



Microgrid Load Flow Study and Simulation using ETAP Software

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Abstract—

The increasing demand for reliable and efficient electrical power has increased the importance of microgrid systems that integrate multiple energy sources such as diesel generators, wind turbines, and solar photovoltaic (PV) systems. This paper presents a load flow analysis of a multi-bus power system using ETAP software. Two operating conditions are considered: one with microgrid integration and the other without microgrid support. Load flow analysis is performed using the Newton-Raphson method to evaluate key parameters such as bus voltage, power flow, and system performance. The results show that microgrid integration improves voltage stability and overall efficiency of the system. A comparison of both cases helps in understanding the benefits of microgrid systems in modern power networks.

Keywords— Microgrid; ETAP; Load-Flow; Simulation; Newton-Raphson; Distributed Generation



I. INTRODUCTION

The demand for electrical energy is continuously increasing due to rapid industrialization, population growth, and technological advancement. Conventional power systems mainly depend on centralized generation, which often leads to higher transmission losses, reduced flexibility, and reliability issues. To overcome these challenges, modern power systems are shifting towards decentralized generation through microgrid technology.

A microgrid is a localized power system that integrates multiple distributed energy resources such as diesel generators, wind turbines, and solar photovoltaic (PV) systems along with loads and transformers. It can operate either independently or in coordination with the main grid. The integration of renewable energy sources in a microgrid helps in improving energy efficiency, reducing environmental impact, and ensuring a more reliable power supply.

However, the operation of a microgrid becomes complex due to the presence of multiple energy sources and varying load conditions. The contribution of each source changes depending on system requirements, which may lead to issues such as voltage fluctuations, overloading, and instability. Therefore, it is important to analyze the performance of the system under different operating conditions.

Load flow analysis is one of the most important tools used in power system studies to evaluate system performance under steady-state conditions. It helps in determining bus voltage levels, power flow through transmission lines, and overall system efficiency. In this study, a multi-bus power system is modeled using ETAP software, which provides accurate and reliable simulation results.

The load flow analysis using the Newton-Raphson method is carried out to evaluate voltage profile and power distribution. This comparison helps in understanding the impact of microgrid on system performance and reliability.

II. DESCRIPTION ABOUT METHOD

ETAP (Electrical Transient Analyzer Program) is a widely used software for modeling, simulation, and analysis of electrical power systems. In this study, ETAP is used to

develop a multi-bus power system model using a single line diagram that includes generators, transformers, transmission lines, and loads.

Each component in the system is defined with appropriate electrical parameters such as voltage rating, power capacity, and impedance. The software provides a clear graphical representation, making it easier to analyze complex power system networks.

Load flow analysis is carried out using the Newton-Raphson method to determine important parameters such as bus voltage, real and reactive power flow, and overall system performance under steady-state conditions.

Two operating cases are considered in this work: with microgrid integration and without microgrid support. The results obtained from ETAP are used to compare system performance and analyze the impact of microgrid on voltage stability and power distribution.

III. MICRO-GRID TECHNOLOGY

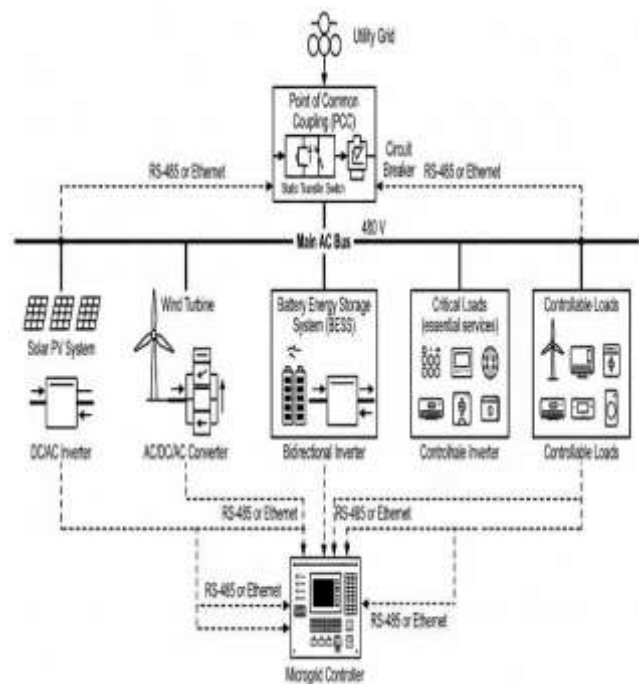


Figure 1. Microgrid

A microgrid is a decentralized group of electricity sources and loads that normally operates connected to and synchronous with the traditional wide-area grid, but can also disconnect to island mode and function autonomously. The



integration of Distributed Energy Resources (DER) and advanced control systems allows for improved local reliability and energy efficiency.

