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Research Article

Design and Stability Analysis of a proposed Microgrid for on Campus Diesel and Photovoltaic Power Sources

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Abstract: Pakistan is currently facing an energy crisis that is detrimental to its growth. Due to persistent load shedding by the National Grid throughout the country, the latest trend is tilting towards generating power at localized level through a mix of renewable and conventional energy sources. Such a mixture is referred to as Distributed Energy Resource (DER). Part of such a DER (i.e. solar energy) is free as naturally and mostly available in Pakistan having no degradation problem while providing benefit to the locality. The idea of using a Microgrid for our local power needs morphed accordingly. In this paper, a Microgrid design for our local campus i.e. University of Engineering & Technology, Peshawar, KPK is proposed. Our campus generators are not interconnected. Consequently, even while servicing small load periods, all of our campus's diesel generators run at full capacity at the same time. Such a behavior is uneconomical, unacceptable and the generators run at low efficiency during islanding from the main utility grid. It is seen that behavior as such is endemic throughout Pakistan. Through design and analysis, it is proposed that if a Microgrid of such unconnected resources on campus is formed then during islanding, all generators and our Photovoltaic (PV) systems will economically and efficiently feed their common loads through load sharing. Synchronization, load flow analysis, short circuit analysis, harmonic analysis, transient stability, cost and reliability of our proposed Microgrid is analyzed using ETAP (Electrical Transient Analyzer Program) in this paper.

Keywords: Power, Microgrid, Diesel, Photovoltaic, Islanding.

1. INTRODUCTION

The demand of electricity generation to provide energy for today's modern living is on the rise [1-2]. The electricity demand in commercial side, residential side and industrial side is increasing due to two main reasons, first and foremost is the modern inventions/innovations in electrical appliances to facilitate modern living while the second one is due to increasing population [1]. The generation of electricity from conventional energy resources is too costly and the other major problem is that these energy resources are depleting day by day [2].

Currently, our old installed electricity supply system is not enough to fulfill the required electricity demands of modern populous. The rural and urban side is facing an unexpected problem of electricity shortage due to which they install isolated backup generators in order to accomplish their requirements which is costly and are less efficient [3-4].

The new concept of Microgrid is ascending to solve problems of modern life in which the locally generating resources are interconnected to fulfill electricity demand locally which is an efficient way of supplying electricity to local people [4-5]. The Microgrid works on both grid connected and islanding mode of operations [5]. In the generating resources of such an arrangement, renewable and some conventional energy resources are interconnected in order to form a Microgrid as shown in Figure 1. The Microgrid is mostly used in rural areas where supply of electricity is a major problem [6]. This research work proposes a Microgrid for our local campus i.e. the University of Engineering & Technology situated in Peshawar, KPK, Pakistan using ETAP version 12.6 simulation/analysis software [7].

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This paper shows the analysis of UET proposed Microgrid using ETAP in a single line diagram approach. The analysis includes load flow, harmonic, short circuit and transient stability case studies [8-9]. The harmonic study on one side includes analysis of distortion in voltage and current waveform [8]. On the other, the load flow study analyzes the steady state performance of the power system, analyzes the voltage profile at load buses, cable or transmission line under load, over load of transformer and under load, under excited and over excited generator [10-11]. While the short circuit study [9] is used to calculate all the short circuit current flowing in the power system, when a fault occurs and accordingly selects the protective devices ratings.

Moreover, the transient stability study [10] is carried out to analyze the system when subjected to sudden change in load, generation or a fault.

2. MATERIALS AND METHODS

2.1 Network Configuration & Modeling

The studied circuit in Figure 2 shows a Microgrid consisting of four diesel generators and one solar system. The rating of three generators is 400kVA and one of 60 kVA. The rating of solar system is 15 kW and having output DC voltage of 400 V.

As Microgrid operating in parallel with utility grid is not viable option here because it is an expensive choice due to high prices of diesel fuel. In future, the share of renewable energy resources production is expected to increase in UET, then grid connected mode will be under consideration. When the Microgrid is in islanding mode due to some failure of main grid or load shedding, the Microgrid will feed their common loads.

The Microgrid system frequency is 50Hz. The generation voltage of all four diesel generators and solar system is 400V, which is fed through cable to different departments of UET Peshawar. G1 is taken as swing generator and the remaining three generators are connected to the PV bus.

2.2 Analysis of Microgrid using ETAP

2.2.1 Load Flow Analysis

Load Flow Analysis is carried out to analyze the voltage profile at the buses, the power factor, the flow of active power and reactive power flow between different types of buses [12]. The load flow study is used to analyze the generator, transformer and cable/transmission line working during their load flow analysis of the entire power system.

