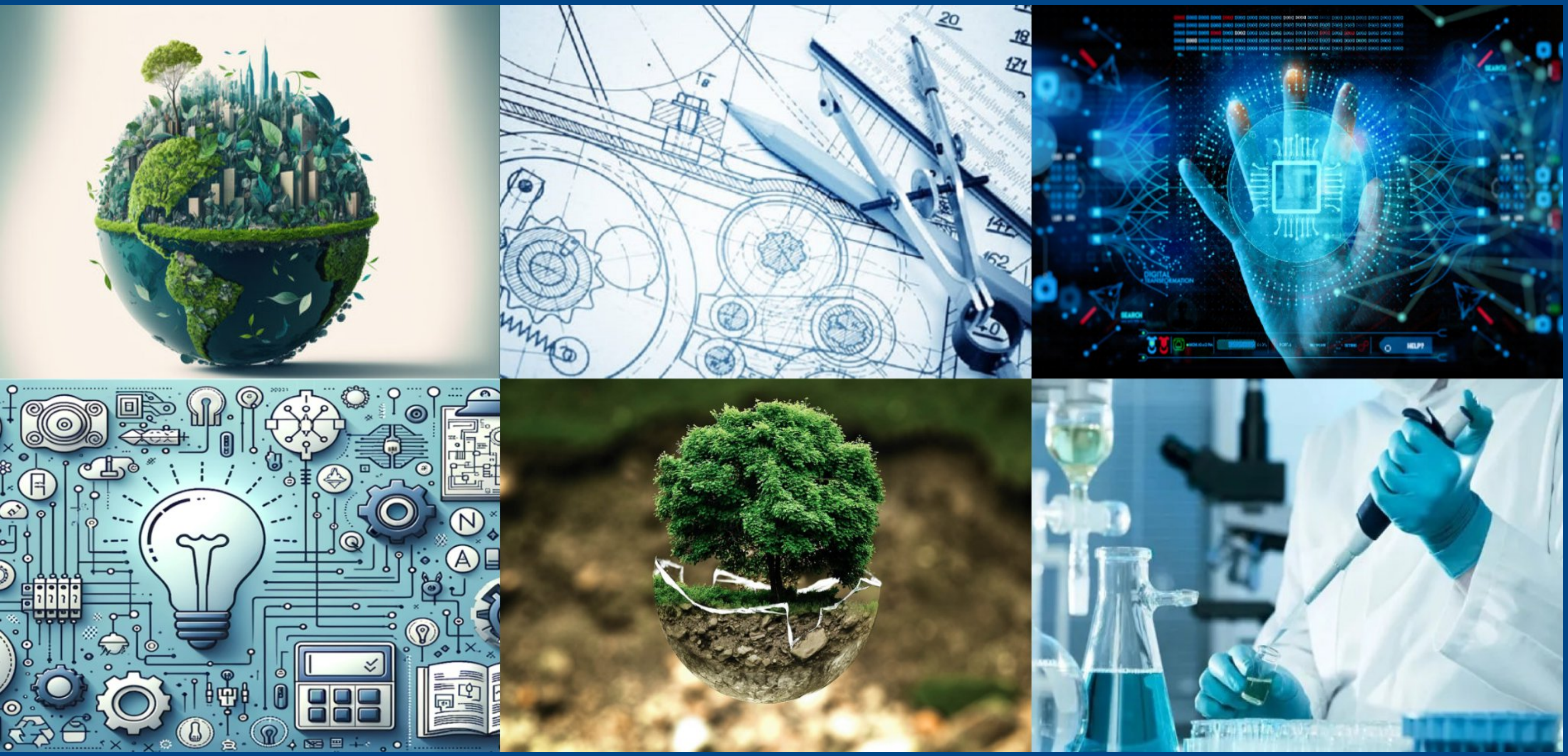
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 9, Issue 4, April 2026

www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

© 2026 IJMRSET | Volume 9, Issue 4, April 2026| DOI:10.15680/IJMRSET.2026.0904143

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Load Flow Analysis and Optimization of Microgrid Systems Using ETAP Software

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ABSTRACT: The increasing demand for reliable and sustainable power has led to the development of microgrid systems integrating distributed energy resources such as solar, wind, and conventional generators. This study presents the load flow and optimal load flow analysis of a microgrid using ETAP software to evaluate system performance under different operating conditions. Initially, load flow analysis Case 0 is performed to determine voltage profile, real power distribution, and system losses under normal conditions. Further, optimal load flow Case 5 is applied to optimize generation dispatch, minimize transmission losses, and maintain voltage within permissible limits. The results demonstrate that optimal load flow significantly improves voltage stability, reduces losses, and ensures efficient power distribution compared to conventional load flow. This work highlights the importance of optimization techniques in modern microgrid planning and operation.

KEYWORD- Microgrid, ETAP, Load-Flow, Simulation

I. INTRODUCTION

A microgrid is a small-scale power system that can operate either independently or in coordination with the main grid. It consists of distributed energy resources such as solar panels, wind turbines, conventional generators, and energy storage systems. Due to the increasing demand for electricity and the depletion of fossil fuels, microgrids have become an important solution for providing reliable and sustainable power supply.

Microgrids offer several advantages, including improved reliability, reduced transmission losses, and better integration of renewable energy sources. They can continue to supply power even during grid failures by operating in islanded mode, which makes them suitable for applications such as remote areas, industries, and smart cities.

To ensure efficient operation of microgrids, power system analysis tools are required. Load flow analysis is one of the most important techniques used to determine bus voltages, real and reactive power flow, and system losses under steady-state conditions. However, conventional load flow does not consider optimization, which may lead to inefficient power distribution and higher losses.

Therefore, Optimal Load Flow (OPF) is used to enhance system performance by minimizing transmission losses, improving voltage profile, and ensuring efficient power distribution while satisfying system constraints. In this study, a microgrid system is modeled and analyzed using ETAP software, and a comparison between load flow (Case 0) and optimal load flow (Case 5) is carried out to evaluate system performance.

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.

