

Power System Analysis of a Microgrid using ETAP

Sneha Kulkarni, Sunil Sontakke

Abstract— Due to evolution in the power system, the development of smaller generating systems such as micro turbines, Wind Turbines, Solar PV system, etc., have opened new opportunities for onsite power generation which is located at user's site called Distributed Energy Resources (DER). The significant potential of DER to meet customers need and utilities independently can be captured by organizing these resources into Microgrid. Power System study and analyses are mandatory parts of power system engineering. This paper deals with a Micro Grid simulation in Electrical Transient Analyzer Program (ETAP). This paper is focused on the detailed analyses by using the most modern software ETAP, which performs numerical calculations of large integrated power system with fabulous speed besides, generating output reports which will be helpful in implementation of a Microgrid system. In this software, Off-line monitoring is made which includes current flowing in every branch, power factor, active and reactive power flow, short circuit analysis and harmonic distortion etc. of large power system. Based upon the recorded data obtained from an actual Microgrid which has been implemented in ETAP for Off-line monitoring and analyses.

Index Terms— DER, DG, ETAP, Microgrid, Distributed Generation, Load flow, Introduction

I. INTRODUCTION

After deregulation, electric power demand has enlarged tremendously. Fossil fuels are reducing day by day therefore power producers are moving towards of renewable energy sources. Out of these wind power and solar power generation has developed up to significant extent. These energy converters can work together in the form of power parks or as a standalone power supplies called Distributed Generators, with the induction of DGs, in the power system, power grid has become more complex, hence invite its own problems like protection, power quality, blackouts, load sharing and shedding etc. Now a day's utility grid is unable to supply the complete demand of electricity. Owing to these problems a new concept of Microgrid, as shown in fig. 1, has come up, which can work in grid connected mode (in case of normal power supply condition) or islanded mode (in case of disturbed power supply condition). The Microgrid concept has the prospective to solve major problems arising from large penetration of distributed generation in distribution systems. Microgrids are almost 85% efficient as they have very little transmission losses and use the surplus heat to warm or cool buildings. During power outage or disturbance, Microgrids can island themselves and retain power availability, avoiding blackouts and lost productivity. For the last few years electrical engineers have been concentrating on the power system studies using software tools. Recent advances in engineering sciences have got a revolution in the field of electrical engineering after the development of powerful computer based software.

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This research work highlights the effective use of Electrical Transient Analyzer Program (ETAP) software for analyses and monitoring of electrical power system which involves a Microgrid consisting of a wind turbine, a solar panel and two diesel generators.

This paper embodies an innovative approach to analyze the power system network by using ETAP with the help of one line diagram. This diagram is executed in ETAP to perform load flow study, harmonic load flow and short circuit analysis. The system is analyzed under steady state by using load flow analyses. Moreover, Harmonic analyses of current and voltage waveforms when sinusoidal voltage is applied to a non-linear load are also made. The short circuit analysis is also carried out to get the full load short circuit current and to decide the protective devices' ratings. Section 2 is the brief idea of the microgrid concept and ETAP. Section 3 is the single line diagram of the system under concern; this diagram is instigated based upon practical data in ETAP for simulation purpose in Section 4 which is Load Modeling and simulation of microgrid in ETAP. Section 5 contains analyses which include load flow, harmonic and short circuit analysis. Section 7 deals with the Conclusion of this research work.

II. BRIEF IDEA OF MICROGRID AND ETAP

What is Microgrid?