In the load flow analysis [13], the generator

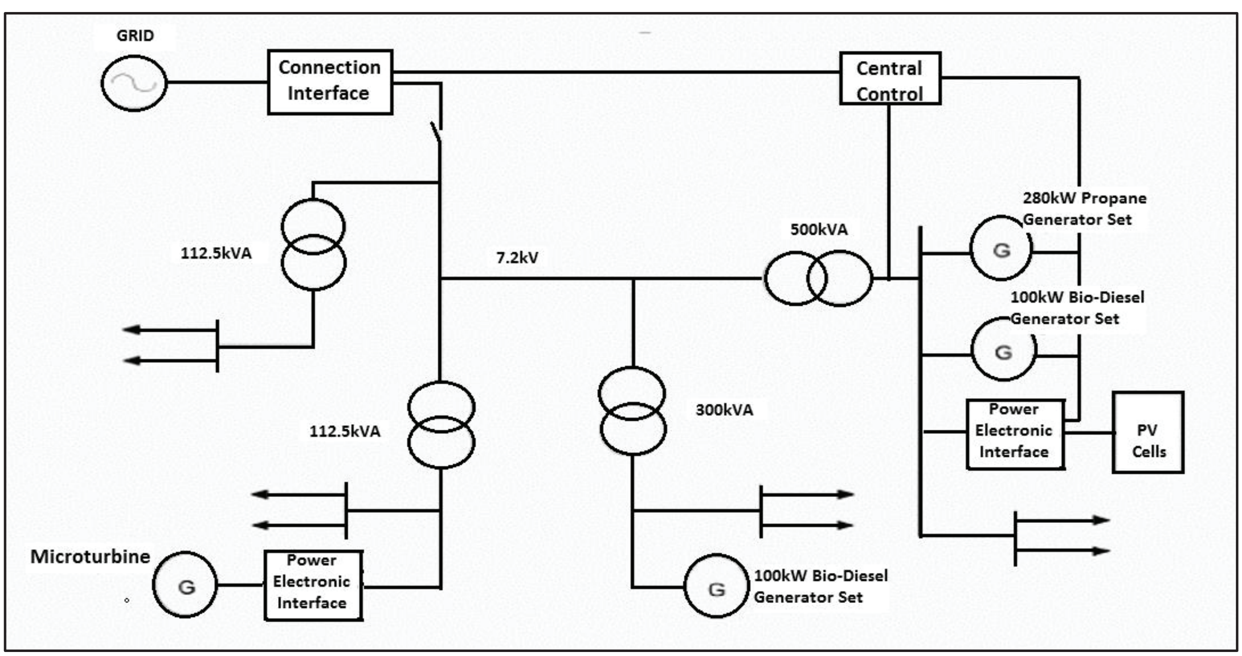

Fig. 1. Single line diagram of Microgrid

under load, over excited, under excited condition and the loading on cable is studied. The proper load sharing of generators is studied and the tolerance in voltage is taken up to the range of +5 to -5 percent.

The iterative method is used for load flow analysis which is Newton Raphson method [14] with 99 iterations of accuracy i.e. 0.0001. Figure 3 shows the load flow analysis results. Table 1 shows operating conditions of generators during load flow analysis. Table 2 on the other hand shows the loading conditions during load flow analysis. Table 3 shows information about each bus in load flow analysis while Table 4 shows all branches information during load flow analysis.

2.2.2 Short Circuit Analysis

Here, short circuit study is used to analyze short circuit current which is the combination of generator and motor current flowing in the overall power system when a fault situation occurs. There are mainly two types of faults i.e. symmetrical and unsymmetrical faults. The analyzed symmetrical fault is a three phase bolted fault, which is known as three phase balanced fault. The resume of a symmetrical fault includes line to ground, line to line and line to line/ground. Figure 4 above shows our short circuit analysis while Table 5 shows the short circuit reading after 3-phase fault occurs on Bus22.

2.2.3 Harmonics Analysis

The harmonic study analyzes the distortion in voltage and current waveform. In ETAP the total harmonic distortion in voltage is denoted by (%VTHD) and the total harmonic distortion in current is denoted by (%ITHD). The presence of harmonics in sinusoidal wave form voltage and current is due to presence of nonlinear devices. Due to this problem of harmonics present in voltage and current wave forms some area of the power system is greatly affected [15]. The frequency components present in the voltage and current wave form are usually integral multiple of the fundamental frequency which are known as harmonics. There are some problems arising due to presence of these harmonics in a power system, including equipment heating, reduction of system power factor and relay malfunction. Figure 5 here shows the harmonic analysis of UET Peshawar Microgrid while Fig. 6 shows the waveforms of voltage harmonics on different analyzed buses.

