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Load Flow Analysis of CIGRE Benchmark Model Using ETAP

Mohsin Mumtaz
Department of Electrical Engineering
Bahria University Islamabad
Islamabad, Pakistan
Mohsin143.comsats@gmail.com

Hussain Sarwar Khan
Department of Electrical Engineering
Bahria University Islamabad
Islamabad, Pakistan
01-244162-025@student.bahria.edu.pk

Muhammad Aamir
Department of Electrical Engineering
Bahria University Islamabad
Islamabad, Pakistan
Muhammadaamir.buic@bahria.edu.pk

Muhammad Ali
Department of Electrical Engineering
Bahria University Islamabad
Islamabad, Pakistan
m.turi21@gmail.com

Ali Rehman
Department of Electrical Engineering
Bahria University Islamabad
Islamabad, Pakistan
eng.alirahman652@gmail.com

Abstract

The microgrid technology is an attractive option to fulfill the growing demand of electricity in the future. Though, the grid coupled microgrid experiences critical stability issues during a fault in the main grid, isolation of the microgrid is the utmost operational solution adapted. The distributive generation sources are meteorologically dependent thus they are vulnerable to inconsistencies and system overloading. Traditionally, when the microgrid system is implemented many more issues emerge, which should be addressed. This paper proposes a CIGRE benchmark microgrid model which is a 14-bus system that is comprised of eight solar system with a different rating, two battery banks, four synchronous generation having different power rating, a wind turbine generator all connected to the main grid. This CIGRE model is 110kv power system that is developed and simulated in ETAP software. For electrical power system operation and planning, the load flow analysis is important and essential to investigate the problems in order to increase the safety and reliability of the system. This research focuses on a comprehensive analysis with the help of ETAP software that executes numerical calculations of integrated systems at large scale with a stupendous speed. Additionally, outputs reports are generated which is helpful in implementing microgrids. The load flow analysis is based on the Newton-Raphson technique or algorithm as it converges rapidly as well as it takes fewer iterations than other methods and comparatively reliable. The results have been validated which shows that all the analysis performed are efficient and optimized.

Keywords: CIGRE; ETAP; Load Flow; 14-IEEE bus.

1. INTRODUCTION

As renewable energy has gained more importance with the passage of time, significant work in the installation of different kind of distributed energy resources (DERs) in order to create an emission-free and smart network. It can also be noticed that the non-renewable energies are getting exhausted due which rapid development of DERs was essential and thus microgrid technology has gradually attracted the wide attention of the whole world[1, 2].In general, distributed energy resources comprises of various technologies, for example, diesel generator, fuel cell, micro-turbine, and energy storage system (ESS) belonging to controllable energy resources, as well as wind energy and photovoltaic as intermittent renewable energy resources. Despite DERs having several benefits such as no transmission and distribution expenditures, fewer losses, provide reliability and safety. DERs may cause different issues in the power system. In comparison to large power grids, an individual small DER would be considered to be a non-regulated energy source.

The power quality is disturbed causing voltage instabilities due to the integration of DERs in the main grid. Likewise, in extreme cases, if there are severe faults occurring in the main grid, there would be a need to disconnection of DERs which reduces the performance of DERs to a great extent. Achieving reliable and stable use of DERs and get rid of the incompatibility among a single DER and big electrical system, a new technology called “Microgrid “was recently introduced.

For a number of years, engineers have been focusing on problems like reliability, smart grid enhancement, and electrical power system efficiency. The researcher has pointed out that microgrid shall play a vital role in fulfilling most of the demands, improving grid stability and guaranteeing control for power supply.

For planning and calculation of different bus voltages, phase angles, the real and reactive power flowing through an electrical system and its components, electrical engineers utilize a calculative technique known as load flow analysis [3-5]. There are different methods for load flow analysis such as Newton –Raphson, Gauss-Seidel and Fast Decoupled method [6]. The Newton-Raphson technique is most preferable due to its reliability as it converges faster as well as has the least number of iterations than other methods [7]. The load flow analysis using ETAP software is performed for the problem of an under voltage in [8]. The study shows that the system planning and system line and generator losses can be minimized in order to maintain the voltage under a safe limit under different loading conditions. In [9], particle swarm optimization (PSO) technique is used to analysis the load flow, and simulation is carried out in ETAP environment. This algorithm optimizes the power flow on the buses of the proposed system by using the particle-based memory algorithm.