Five operating cases are considered in this work. 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

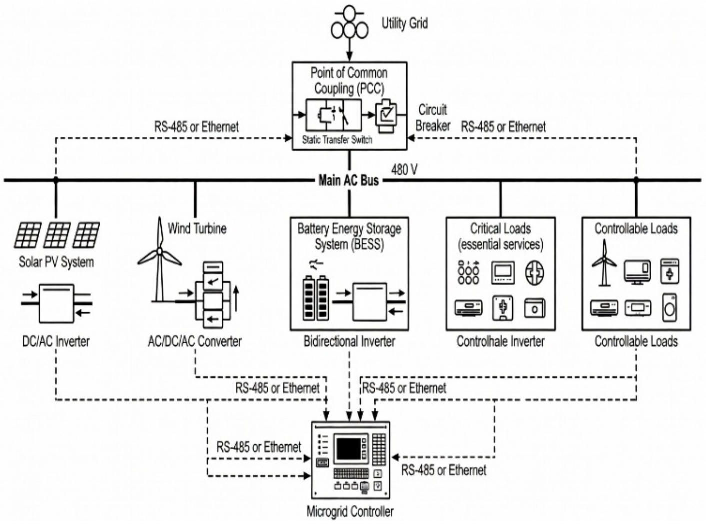

Fig1. Microgrid

A microgrid is a decentralized group of electricity sources and loads that normally operates connected to and synchronous with the traditional wide-area microgrid, 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: Inverter 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; In Primary Control Localized droop control for frequency and voltage stabilization within milliseconds whereas in Secondary Control Corrects steady-state deviations in frequency and voltage, ensuring the microgrid operates within nominal limits and Tertiary Control High-level optimization for economic dispatch and coordination with the distribution system operator (DSO).

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

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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 equation is given below:
Real Power (P)-

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

Reactive Power (Q)-

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

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

V. METHODOLOGY

This study is based on modeling and analyzing a microgrid system using ETAP software. The microgrid is designed by connecting different components such as generators, wind turbine, photovoltaic system, transformers, buses, and loads to form a complete power network. Each component is assigned its proper rating and operating conditions to represent a realistic system.

After designing the system, load flow analysis is performed to study the steady-state behavior of the microgrid. The Newton-Raphson method is used for solving the load flow equations because of its accuracy and fast convergence. This analysis helps in finding bus voltages, real power flow, and system losses under normal operating conditions. This condition is considered as Case 0, where no optimization is applied.

Further, optimal load flow analysis is carried out to improve the performance of the system. In this case, ETAP adjusts the generation and system parameters to reduce power losses and maintain voltage within acceptable limits. This optimized condition is referred to as Case 5.

Finally, the results of both cases are compared based on voltage profile, real power distribution, and system losses. This comparison helps in understanding how optimal load flow improves the efficiency and stability of the microgrid system.

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 main purpose of using the IEEE 11-bus system is to analyze the performance of the power under different operating conditions. The IEEE 11-bus system consists of the following components:

PV Array : In the modified IEEE 11-bus system, a PV (Photovoltaic) array is integrated as a renewable energy source. The PV array converts solar energy into electrical energy and supplies power to the gird.

Buses: There are 11 buses in the system, which act as connection points. Each bus has a specific voltage level and is used to distribute power throughout the network.

Generators: Generators are used to produce electrical power. In this system, multiple generators supply power to different buses. And they are considered as the swing bus, which maintains system balance by supplying required power.

Transformers: Transformers are used to change voltage levels:Step-up transformer → increases voltage for transmission.

Transmission Lines: Transmission lines connect different buses and carry electrical power across the network. They have parameters like resistance, reactance, and impedance.

Loads: Loads represent the power consumption in the system. These are connected to different buses and consume real and reactive power.

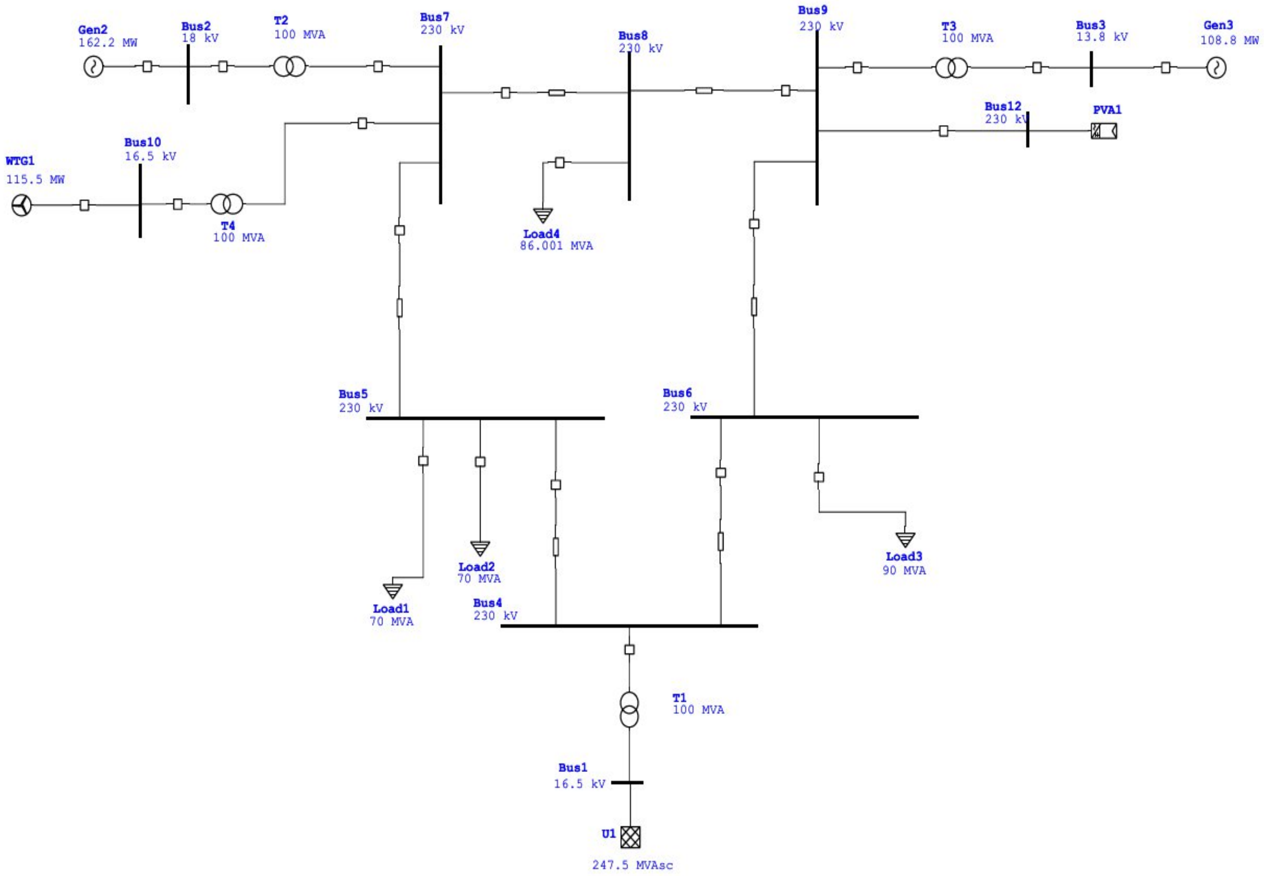


Fig2. ETAP Model

The IEEE 11-bus system modeled in this study consists of a power grid, multiple generators, renewable energy sources, transmission lines, and loads. All components are represented in per-unit system and simulated in ETAP for load flow analysis using the Newton-Raphson method.