1. Microgrid Architecture

The fundamental structure of a microgrid revolves around a common bus (AC or DC) that interfaces with various energy assets. The connection to the utility grid is managed at a single functional point known as the Point of Common Coupling (PCC).

2. Primary Components

Generation Sources: These include renewable sources like solar PV and wind turbines, as well as dispatchable units like microturbines or diesel generators.

Energy Storage Systems (ESS): Typically Lithium-ion batteries, these units mitigate the intermittency of renewables and provide frequency regulation.

Power Electronics: Inverters and converters are critical for matching the voltage and frequency of the DERs to the bus requirements.

Control System: The Energy Management System (EMS) optimizes the dispatch of resources based on economic or technical constraints.

3. Operational Dynamics and Power Balance

The stability of the microgrid depends on maintaining a continuous balance between generation and demand. In grid-connected mode, the microgrid acts as an infinite bus, absorbing or supplying the deficit power. In island mode, the microgrid must perform its own voltage and frequency control.

4. Control Strategies

Microgrid control is often structured in a hierarchical manner:

Primary Control — Localized droop control for frequency and voltage stabilization within milliseconds.

Secondary Control — Corrects steady-state deviations in frequency and voltage, ensuring the microgrid operates within nominal limits.

Tertiary Control — High-level optimization for economic dispatch and coordination with the Distribution System Operator (DSO).

IV. LOAD FLOW ANALYSIS

Load flow analysis is an essential method used to evaluate the steady-state performance of power systems. It determines key parameters such as active power, reactive power, bus voltages, and phase angles under normal operating conditions.

In this work, an IEEE 11-bus microgrid system is modeled using ETAP. The system consists of a swing bus, generator buses, and load buses, along with components such as transformers, transmission lines, and circuit breakers. All necessary system data, including generator ratings and line parameters, are incorporated into the model.

The load flow analysis results show that the system operates within acceptable limits, with all electrical parameters remaining stable and no faults observed. The study also demonstrates that the model can be used to analyze system performance under future expansions or modifications.

The power flow equations are given below.

Real Power (P):

$$P_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) \quad (1)$$

Reactive Power (Q):

$$Q_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \quad (2)$$

where $|V_i|, |V_j|$ = Voltage magnitudes; δ_i, δ_j = Voltage angles; θ_{ij} = Angle of admittance.

V. METHODOLOGY

This study presents a simulation-based load flow analysis of a microgrid system using ETAP software. The test system considered for analysis is the IEEE 11-bus system, which includes buses, transmission lines, loads, and generation units. The system is modeled in the ETAP environment using standard system parameters.

Two different cases are investigated in this work: without microgrid integration and with microgrid integration. In the first case, the conventional power system is analyzed, whereas in the second case, distributed generation sources are incorporated to form a microgrid. The load flow analysis is performed for both cases using the Newton-Raphson iterative method.

The Newton-Raphson method is employed due to its fast convergence and high accuracy for solving nonlinear algebraic equations in power systems. The algorithm iteratively calculates bus voltages, phase angles, active power, and reactive power until the mismatch between specified and calculated values is minimized.

The performance of the system is evaluated based on parameters such as voltage profile, real and reactive power flow, and transmission losses. A comparative analysis is carried out to assess the impact of microgrid integration on system performance.

VI. SIMULATION OF IEEE 11 BUS

The IEEE 11-bus system is a standard test system used in power system studies. It represents a simplified electrical network consisting of multiple buses, generators, transmission lines, transformers, and loads.

A bus is a node in the power system where different components like generators, loads, and transmission lines are connected. The IEEE 11-bus system consists of the following components:

PV Array: Integrated as a renewable energy source, the PV array converts solar energy into electrical energy and supplies power to the grid.



Buses: There are 11 buses in the system, each with a specific voltage level, used to distribute power throughout the network.

Generators: Multiple generators supply power to different buses. They operate in swing mode, maintaining system balance by supplying required power.