The remaining paper is organized as follows. In section 2, the factors affecting the stability of microgrid are discussed. Section 3 provides the detail description of the system understudied. Section 4 discussed the mathematical modeling of load flow techniques and discussed the results obtained through simulations. Finally, section 5 provides the conclusion.

2. DESCRIPTION OF POWER SYSTEM.

In this research paper a medium voltage microgrid having a rated voltage of 20-kV that is powered from a 110-kV transformer station. The microgrid benchmark system is composed of two separate subsystems known as sub-network 1 and sub-network 2. The Subsystems are powered by a 110/20kV transformers, known as TR1 and TR2 [10].

3. MODELING AND SIMULATION

Load flow analysis is an approach to determine system parameters of a power system in a steady operation which can be supportive in planning as well as operation phase of a microgrid. In load flow analysis a Y_{bus} admittance matrix is built. The Nodal equation of any power model using Y_{bus} can be expressed as follows:

$$I = Y_{bus} V \qquad (1)$$

Where I is current

Y_{bus} is the nodal bus admittance

V is the voltage matrices

The nodal equation for n bus model is given as:

$$I_i = \sum_{i=1}^{n} Y_{ij} v_{ij} \qquad (2)$$

For i=1, 2, 3, 4……………….,n

Power delivered to the bus is given as

$$P_i + jQ_j = V_i I_j^* \qquad (3)$$

Where Pi and Qj are complex real and reactive power of bus i. Substituting the value of I_j^* in equation 2 in terms of Pi and Qj we get:

$$\frac{P_i - jQ_j}{V_i^*} = V_i \sum_{j=1}^{n} Y_{ij} - \sum_{\substack{j=1 \\ J \neq 1}}^{n} Y_{ij} V_j \qquad (4)$$

Table 1. Load parameters connected at each bus.

Bus ID	Residential Load (kVA)	Industrial Load (kVA)
Bus 0	**2.8**	**51**
Bus 3	**2.8**	**114000**
Bus 4	**4.453**	**-**
Bus 5	**7.5**	**-**
Bus 6	**5.7**	**-**
Bus 7	**0.91**	**-**
Bus 8	**6.1**	**-**
Bus 9	**-**	**4000**
Bus 10	**3**	**0.8**
Bus 11	**3.4**	**-**
Bus 12	**153**	**52.8**
Bus 13	**-**	**0.38**
Bus 14	**2.11**	**3.9**

In ETAP, the load flow calculations are performed through the following methods.

- Newton –Raphson Method
- Adaptive Newton Raphson Method

- Fast- Decoupled Method
- Accelerated Gauss-Seidel Method

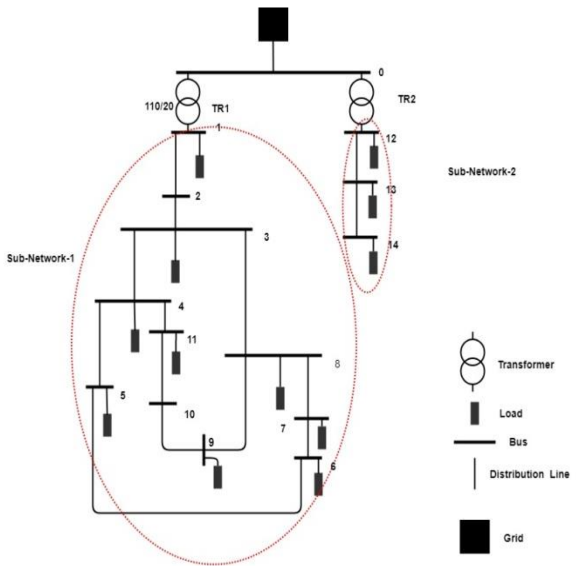

Figure 1 CIGRE Benchmark model.

Table 2. Parameters of different DGs at each Bus.

Bus I.D	**Generation (kVA)**
Bus 0	**Diesel (1176)**
Bus 3	**PV (25)**
Bus 4	**PV (18)**
Bus 5	**PV (30.6), Diesel (392) Battery (1800Ah)**
Bus 6	**PV (500)**
Bus 7	**Wind (1765)**
Bus 8	**PV (27)**
Bus 9	**PV (27), Diesel (365), Steam (249)**
Bus 10	**PV (36), Battery (1800 Ah)**
Bus 11	**PV (10)**

In this research, the load flow is based on the Newton-Raphson technique or algorithm as it converges rapidly as well as it takes fewer iterations than other methods. In addition, it is comparatively reliable.