The system is connected to a main power grid with a capacity of 247.5 MVA, which supports the overall power demand. Two conventional generators are considered in swing mode operation. Generator 2 operates at 18 kV and supplies approximately 163.2 MW of active power, while Generator 3 operates at 13.8 kV with a generation of about 108.8 MW. These generators play a crucial role in maintaining system voltage and balancing power.

In addition to conventional generation, renewable energy sources are integrated into the system. A wind turbine generator (WTG) produces approximately 115.8 MW at 16.5 kV. A photovoltaic (PV) array is also included, generating 37.8 MW, with an inverter rated at 42000 kW (DC) and 37800 kVA (AC). These distributed energy resources contribute to improving system efficiency and support microgrid operation.

The load demand in the system is distributed across multiple buses. Load 1 and Load 2 each consume 70 MVA, while Load 3 and Load 4 demand 90 MVA and 86.001 MVA respectively. The variation in load demand significantly affects power flow and voltage profile across the network.

The transmission lines interconnecting the buses are modeled using positive and negative sequence parameters. The positive sequence parameters include resistance (R) of 0.1 pu, reactance (X) of 0.3 pu, and admittance (Y) of 3.3 pu. The negative sequence parameters are given as resistance (R) of 1.8 pu, reactance (X) of 2.8 pu, and admittance (Y) of 2.1 pu. These parameters influence the power transfer capability, system losses, and voltage stability. All the above system data is implemented in ETAP, and load flow analysis is carried out using the Newton-Raphson iterative method to evaluate system performance under different operating conditions, including with and without microgrid integration.