The U.S. Department of Energy (DOE) has offered the following description of Microgrids:

"A Microgrid, a local energy network, offers integration of distributed energy resources (DER) with local elastic loads, which can operate in parallel with the grid or in an intentional island mode to provide a customized level of high reliability and resilience to grid disturbances. This advanced, integrated distribution system addresses the need for application in locations with electric supply and/or delivery constraints, in remote sites, and for protection of critical loads and economically sensitive development.^[1] In another slightly different definition of a Microgrid:

"A Microgrid is any small or local electric power system that is independent of the bulk electric power network. For example, it can be a combined heat and power system based on a natural gas combustion engine (which cogenerates electricity and hot water or steam from water used to cool the natural gas turbine), or diesel generators, renewable energy, or fuel cells. A Microgrid can be used to serve the electricity needs of data centers, colleges, hospitals, factories, military bases, or entire communities (i.e., village power)."^[1]

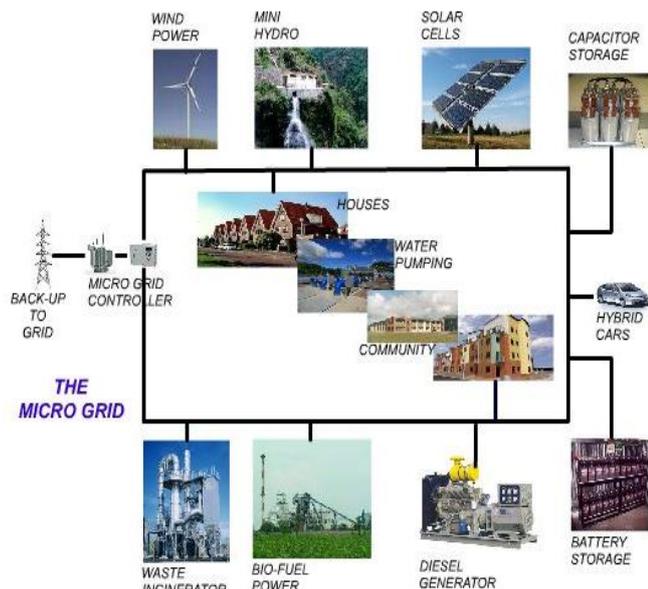


Figure 1: Microgrid Taxonomy

The Key Features of a Microgrid

Operation in both island mode or grid-connected

- Presentation to the Microgrid as a single controlled entity
- Combination of interconnected loads and co-located power generation sources
- Provision of varied levels of power quality and reliability for end-uses, and
- Designed to accommodate total system energy requirements

Microgrid-Enabling Technologies

The key capability and feature of a Microgrid is its ability to island itself (i.e., separate and isolate itself) from a utility's distribution system during brownouts and blackouts. However, in order to have an operational Microgrid that can perform in the manner expected – both online and islanded – requires use of the following technologies:

- Distributed Generation (DG)
- Islanding and Bi-Directional Inverters
- Smart Meters
- Distribution Automation (DA)
- Substation Automation
- Microgrid Control Systems
- Smart Transfer Switches
- Advanced Energy Storage [3]

ETAP: Electrical Transient Analyzer Program

As power system become increasingly complex, there is a critical need to make available improved tools for analyzing the power system. In addition, it gives guidance to the entry of new working professional into the power system with at least a basic understanding of power system operation.^[9]

ETAP is the most comprehensive analysis platform for the design, simulation, operation, control, and optimization, automation of generation, transmission, distribution and industrial power systems. ETAP offers a suite of fully integrated software solutions including arc flash, load flow, short circuit, relay coordination, cable capacity, transient stability, optimal power flow, and more. Its modular functionality can be tailored to fit the needs of any company

from small to large power systems. Typical information for all equipment (Generator, Transformer, Shunt equipment) is readily available which reduces the considerable time of the user. ETAP provides error report and highlight the mistake to the user in brief report.

Key elements of power systems that are included in ETAP are:

1. Load flow (power flow study)
2. Short circuit
3. Transient stability
4. Harmonic Study
5. Voltage Instability Analysis
6. Relay Coordination
7. Sub-synchronous Resonance
8. Load forecasting
9. Load shedding studies
10. Online monitoring.