The polar expression of equation (2) is substituted in equation (3) then the real and imaginary components of the resultant equation are as follows [11]

$$P_i = \sum_{j=1}^{n} |V_i|\,|V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \qquad (5)$$

$$Q_i = \sum_{j=1}^{n} |V_i|\,|V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \qquad (6)$$

As δ_i ,δ_j and θ_{ij} represent the angles of V_i ,$V_j$and Y_{ij} elements respectively.

Expanding the equations (6) and (7) in Taylor's series and neglecting the higher order terms, it then can be represented in a matrix form as follows

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \text{-} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \qquad (7)$$

Where P and Q are the real power and reactive power respectively, J_1 to J_4 are the entries of the Jacobian matrices.

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq i}^{\infty} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \qquad (8)$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \qquad (9)$$

Equations (8) and (9) show the diagonal and off-diagonal elements of J_1.

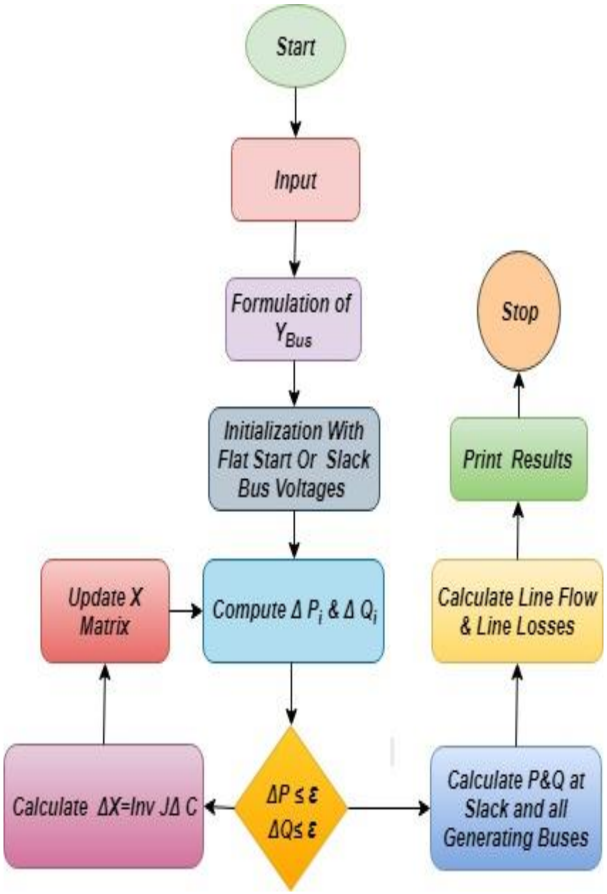

Figure 2 Load flow Algorithm Chart

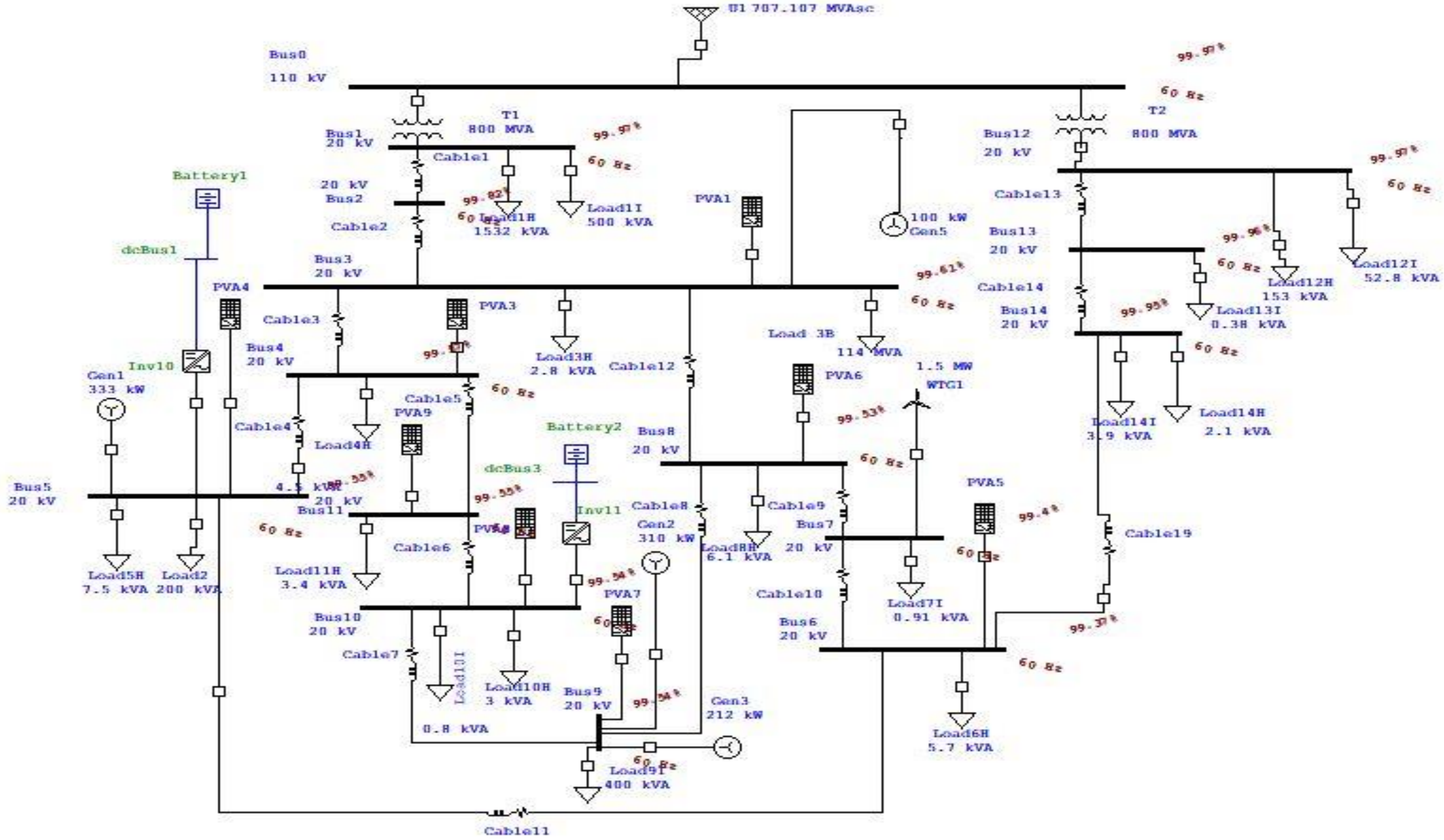

Figure. 3 CIGRE microgrid model simulation results in ETAP

Table 1. Load Flow Report.

4. SIMULATION RESULTS OF LOAD FLOW ANALYSIS

The load flow analysis in which the generated power, consumed power and transmitted power at each bus is reflected in the table. The magnitudes, phase angles of the voltage at each bus are also given. The negative sign of power in the load flow column indicates that power is supplied by that bus.

