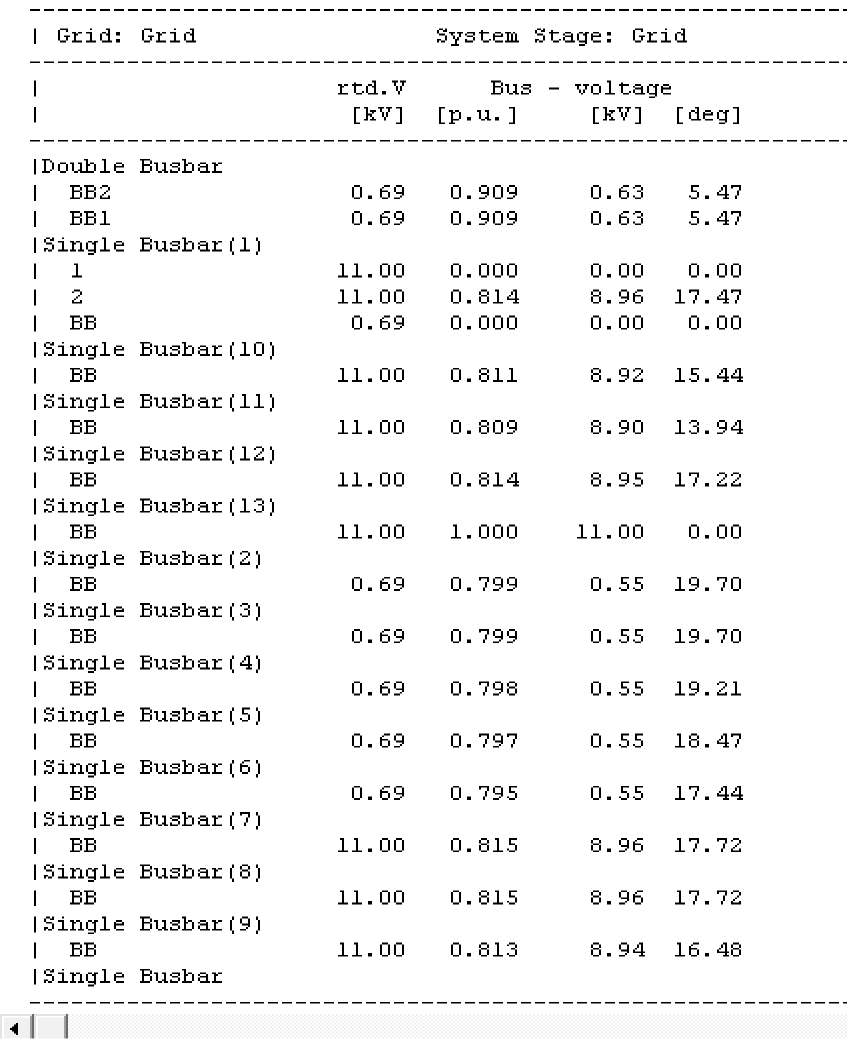

```
-------------------------------------------------------------
| Grid: Grid                   System Stage: Grid
-------------------------------------------------------------
|                      rtd.V      Bus - voltage
|                       [kV]  [p.u.]     [kV]  [deg]
-------------------------------------------------------------
|Double Busbar
|  BB2                  0.69  0.909      0.63   5.47
|  BB1                  0.69  0.909      0.63   5.47
|Single Busbar(1)
|  1                   11.00  0.000      0.00   0.00
|  2                   11.00  0.814      8.96  17.47
|  BB                   0.69  0.000      0.00   0.00
|Single Busbar(10)
|  BB                  11.00  0.811      8.92  15.44
|Single Busbar(11)
|  BB                  11.00  0.809      8.90  13.94
|Single Busbar(12)
|  BB                  11.00  0.814      8.95  17.22
|Single Busbar(13)
|  BB                  11.00  1.000     11.00   0.00
|Single Busbar(2)
|  BB                   0.69  0.799      0.55  19.70
|Single Busbar(3)
|  BB                   0.69  0.799      0.55  19.70
|Single Busbar(4)
|  BB                   0.69  0.798      0.55  19.21
|Single Busbar(5)
|  BB                   0.69  0.797      0.55  18.47
|Single Busbar(6)
|  BB                   0.69  0.795      0.55  17.44
|Single Busbar(7)
|  BB                  11.00  0.815      8.96  17.72
|Single Busbar(8)
|  BB                  11.00  0.815      8.96  17.72
|Single Busbar(9)
|  BB                  11.00  0.813      8.94  16.48
|Single Busbar
-------------------------------------------------------------
```

Fig. V. 3.2 Load flow Result

The successful execution and convergence of the load flow analysis using the Newton-Raphson method, as indicated by Figure V.3, confirms that a stable operating point for the wind farm and its connection to the grid was found. This provides a foundational understanding of the wind farm's operation.