III. SINGLE LINE DIAGRAM OF SYSTEM UNDER OBSERVATION

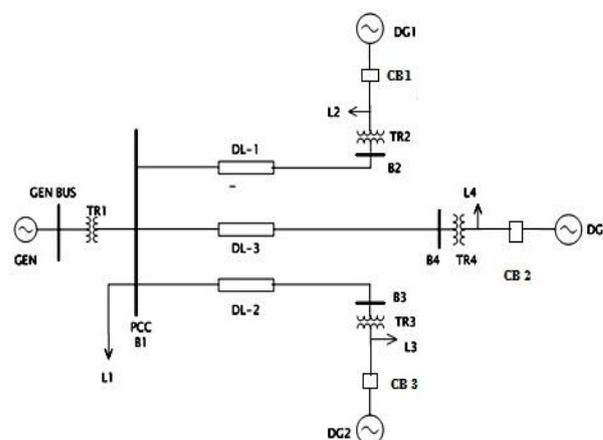


Figure 2 : Schematic of Microgrid to be analyzed

The above figure shows the schematic of Microgrid to be analyzed. The DG1 shows the combination of two diesel generators of 62.5 kVA and 45 kVA resp. The DG2 represents a wind turbine generator of capacity 100 kW whereas the DG3 implies the solar power generator of 100 kW. The main generator (GEN) is the line from MSEDCL of 11 kV and a transformer of 500 kVA; 11kV/440V is connected to it. The wind turbine has capacity 100 kW and can provide 380 V AC voltage. The solar panel has rating of 100 kW and capacity of 3000AH and can provide 220 V DC. A smart switch is connected between the DL the main 11 kV line and distributed generators at point of common coupling (PCC) so that the Microgrid can be islanded.

The load can be classified as lights, fans, air conditioners, room coolers, water coolers, Photostat machines, printers, computers, induction motors, irrigation pumps and the other industrial equipment etc. Comprehensive load modeling is performed in ETAP based upon original system data.

IV. LOAD MODELING AND SIMULATION OF SYSTEM IN ETAP

Fig.2. gives that, in the system there are three DERs and one 11 kV line coming from MSEDCL. There is a 500 kVA transformer connected in the system.

The same is shown or implemented in ETAP as shown in Fig. 3.

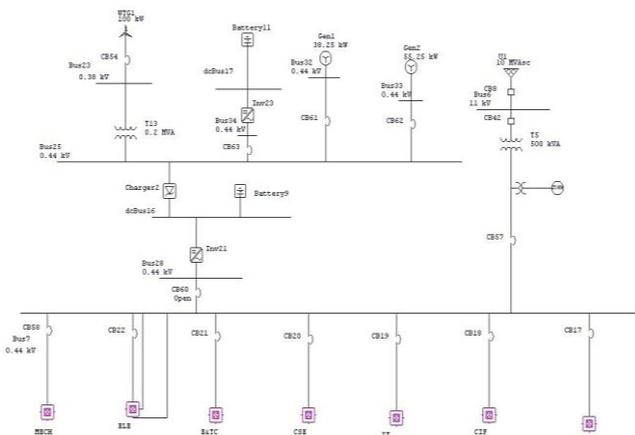


Figure 3 : SLD of Microgrid in ETAP

Bus 7, which is the main load bus, operating at 440 V has 100% operating magnitude with power of 0.012 MW and 0.004 MVar. The same bus at constant impedance requires 0.139 MW real power while 0.079 MVar. Bus 25 is the bus, where all the DERs are connected together, which is also operating at 440 V and 1.0 p.u. and with giving real power of 0.12MW and reactive power of 0.008 MVar. Bus 6 is the swing bus connected to utility grid line of 11 kV. Bus 23 is a MVar/pf control bus connected to a wind turbine of 100 kW and 0.380 kV. Bus 32 and bus 33 are the voltage control buses connected to DG 1 that is to the diesel generators of 62.5 KVA and 45 KVA ratings. There are two transformers connected in the system. The transformer T5 is a 500 kVA, 11/0.44 kV, plinth mounted, ONAN cooled, DYn11 transformer whereas the T13 is a 200 kVA, 0.380/0.440 kV, step up transformer. For the simplicity of simulation and lack of space available, the loads of different departments in the college had been implemented by using a combination of composite network and panel assembly. The following figure will demonstrate the connection of load in electrical department.