CASE 1: The Power Grid, Generators and renewable Sources are all ON

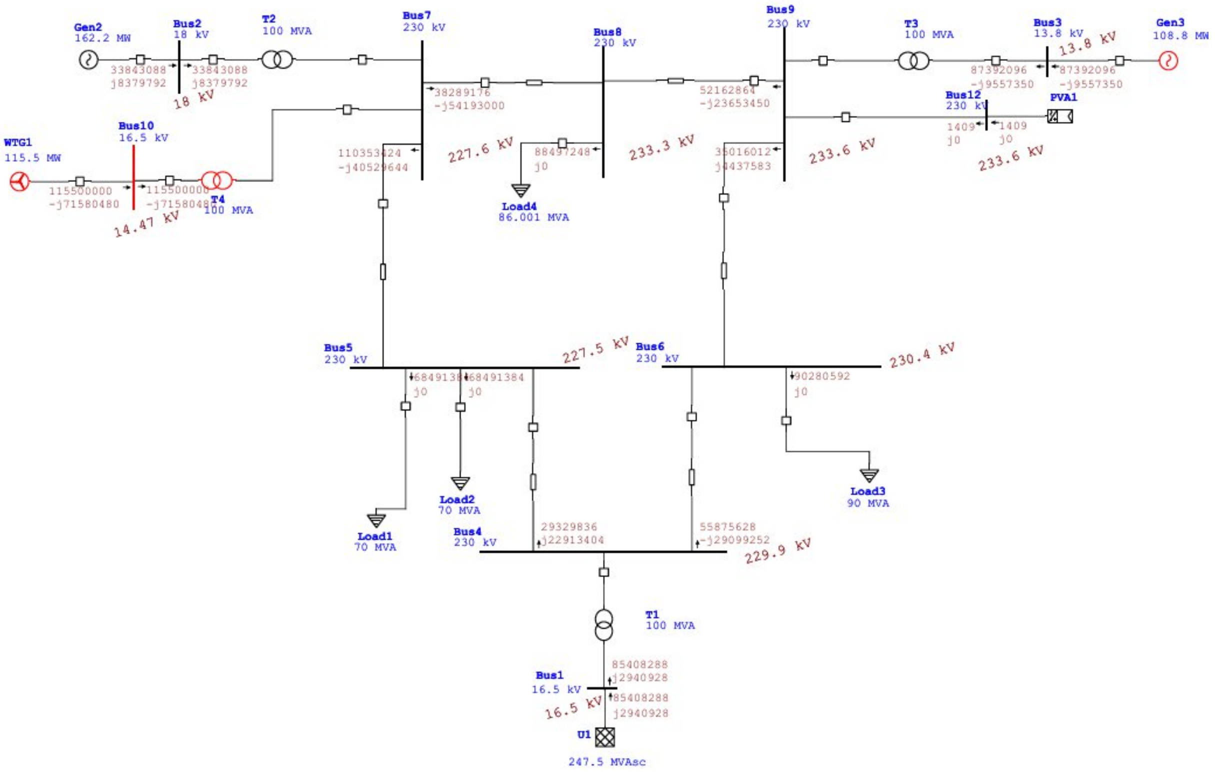


Fig3: IEEE 11 bus with microgrid

CASE 2: The Power Grid and Diesel Generators both are ON

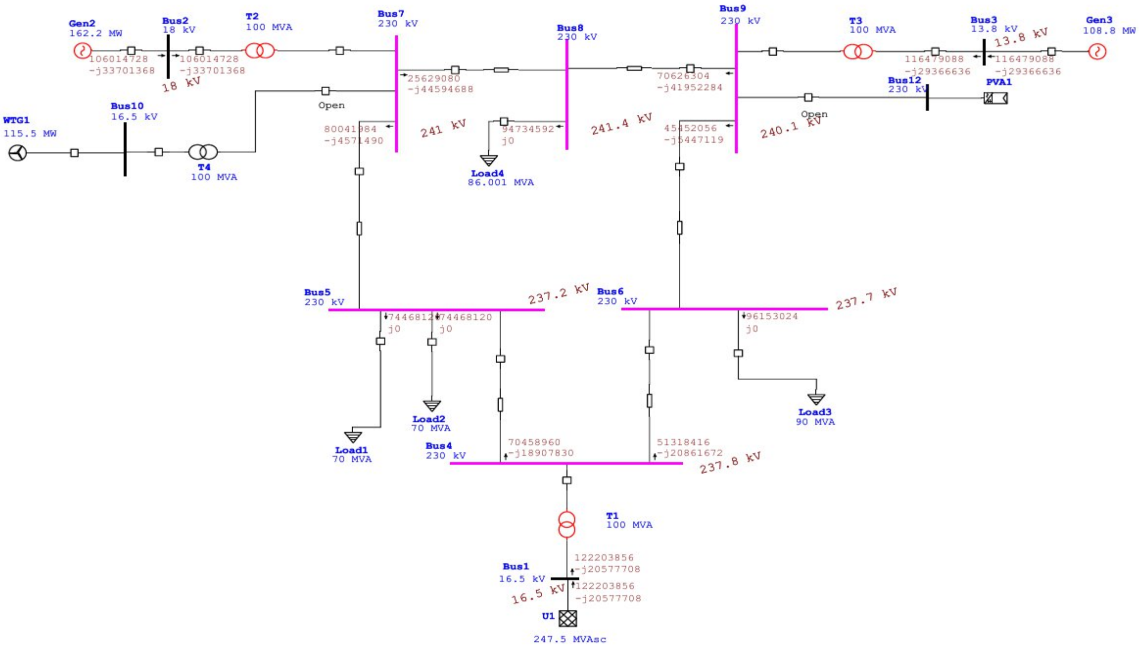


Fig4: IEEE 11 bus in Generator Sources are ON condition

Case 3: The power Grid and Renewable Sources are both ON condition

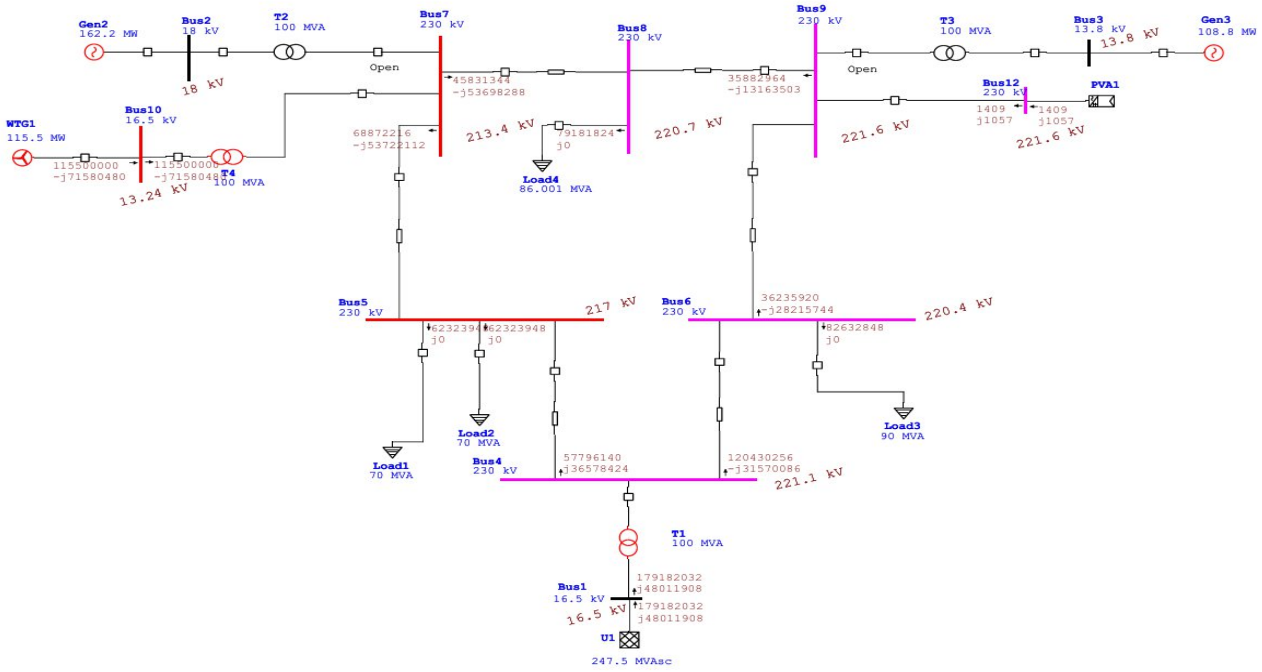


Fig5: IEEE 11 bus in power Grid and Renewable Sources are both ON condition

Case 4: Only Diesel Generators and Renewable source are ON condition

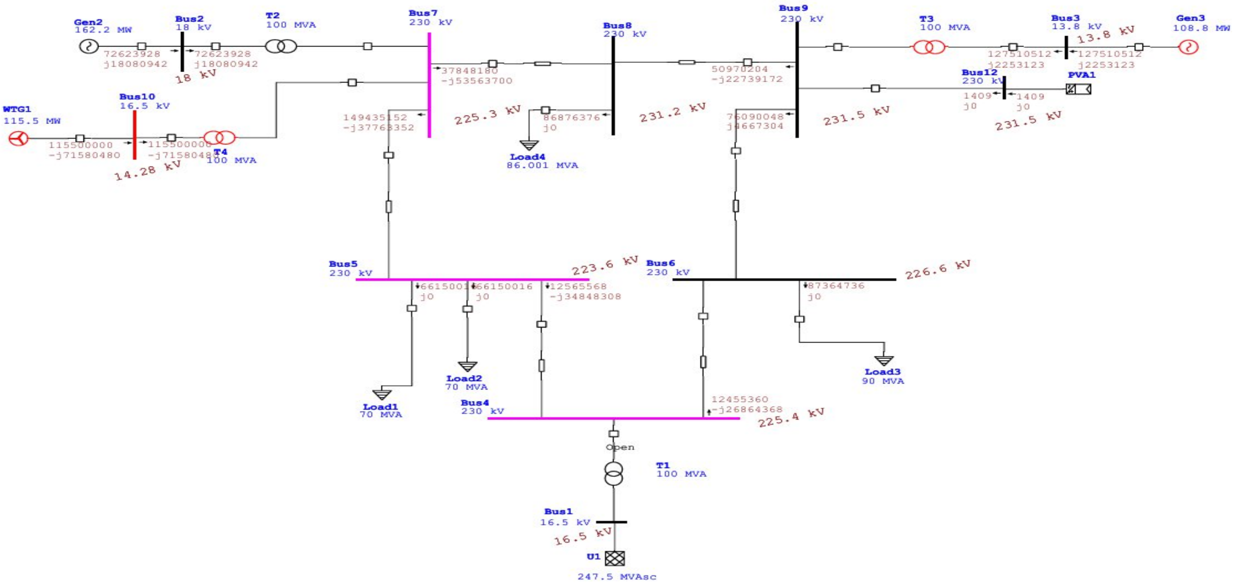
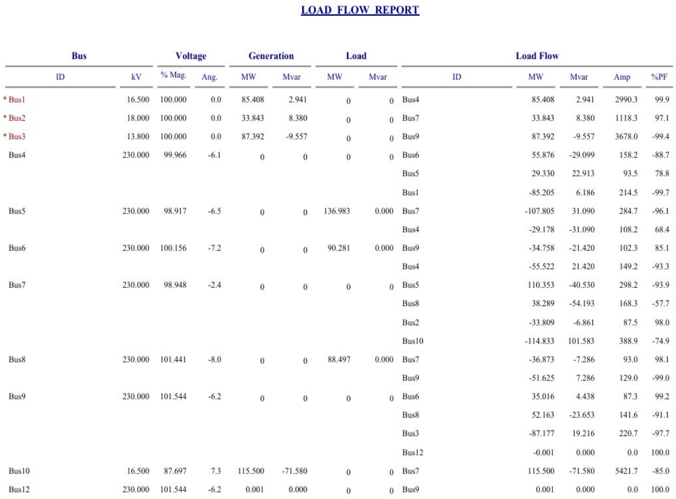