Transformers: Step-up transformers increase voltage for efficient transmission across lines.

Transmission Lines: These connect different buses and carry electrical power across the network, characterized by resistance, reactance, and impedance.

Loads: Connected to different buses, loads consume real and reactive power representing the system demand.

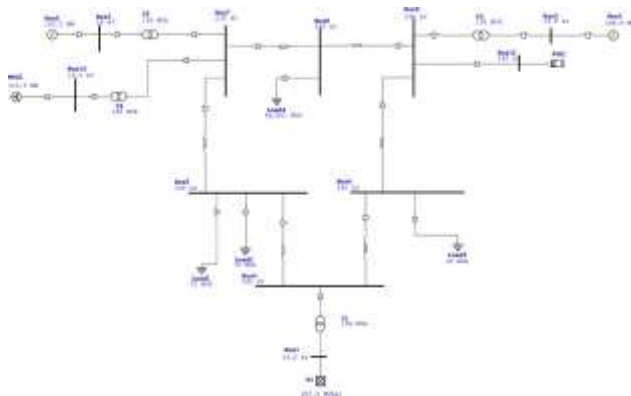


Figure 2. ETAP Model

The IEEE 11-bus system consists of a power grid (247.5 MVA), two conventional generators in swing mode (Gen 2: 18 kV, ≈163.2 MW; Gen 3: 13.8 kV, ≈108.8 MW), a wind turbine generator (WTG: 16.5 kV, ≈115.8 MW), and a PV array (37.8 MW; inverter: 42,000 kW DC / 37,800 kVA AC). Loads are distributed as: Load 1 and Load 2 — 70 MVA each; Load 3 — 90 MVA; Load 4 — 86.001 MVA.

Transmission line positive sequence parameters: $R = 0.1$ pu, $X = 0.3$ pu, $Y = 3.3$ pu. Negative sequence parameters: $R = 1.8$ pu, $X = 2.8$ pu, $Y = 2.1$ pu.

1. Case 1: Grid-Connected Mode (With Microgrid)

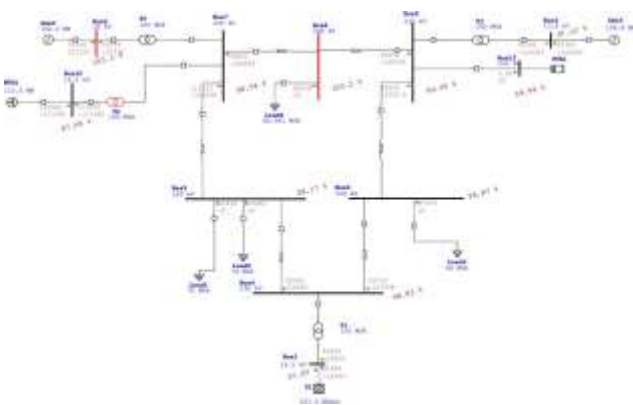


Figure 3. IEEE 11-Bus With Microgrid

2. Case 2: Conventional Sources Only (Without Microgrid)

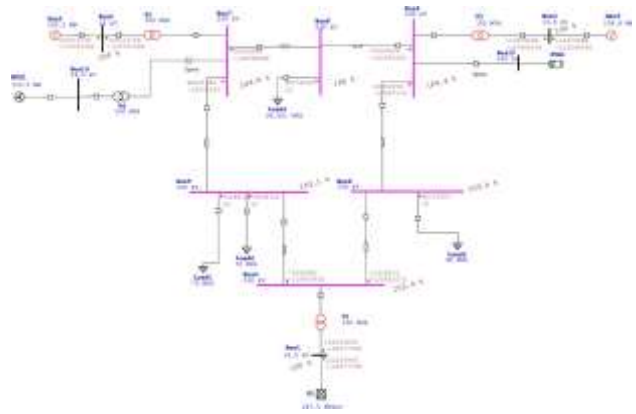


Figure 4. IEEE 11-Bus Without Micro Sources

Table 1. Case Comparison Summary

Case	Grid	DG	Wind	PV	Observation
Case 1	ON	ON	ON	ON	Bus nos. 4-9: Normal condition
Case 2	ON	ON	OFF	OFF	Bus nos. 4-9: Overvoltage condition