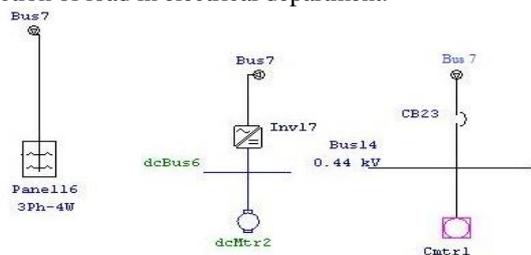


Figure 4 : Load connection of Electrical Department

V. ANALYSIS OF MICROGRID BY USING ETAP

5.1 Load Flow Analysis

Based on the network topology with the impedances of all devices as well as with the in feeds and the consumers, the load-flow calculation can provide voltage profiles for all nodes and loading of network components, such as cables and transformers. With this information, compliance to operating limitations such as those stipulated by voltage ranges and maximum loads, can be examined. The Newton- Raphson method with 0.0001precesion and 999 iterations is used for load flow analysis.

In the given system, buses 28, 32, 33, 34 are the generation buses therefore no load is connected to these buses directly. Bus 7 is the main load bus, where total load of 0.151 MW,

0.083 MVar is connected. Bus 25 is the bus where all the DERs are connected, which has total load connection of 0.043 MW and 0.026 MVar. The power factor for the bus 7 is 87.3% whereas for bus 25, it is 98 %. The total current flowing through the bus 7 is 245.2A, while from bus 25 it is 253.1A. The critical overloading of any equipment is considered when it is operating at a load equal to or more than its 100% of operating values. And that is considered as marginally overloaded when it is operating at 95% load. In the given system, the gen1 and WTG1 are overloaded, while the gen2 is marginally overloaded.

Table 1: ETAP alerts in Load Flow Analysis

Device ID	Type	Condition	Rating	Operating	% Operating
GEN 1	Generator	Critical Overload	0.038 MW	0.038 MW	100.0
WTG 1	Wind turbine Generator	Critical Overload	0.100 MW	0.100 MW	100.0
GEN 2	Generator	Marginally Overload	0.055 MW	0.053M W	95.9

To summarize, the total load demand of the system is 0.206 MW, 0.120 MVar at 86.42% lagging pf. The total motor load is 0.067 MW at 86.84% pf and the total static load is 0.139 MW at 86.87%. The total generation is 0.206 MW

Table 2 : Summary Report of Total Demand

	MW	MVar	MVA	% PF
Source(swing)	0.015	0.101	0.102	14.51 lagging
Source (non-swing)	0.191	0.019	0.192	99.50 lagging
Total Demand	0.206	0.120	0.238	86.42 lagging
Total Static Load	0.139	0.079	0.160	86.87 lagging
Total Motor Load	0.097	0.039	0.077	86.64 lagging

5.2 Unbalanced Load Flow Analysis

As microgrid contains large no. of single phase loads, unbalanced load flow plays a very important role in the analysis of microgrid. After unbalanced load distribution, the load flow gives following results.

Table 2: Unbalanced Load Flow Analysis

	kV	Phase	MW	MVA _r	MVA	% pf
Bus 7	0.44	A	0.054	0.025	0.059	90.9
		B	0.079	0.046	0.091	86.4
		C	0.030	0.021	0.037	82.4
Bus 25	0.44	A	0.064	0.010	0.064	98.8
		B	0.064	0.010	0.064	98.8
		C	0.064	0.010	0.064	98.8
Bus 28	0.44	A	0.054	0.025	0.059	90.9
		B	0.079	0.046	0.091	86.5
		C	0.030	0.021	0.037	82.4

This analysis gives the reduction of power factor due to overloading of a phase in an unbalanced system. So, it is necessary to minimize the overloading of the phase and to make sure that the load is balanced in nature.