Fig6: IEEE 11 bus in Diesel Generators and Renewable source are ON condition

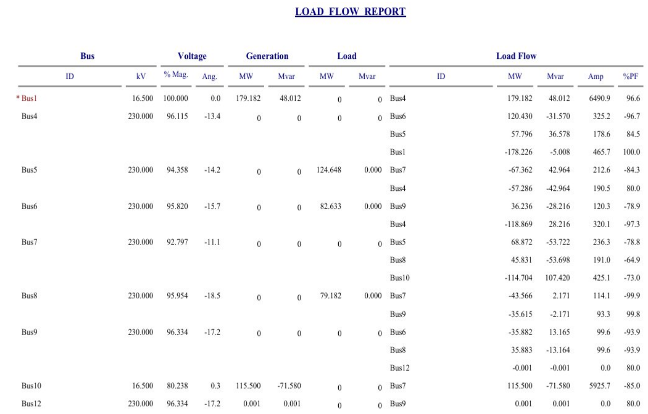
CASES	U1	G2	G3	WTG	PV
CASE 1	ON	ON	ON	ON	ON
CASE 2	ON	ON	ON	OFF	OFF
CASE 3	ON	OFF	OFF	ON	ON
CASE4	OFF	ON	ON	ON	ON

VII. RESULT DISPLAY


LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF
* Bus1	16.500	100.000	0.0	85.408	2.941	0	0	Bus4	85.408	2.941	2990.3	99.9
* Bus2	18.000	100.000	0.0	33.843	8.380	0	0	Bus7	33.843	8.380	1118.3	97.1
* Bus3	13.800	100.000	0.0	87.392	-9.557	0	0	Bus9	87.392	-9.557	3678.0	-99.4
Bus4	230.000	99.966	-6.1	0	0	0	0	Bus6	55.876	-29.099	158.2	-88.7
								Bus5	29.330	22.913	93.5	78.8
								Bus1	-85.205	6.186	214.5	-99.7
Bus5	230.000	98.917	-6.5	0	0	136.983	0.000	Bus7	-107.805	31.090	284.7	-96.1
								Bus4	-29.178	-31.090	108.2	68.4
Bus6	230.000	100.156	-7.2	0	0	90.281	0.000	Bus9	-34.758	-21.420	102.3	85.1
								Bus4	-55.522	21.420	149.2	-93.3
Bus7	230.000	98.948	-2.4	0	0	0	0	Bus5	110.353	-40.530	298.2	-93.9
								Bus8	38.289	-54.193	168.3	-57.7
								Bus2	-33.809	-6.861	87.5	98.0
								Bus10	-114.833	101.583	388.9	-74.9
Bus8	230.000	101.441	-8.0	0	0	88.497	0.000	Bus7	-36.873	-7.286	93.0	98.1
								Bus9	-51.625	7.286	129.0	-99.0
Bus9	230.000	101.544	-6.2	0	0	0	0	Bus6	35.016	4.438	87.3	99.2
								Bus8	52.163	-23.653	141.6	-91.1
								Bus3	-87.177	19.216	220.7	-97.7
								Bus12	-0.001	0.000	0.0	100.0
Bus10	16.500	87.697	7.3	115.500	-71.580	0	0	Bus7	115.500	-71.580	5421.7	-85.0
Bus12	230.000	101.544	-6.2	0.001	0.000	0	0	Bus9	0.001	0.000	0.0	100.0

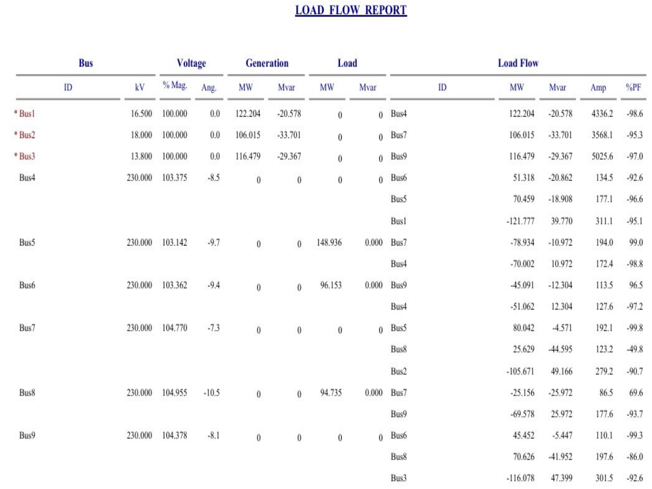
Fig7: Load Flow Report Case 1



LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF
* Bus1	16.500	100.000	0.0	179.182	48.012	0	0	Bus4	179.182	48.012	6490.9	96.6
Bus4	230.000	96.115	-13.4	0	0	0	0	Bus6	120.430	-31.570	325.2	-96.7
								Bus5	57.796	36.578	178.6	84.5
								Bus1	-178.226	-5.008	465.7	100.0
Bus5	230.000	94.358	-14.2	0	0	124.648	0.000	Bus7	-67.362	42.964	212.6	-84.3
								Bus4	-57.286	-42.964	190.5	80.0
Bus6	230.000	95.820	-15.7	0	0	82.633	0.000	Bus9	36.236	-28.216	120.3	-78.9
								Bus4	-118.869	28.216	320.1	-97.3
Bus7	230.000	92.797	-11.1	0	0	0	0	Bus5	68.872	-53.722	236.3	-78.8
								Bus8	45.831	-53.698	191.0	-64.9
								Bus10	-114.704	107.420	425.1	-73.0
Bus8	230.000	95.954	-18.5	0	0	79.182	0.000	Bus7	-43.566	2.171	114.1	-99.9
								Bus9	-35.615	-2.171	93.3	99.8
Bus9	230.000	96.334	-17.2	0	0	0	0	Bus6	-35.882	13.165	99.6	-93.9
								Bus8	35.883	-13.164	99.6	-93.9
								Bus12	-0.001	-0.001	0.0	80.0
Bus10	16.500	80.238	0.3	115.500	-71.580	0	0	Bus7	115.500	-71.580	5925.7	-85.0
Bus12	230.000	96.334	-17.2	0.001	0.001	0	0	Bus9	0.001	0.001	0.0	80.0