2.2.4 Transient stability Analysis

Transient stability study analyzes the stability of the proposed power system, when subjected to some sort of disturbance. The disturbance may be on source side i.e. some generators to stop working during some fault situation or the disturbance may be on a load side i.e. the load increases up to very high level or decreases up to very low level. The transient stability analysis of UET Peshawar Microgrid is done by a 3-phase fault which occurs at Bus21 as shown in Figure 4 and this fault is cleared at 0.02s. Figure 7 shows the transient stability of UET Peshawar Microgrid.

Figure 8(a) till 8(f) shows different transient stability graphs of four generators based on separate analyzed parameters while Figure 9(a) till 9(c) shows different transient stability graphs of lump loads. Moreover, Figure 10 shows the frequency stability of our proposed Microgrid under fault condition.

3. RESULTS - COST EFFECTIVITY ANALYSIS OF UET PESHAWAR MICROGRID

The main consideration in the Microgrid operation is economical and optimum generation that can fulfill the dynamic demand keeping intact the quality of the power system. The grid connected Microgrid analysis is not performed because of high prices of diesel oil and lack of high amount of renewable energy. The economic analysis of UET proposed Microgrid includes two operation modes i.e. (a) Without Microgrid and (b) With Microgrid which are discussed here.

3.1 Mode of operation (Without Microgrid)

In this mode, analysis is done without the implementation of Microgrid as shown in Fig. 11, in which all the generators and solar system are working independently when the main grid supply is off due to utility power failure or contingency on the power system. The percent generation of generators is given in Table 6. The percentage