Table.3 describes the flow of real power and reactive power sharing among different branches in the micro-grid network. The Swing bus has a real power which is 0.245MW and a reactive power which is 0. 343Mvar. It can be seen that Bus 3,4,7,8,10 are heavily loaded. The negative sign shows that the bus is acting as a sink while others are as a source. Bus 5,6,11 the real power is in a negative sign that shows instead of power flowing to the other branches real power is flowing towards these buses 5,6,11. Same is to the reactive power.

5. CONCLUSIONS

The CIGRE Microgrid Model has simulated in ETAP software and the load flow analysis is determined to analyze its voltage Stability, the power flow both real and reactive among all the buses. The results expressed the power flows between the buses and loads and also explained the system voltage at buses and shows these results will be helpful during system physical implementation and planning. Further research work incorporates the load transients and transient's stability study.

Bus ID	**Bus kV**	**Voltage Mag. (%)**	**Voltage Angle**	**Gen (MW)**	**Gen (MVAr)**	**Load**	
						(MW)	**(MVAr)**
Bus 0	110	100	0	0.245	0.343	0	0
Bus 1	20	99.9997	0	0	0	0.002	0.320
Bus 2	20	100	0	0	0	0.004	0.001
Bus 3	20	100.005	0	0.020	0	0.007	0.001
Bus 4	20	100.002	0	0.017	0	0.005	0.001
Bus 5	20	100	0	-0.035	0.016	0	0
Bus 6	20	100	0	-1.353	0.829	0.006	0.001
Bus 7	20	100.47	0	1.500	-0.930	0	0
Bus 8	20	100.008	0	0.026	0	0.006	0.001
Bus 9	20	100	0	0.226	0.239	0.369	0.154
Bus 10	20	100.001	0	0.034	0	0.003	0.002
Bus 11	20	100	0	-0.022	0.006	0.003	0.001
Bus 12	20	100	0	0	0	0.050	0.017
Bus 13	20	99.998	0	0	0	0	0
Bus 14	20	99.985	0	0	0	0.005	0.003

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