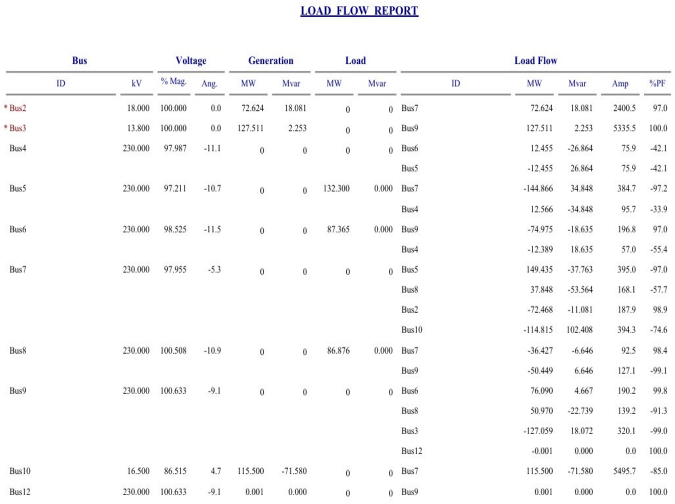
Fig9: Load Flow Report Case 3



LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF
* Bus1	16.500	100.000	0.0	122.204	-20.578	0	0	Bus4	122.204	-20.578	4336.2	-98.6
* Bus2	18.000	100.000	0.0	106.015	-33.701	0	0	Bus7	106.015	-33.701	3568.1	-95.3
* Bus3	13.800	100.000	0.0	116.479	-29.367	0	0	Bus9	116.479	-29.367	5025.6	-97.0
Bus4	230.000	103.375	-8.5	0	0	0	0	Bus6	51.318	-20.862	134.5	-92.6
								Bus5	70.459	-18.908	177.1	-96.6
								Bus1	-121.777	39.770	311.1	-95.1
Bus5	230.000	103.142	-9.7	0	0	148.936	0.000	Bus7	-78.934	-10.972	194.0	99.0
								Bus4	-70.002	10.972	172.4	-98.8
Bus6	230.000	103.362	-9.4	0	0	96.153	0.000	Bus9	-45.091	-12.304	113.5	96.5
								Bus4	-51.062	12.304	127.6	-97.2
Bus7	230.000	104.770	-7.3	0	0	0	0	Bus5	80.042	-4.571	192.1	-99.8
								Bus8	25.629	-44.595	123.2	-49.8
								Bus2	-105.671	49.166	279.2	-90.7
Bus8	230.000	104.955	-10.5	0	0	94.735	0.000	Bus7	-25.156	-25.972	86.5	69.6
								Bus9	-69.578	25.972	177.6	-93.7
Bus9	230.000	104.378	-8.1	0	0	0	0	Bus6	45.452	-5.447	110.1	-99.3
								Bus8	70.626	-41.952	197.6	-86.0
								Bus3	-116.078	47.399	301.5	-92.6

Fig8: Load Flow Report Case 2



LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF
* Bus2	18.000	100.000	0.0	72.624	18.081	0	0	Bus7	72.624	18.081	2400.5	97.0
* Bus3	13.800	100.000	0.0	127.511	2.253	0	0	Bus9	127.511	2.253	5335.5	100.0
Bus4	230.000	97.987	-11.1	0	0	0	0	Bus6	12.455	-26.864	75.9	-42.1
								Bus5	-12.455	26.864	75.9	-42.1
Bus5	230.000	97.211	-10.7	0	0	132.300	0.000	Bus7	-144.866	34.848	384.7	-97.2
								Bus4	12.566	-34.848	95.7	-33.9
Bus6	230.000	98.525	-11.5	0	0	87.365	0.000	Bus9	-74.975	-18.635	196.8	97.0
								Bus4	-12.389	18.635	57.0	-55.4
Bus7	230.000	97.955	-5.3	0	0	0	0	Bus5	149.435	-37.763	395.0	-97.0
								Bus8	37.848	-53.564	168.1	-57.7
								Bus2	-72.468	-11.081	187.9	98.9
								Bus10	-114.815	102.408	394.3	-74.6
Bus8	230.000	100.508	-10.9	0	0	86.876	0.000	Bus7	-36.427	-6.646	92.5	98.4
								Bus9	-50.449	6.646	127.1	-99.1
Bus9	230.000	100.633	-9.1	0	0	0	0	Bus6	76.090	4.667	190.2	99.8
								Bus8	50.970	-22.739	139.2	-91.3
								Bus3	-127.059	18.072	320.1	-99.0
								Bus12	-0.001	0.000	0.0	100.0
Bus10	16.500	86.515	4.7	115.500	-71.580	0	0	Bus7	115.500	-71.580	5495.7	-85.0
Bus12	230.000	100.633	-9.1	0.001	0.000	0	0	Bus9	0.001	0.000	0.0	100.0

Fig10: Load flow Report for Case 4

The four different cases represent how the microgrid behaves under different operating conditions, showing how changes in generation and network setup affect overall performance, voltage levels, and real power flow. In Case 1, the system works under normal and balanced conditions where most of the generation sources are active. Because of this, power flows smoothly through the network, and the voltages at different buses stay close to their ideal values (around 230 kV). This indicates that the system is stable, well-regulated, and operating efficiently with low transmission losses.

In Case 2, small changes in generation or system configuration cause the voltage at some buses to increase slightly. This usually happens when there is less load or more generation available in the system. Even though the system remains stable, the power flow becomes a little uneven, and some buses experience higher-than-normal voltage. However, since enough generation is still available, the system continues to meet the demand without any major issues.

In Case 3, the system condition becomes more stressed, as seen from the noticeable drop in voltage levels across many buses. This can happen when generation is reduced or the load demand increases. Due to this, power flow becomes less efficient, and some transmission lines carry more load than they ideally should, which increases losses. The lower voltage levels also indicate weaker system support, making the system less stable and more prone to performance issues.