5.3 Harmonics Analysis

After performing harmonic analysis on the entire power system under consideration in ETAP, the obtained information includes Total Harmonic Distortion in voltage (% VTHD) and Total Harmonic Distortion in current (% ITHD).

The system contains different types of motors and synchronous machines with a utility grid connected all together. The utility grid is to be considered to have % negative sequence X/R = 0.05, X2=4.99, R2= 99.875 and that of zero sequence X/R is 0.05, R0 = 99.875, X0=4.99. The generators have negative sequence X/R=9.00, X2=18.00, R2=2.00. For zero sequence the generators have X/R = 7.00, X0= 7.00 and R0= 1.00. The utility is considered to have harmonics of typical arc furnace and all motors and synchronous machines are considered to have typical IEE 12 pulse 1 type harmonics.

Bus 7 has voltage distortion of 101.01% in RMS, 143.97% in ASUM and VTHD of 14.46%. Bus 34 has voltage distortion of 127.63% in RMS, 298.53% in ASUM and VTHD of 79.31%. For current distortion, Bus 7 has RMS amp of 249.71A, ASUM amp of 362.34 A and ITHD of 19.27%. Bus 34 has RMS amp of 204.34A, ASUM amp of 317.08 A and ITHD of 23.97%.

At bus 7 and bus 14, the harmonic voltage at 5th harmonics order is 9.65 %, at 7th harmonic order 5.70% and at 11th & 13th harmonics order it is 2.53% of the fundamental voltage. The alert report gives that the harmonics at any branch or bus exceeds its permissible limit, so an appropriate mitigation equipment should be introduced in the system.

It can be seen that the harmonics are maximum at harmonics of order $12p \pm 1$, so a combination of filters consisting of 11th and 13th order single tuned filters and high pass filters is to be introduced in the system.

The following figures give the waveforms for the voltage distortions and the order of harmonics in each of the buses.

Table 3: VTHD (Total Voltage Distortion)

Bus ID	kV	Voltage Distortion	
		% Fund. Voltage	VTHD
Bus 7	0.440	100.00	7.03
Bus 14	0.440	100.00	7.03
Bus 23	0.380	100.00	69.86
Bus 25	0.440	100.00	79.76
Bus 28	0.440	100.00	7.03
Bus 32	0.440	100.00	79.76
Bus 33	0.440	100.00	79.76
Bus 34	0.440	100.00	79.76