From the Figures V.3.1 & 3.2, the 0.69 kV buses, voltages were around 0.63 kV (0.909 p.u.) and 0.55 kV (0.79-0.80 p.u.), while 11 kV buses consistently registered around 8.90-8.96 kV (0.81 p.u.), indicating voltage drops across the network. Active power flows confirmed generation and distribution, with a "2-Winding Transformer" showing 2.89 MW active and -2.52 Mvar reactive power, and lines/generators contributing 0.60 MW active power. Negative reactive power flows suggest absorption by inductive elements or compensation.

Many components exhibited a power factor of 0.88 or 0.86, and maintaining this within acceptable limits is vital for minimizing losses and optimizing grid performance.

VI. CONCLUSION AND FUTURE SCOPE

CONCLUSION

This project successfully initiated the analysis in grid-connected wind farms, commencing with a load flow analysis as its initial phase. The report highlighted the increasing importance of grid-connected wind farms in sustainable energy generation and their role in reducing reliance on fossil fuels.

The load flow analysis, a steady-state evaluation of the power system, was performed to analyse the system planning, operational management, voltage control, power loss identification, and contingency analysis. The simulation was carried out using DIgSILENT PowerFactory, an industry-leading software renowned for its comprehensive functionality and

DOI: 10.17148/IJIREEICE.2026.14409

robust modeling capabilities.The successful execution of the load flow analysis in PowerFactory provides the foundational understanding of the wind farm's operation.

FUTURE SCOPE

The future scope of this work mainly concentrates the expansion of load flow analysis to address the power quality issues in further detail. The motive is to identify and reduce the power quality issues and ensures the system is stable and reliable when the grid is connected

REFERENCES

[1]. W.Yang,X.Zhao,A.Zhang,C. He and C.Qi, Coordinated Planning of Grid connected wind farms and Grid Expansion Considering of Wind Generation, “2020 Asia Energy and Electrical Engineering Symposium (AEEES), Chegdu, China,2020, pp. 782-787.

[2]. C.Wang, P.Yang, X.Chen, C.Liu, Y.Lan and H.Chen,Power quality issues of analysis of wind-storage combined system connected to power grid, “2022 Power System and Dreen Energy Conference (PSGEC), Shanghai, China, 2022, pp.442-446.

[3]. M. Rosyadi, A. Umemura, R.Takahashi, J.Tamura, N.Uchiyama and K. Ide, “A new simple model of wind turbine driven Doubly-Fed Induction Generator for dynamic analysis of grid connected large scale wind farm,” 3 rd Renewable Power Generation Conference (RPG 2014), Naples, 2014, pp. 1-6.S. Sutar et al., "D-PUF: An Intrinsically Reconfigurable Dram PUF for Device Authentication and Random Number Generation", *ACM Trans. Embedded Computing Systems (TECS)*, vol. 17, no. 1, pp. 1-31, 2017.

[4]. Q. Xia, Z. Wang, F.Liu, Li, Y. Peng and Z. Xu , “Study on power quality issues of wind farm,” 2017 36 th Chinese Control Conference (CCC), Dalian, China, 2017, pp. 10490-10494.

[5]. Y.-Z. Sun, J. Lin, G. -j. Li and X.Li, “A review on the integration of wind farms with variable speed wind turbine systems into power systems,” 2009 International Conference on Sustainable Power Generation and Supply, Nanjing, China, 2009, pp. 1-6.

[6]. D.Dragomir, N. Golovanov, P.Postolache and C. Toader, “The connection to the grid of wind turbines,” 2009 IEEE Bucharest Powertech, Bucharest, Romania,2009, pp. 1-8.