VII. RESULT DISPLAY

LOAD FLOW REPORT

Bus	V	Angle	Generation		Load		Load Flow							
			MW	MVar	MW	MVar	W	MVar	Angle	V/T				
Bus1	15.750	98.800	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus2	15.750	98.800	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus3	15.750	98.800	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus4	20.000	95.964	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus5	20.000	95.917	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus6	20.000	96.076	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus7	20.000	95.948	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus8	20.000	95.940	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus9	20.000	95.940	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus10	15.750	97.407	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bus11	20.000	95.944	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 5. Load Flow Report — Case 1



SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	206.644	1.761	206.651	100.00 Lagging
Source (Non-Swing Buses):	111.501	-71.581	133.854	83.00 Leading
Total Demand:	322.145	-69.817	329.624	93.73 Leading
Total Motor Load:	0.000	0.000	0.000	
Total Static Load:	315.763	0.000	315.761	100.00 Lagging
Total Constant Load:	0.000	0.000	0.000	
Total Generac Load:	0.000	0.000	0.000	
Apparent Losses:	6.384	-69.817		
System Mismatch:	0.000	0.000		

Number of Iterations: 4

Figure 6. Summary Report — Case 1

LOAD FLOW REPORT

Bus	Voltage		Generation		Load		Load Flow				
	W	V/Mg	W	Mvar	W	Mvar	W	Mvar	Mag	Angle	Q/F
Bus1	3.00	99.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus2	3.00	99.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus3	3.00	99.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus4	28.00	81.77	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus5	28.00	81.92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus6	28.00	82.32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus7	28.00	84.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus8	28.00	84.85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus9	28.00	84.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bus10	28.00	84.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 7. Load Flow Report — Case 2

SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	344.698	-63.646	354.701	97.18 Leading
Source (Non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	344.698	-63.646	354.701	97.18 Leading
Total Motor Load:	0.000	0.000	0.000	
Total Static Load:	339.824	0.000	339.824	100.00 Lagging
Total Constant Load:	0.000	0.000	0.000	
Total Generac Load:	0.000	0.000	0.000	
Apparent Losses:	4.874	-63.646		
System Mismatch:	0.000	0.000		

Number of Iterations: 4

Figure 8. Summary Report — Case 2

The load flow analysis was carried out under two different cases using ETAP software. The comparison clearly highlights the impact of distributed generation sources such as WTG and PV on overall system performance.

In Case 2 (without microgrid), the power system relies mainly on conventional generators. Bus voltages show noticeable deviations, with several buses operating below nominal (around 97–99%). Power flow depends heavily on long transmission paths, resulting in higher line loading, increased losses, higher reactive power demand, and reduced voltage regulation.

In Case 1 (with microgrid), additional local generation from WTG and PV significantly improves performance. Voltage profiles stabilize closer to 1.0 pu across all buses. Local generation reduces the burden on the main grid, decreasing line loading and minimizing real and reactive power losses. Distributed energy resources also enhance reactive power support, strengthening voltage stability.

Power flow distribution becomes more balanced in the microgrid case. Load demand is shared across multiple sources, reducing congestion in critical lines and improving reliability. The non-microgrid system shows uneven power distribution and higher stress on certain transmission elements.

Furthermore, microgrid integration enhances system efficiency and resilience. In case of faults, local generation can support critical loads, reducing dependency on the main grid. The results also indicate improved power factor and reduced current magnitude in several lines, contributing to overall system optimization.

VIII.CONCLUSION

The load flow analysis of the IEEE 11-bus system has been carried out using ETAP software with the Newton-Raphson method to evaluate system performance in terms of voltage profile, power flow, and overall stability. The results show the system operates within acceptable limits, with most bus voltages remaining close to their nominal values.

Minor voltage deviations are observed at certain buses due to uneven load distribution and line impedance. Power flow is not uniformly distributed across the network; some lines carry higher loading, leading to increased losses and reduced efficiency. Reactive power support is found to be a critical factor in maintaining voltage stability.

The integration of microgrid significantly improves system performance by enhancing voltage profile, reducing transmission losses, and providing better load support through distributed generation. The comparative analysis confirms that microgrid implementation increases the overall reliability and efficiency of the network.

It can therefore be concluded that the application of microgrid along with efficient load flow analysis techniques such as the Newton-Raphson method plays a vital role in improving the stability, performance, and reliability of modern power systems.

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