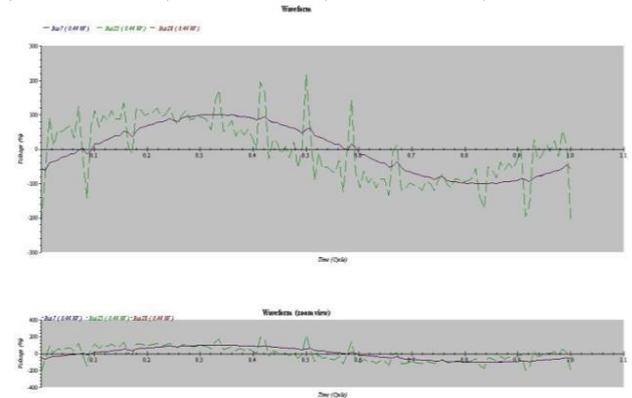


Figure 5: Harmonics waveforms of Voltage Distortion

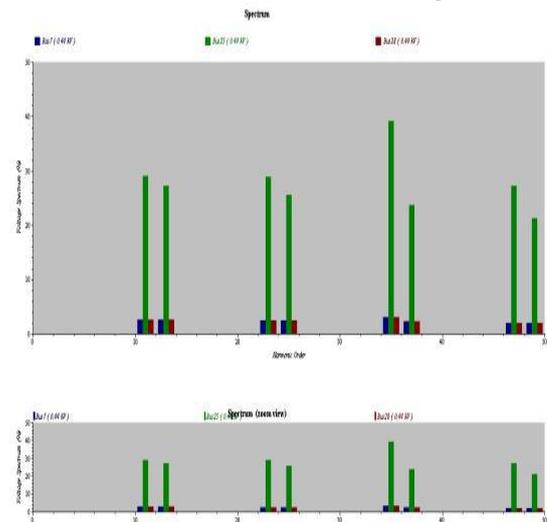


Figure 6: Spectrum view of Harmonics order at different buses

5.4 Short Circuit Analysis

Short circuit analysis analyzes the power flow after a fault occurs in a power network. The faults may be three phase short circuit, one-phase grounded, two phase short circuit, two-phase grounded, one phase break, two-phase break or complex faults. In the given system two synchronous generators are connected which is of 45 kVA and 65 kVA respectively and having X/R ratio of 19.00. There are 4 induction motors with X/R ratio of 15.00, X''= 27.83.

When a three phase fault is occurred on bus 6, current of 0.546 kA is obtained in bus 6 at ½ cycle calculation and that for 0.544kA current at 1.5-4 cycle calculation. There is effect on bus 7 where a 4.30 % voltage from bus 7 to bus 6 is observed. A current of 0.021 kA is observed in bus 7.

When a three phase fault is occurred on bus 7, all the motors and synchronous motors are affected by that fault. A current of 6.637 kA real is observed in bus7. Bus 14 and bus 28 gives a fault through a tie circuit breaker.

When a three phase fault is occurred on bus 14 then all the four induction motors and synchronous motors are affected. A total current of 6.637kA is flown through the bus 14 at ½ cycle.

Table 3: Momentary Data Summary Data

BUS		Momentary Duty				
ID	kV	Symm. kA rms	X/R ratio	Asymm. kA rms	Asymm. kA peak	M.F.
Bus 7	0.440	8.619	0.00	8.619	8.619	1.00
Bus 14	0.440	8.619	0.00	8.619	8.619	1.00
Bus 25	0.440	1.493	0.0	1.493	1.493	1.079

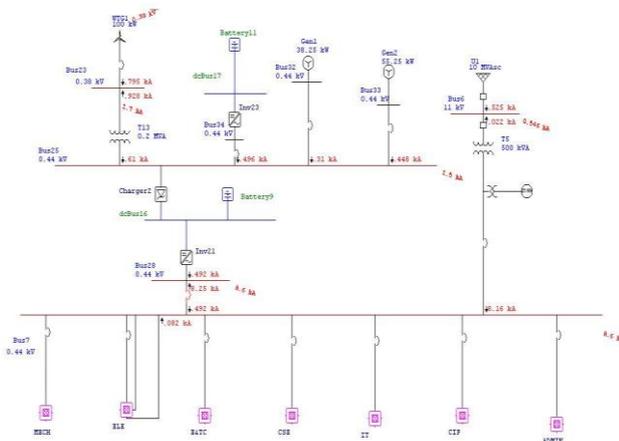


Figure 5: Short Circuit Analysis 3 phase device duty in ETAP

VI. CONCLUSIONS

Simulation of large electrical power system performed in this research paper for monitoring and analyses purpose has open new pathways for power sector stake holders. Over loading of power/distribution transformers, line conductors/cables current carrying ability, power factor, supply demand gap, voltage drop at the tail end, technical losses, active and reactive power flow, voltage and current magnitudes, Total Harmonic Distortion in voltage and current etc. can be analyzed and monitored at any desired location using this innovative approach. Moreover, utilities can simulate the complete power system and can integrate different grids as they are actually connected referring to this research work. This simulation can also be helpful for utilities in their planning and development sectors. Once the simulation is performed in ETAP for complete power system, it may be very helpful for converting conventional grid network into smart grid.

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