In Case 4, the system shows some improvement compared to Case 3. The voltage levels increase again, which means the system is recovering, possibly due to better load sharing or the return of some generation sources. However, the voltages are still not as well maintained as in Case 1, so the system is still under moderate stress. Power flow becomes more balanced than in Case 3, but some losses and inefficiencies still remain.

Overall, this comparison shows that the performance of a microgrid strongly depends on how much generation is available and how well the system is managed. When generation is sufficient and properly distributed, the system runs smoothly with stable voltage and low losses. But when generation is reduced or the system becomes stressed, voltage drops, power flow becomes uneven, and efficiency decreases. Therefore, proper planning and the use of techniques like optimal load flow are very important to keep the system stable, efficient, and reliable.

Case 5: Optimal load flow Condition

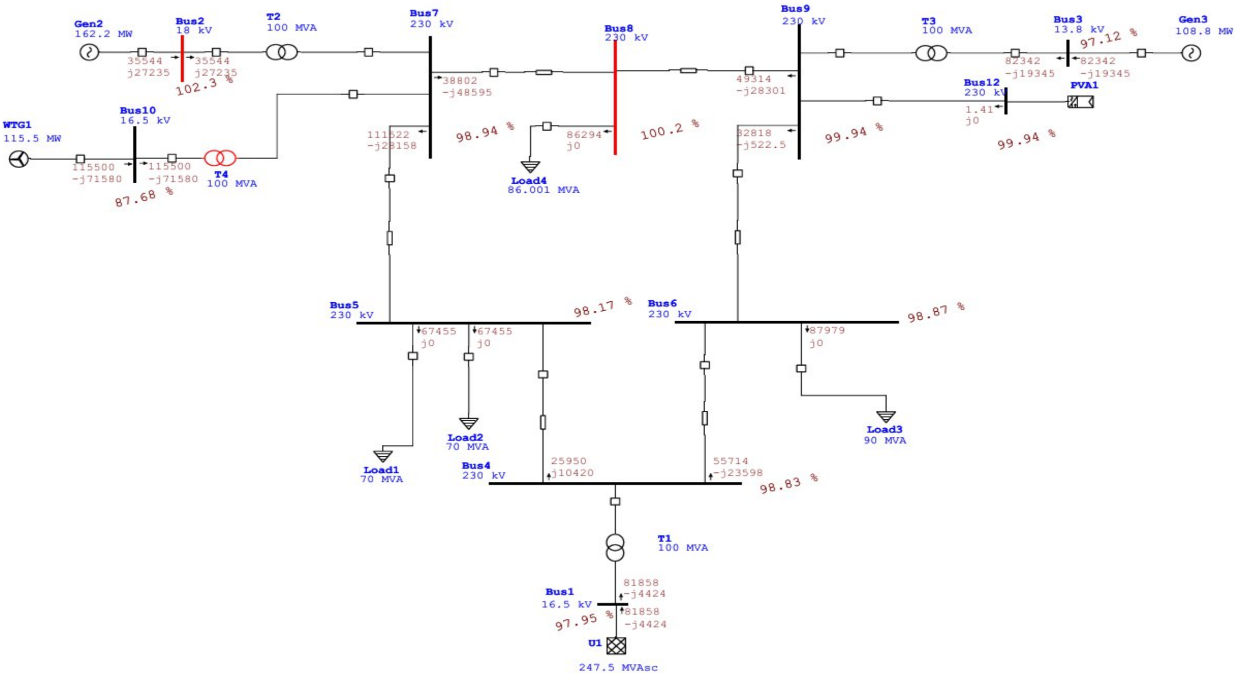
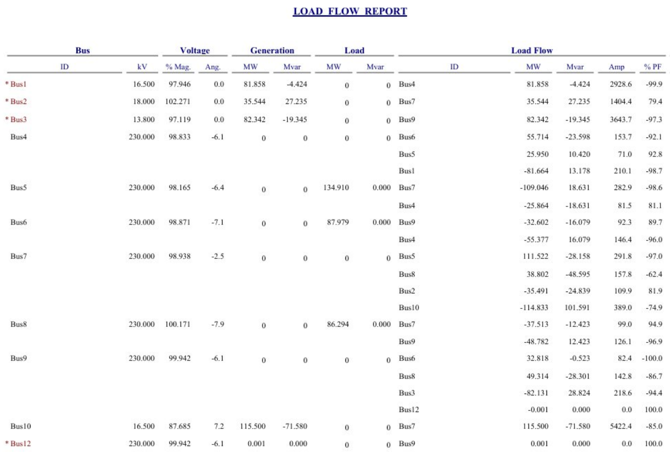


Fig11: IEEE 11 bus in Optimal Load Flow

Result Display: Optimal Load flow analysis



LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF
* Bus1	16.500	97.946	0.0	81.858	-4.424	0	0	Bus4	81.858	-4.424	2928.6	-99.9
* Bus2	18.000	102.271	0.0	35.544	27.235	0	0	Bus7	35.544	27.235	1404.4	79.4
* Bus3	13.800	97.119	0.0	82.342	-19.345	0	0	Bus9	82.342	-19.345	3643.7	-97.3
Bus4	230.000	98.833	-6.1	0	0	0	0	Bus6	55.714	-23.598	153.7	-92.1
								Bus5	25.950	10.420	71.0	92.8
								Bus1	-81.664	13.178	210.1	-98.7
Bus5	230.000	98.165	-6.4	0	0	134.910	0.000	Bus7	-109.046	18.631	282.9	-98.6
								Bus4	-25.864	-18.631	81.5	81.1
Bus6	230.000	98.871	-7.1	0	0	87.979	0.000	Bus9	-32.602	-16.079	92.3	89.7
								Bus4	-55.377	16.079	146.4	-96.0
Bus7	230.000	98.938	-2.5	0	0	0	0	Bus5	111.522	-28.158	291.8	-97.0
								Bus8	38.802	-48.595	157.8	-62.4
								Bus2	-35.491	-24.839	109.9	81.9
								Bus10	-114.833	101.591	389.0	-74.9
Bus8	230.000	100.171	-7.9	0	0	86.294	0.000	Bus7	-37.513	-12.423	99.0	94.9
								Bus9	-48.782	12.423	126.1	-96.9
Bus9	230.000	99.942	-6.1	0	0	0	0	Bus6	32.818	-0.523	82.4	-100.0
								Bus8	49.314	-28.301	142.8	-86.7
								Bus3	-82.131	28.824	218.6	-94.4
								Bus12	-0.001	0.000	0.0	100.0
Bus10	16.500	87.685	7.2	115.500	-71.580	0	0	Bus7	115.500	-71.580	5422.4	-85.0
* Bus12	230.000	99.942	-6.1	0.001	0.000	0	0	Bus9	0.001	0.000	0.0	100.0

Fig12: Optimal Load flow analysis

Comparison Between Case 0 and Case 5

Case 0 represents the normal load flow analysis, where power is distributed in the system based on fixed generation and load values without any optimization. Because of this, the voltage at different buses can deviate more from the desired level, and the real power flow is not evenly distributed, which may increase transmission losses and put extra load on some lines. On the other hand, Case 5 uses optimal load flow, where the system automatically adjusts generation and other parameters to improve overall performance. In this case, the bus voltages are maintained closer to their ideal values, and real power is shared more efficiently among sources like the grid, generators, wind turbine, and PV system. This leads to smoother power flow, reduced losses, and better use of available resources. Overall, optimal load flow helps the system operate in a more stable, efficient, and reliable way compared to the conventional load flow approach.

VIII. CONCLUSION

This study presented the load flow and optimal load flow analysis of a microgrid system using ETAP software. The microgrid model consists of multiple distributed energy sources such as grid supply, wind turbine, solar PV, and conventional generators, supplying different load buses. Load flow analysis was performed under different operating cases to understand system behavior under various generation conditions.

From the results, it is observed that in Case 0 (normal load flow), the system operates satisfactorily, but the power distribution is not optimized, leading to higher voltage deviations and increased transmission losses. In contrast, Case 5 (optimal load flow) shows improved system performance by optimally adjusting generation and maintaining bus voltages within acceptable limits. The voltage profile becomes more stable and closer to the rated values, indicating better system efficiency.

The comparison between Case 0 and Case 5 clearly demonstrates that optimal load flow significantly enhances real power distribution across the network. It reduces unnecessary power circulation, minimizes system losses, and improves overall voltage stability. Additionally, the system operates in a more balanced and reliable manner under optimal conditions.

Furthermore, the analysis of different cases highlights that system performance depends strongly on the availability of distributed energy resources. When fewer sources are active, the system becomes stressed, voltage drops occur, and losses increase. However, with proper optimization techniques like OPF, these issues can be effectively managed.

Therefore, it can be concluded that optimal load flow plays a crucial role in modern microgrid operation by ensuring efficient power management, improved stability, and reduced losses. The use of ETAP software proves to be an effective tool for modeling, simulation, and analysis of such complex power systems. This study can be useful for planning and designing reliable and efficient microgrid systems in real-world applications.

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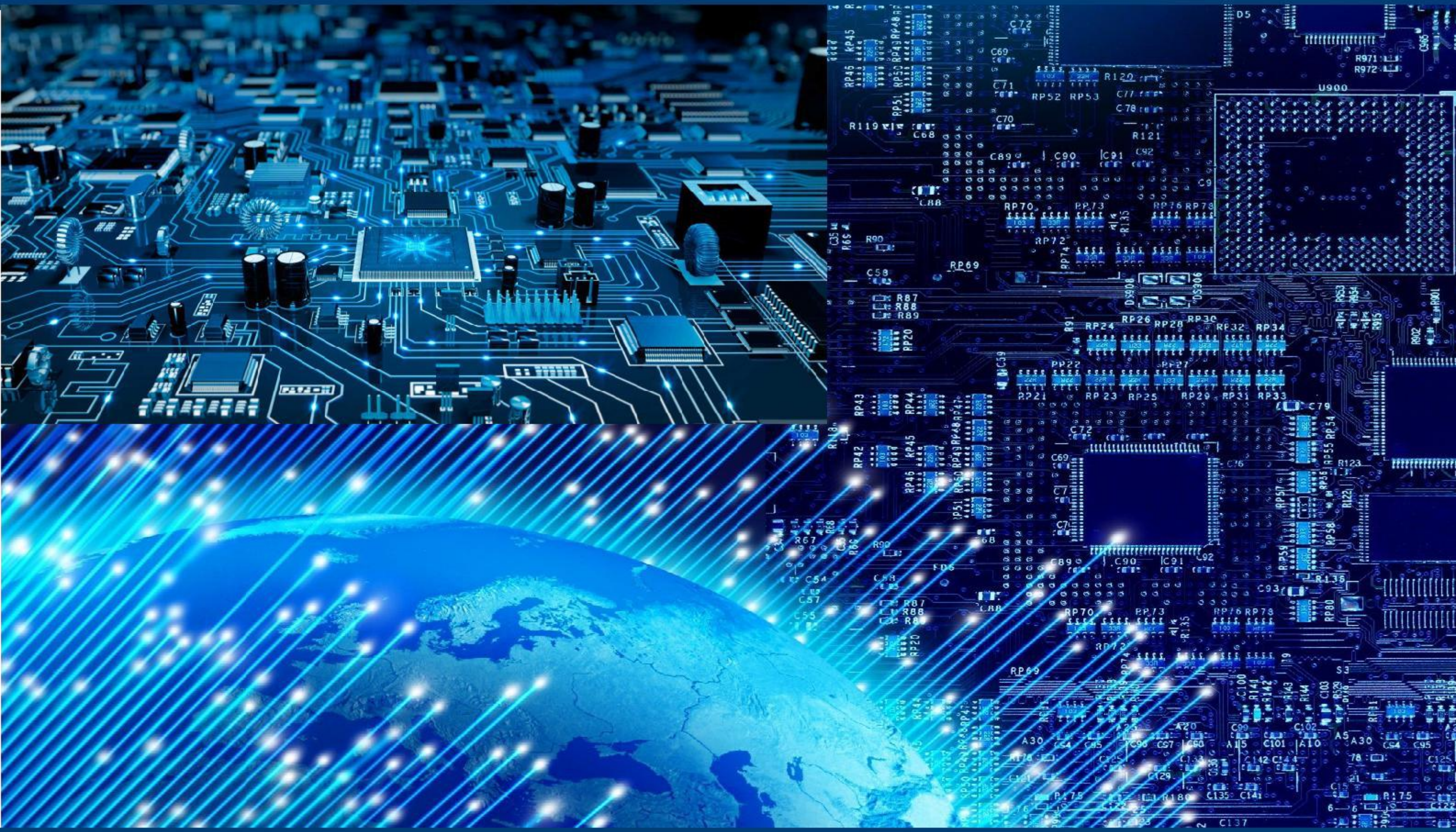

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