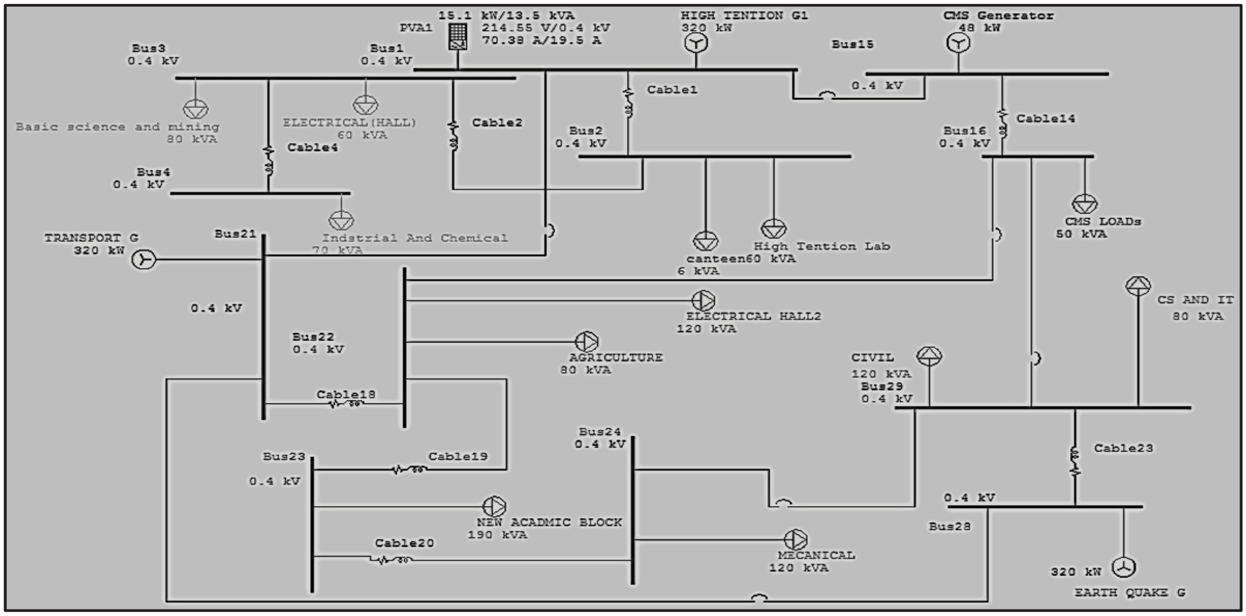

Fig. 2. Model of Microgrid network

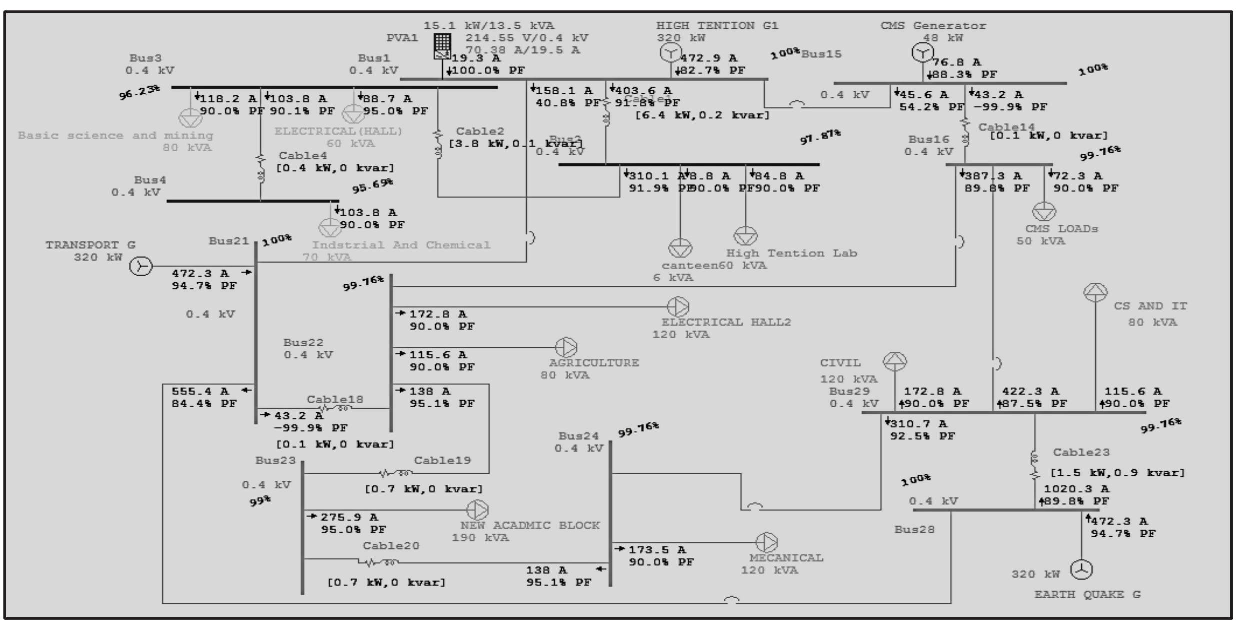

Fig. 3. Load flow analysis

Table 1. Generators operating in load flow

Generator ID	Rating (kW)	Rated (kV)	kW	kvar	Amp	%PF	% Generation
CMS Generator	48	0.4	47	25	76.84	88.29	97.9
Earth Quake G	320	0.4	310	105	472.3	94.74	96.9
High Tension G1	320	0.4	271	184	472.9	82.67	84.7
Transport G	320	0.4	310	105	472.3	94.74	96.9

Table 2. Loading condition during load flow analysis

Load ID	Rating (kVA)	Rated (kV)	kW	kvar	Amp	%PF	% Loading	% V(terminal)
Agriculture Department	80	0.4	71.93	34.837	115.6	90	100.1	99.76
Basic Sciences Department	80	0.4	70.935	34.356	118.2	90	102.4	96.23
Canteen	6	0.4	5.354	2.593	8.774	90	101.3	97.87
Civil Department	120	0.4	107	52.052	172.8	90	99.8	99.76
CMS Loads	50	0.4	44.956	21.773	72.27	90	100.1	99.76
CS&IT Department	80	0.4	71.93	34.837	115.6	90	100.1	99.76
Electrical Department Hall 1	120	0.4	107	52.052	172.8	90	99.8	99.76
Electrical Department Hall 2	60	0.4	56.157	18.458	88.66	95	102.4	96.23
High Tension Laboratory	60	0.4	51.725	25.051	84.76	90	97.9	97.87
Industrial & Chemical Departments	70	0.4	61.938	29.998	103.8	90	102.7	95.69
Mechanical Department	120	0.4	108	52.256	173.5	90	100.1	99.76
New Academic Block	190	0.4	180	59.092	275.9	95	100.6	99

Table 3. Information about each bus in load flow analysis

Bus ID	Nominal kV	Type	Voltage	kW Loading	kvar Loading	Amp Loading
Bus1	0.4	Swing	100	301	211	530.9
Bus2	0.4	Load	97.87	250	111	403.6
Bus3	0.4	Load	96.23	189	82.827	310.1
Bus4	0.4	Load	95.69	61.938	29.998	103.8
Bus15	0.4	Gen	100	47	26.531	77.9
Bus16	0.4	Load	99.76	285	141	460.5
Bus21	0.4	Gen	100	355	206	592.2
Bus22	0.4	Load	99.76	270	118	426.4
Bus23	0.4	Load	99	180	59.092	275.9
Bus24	0.4	Load	99.76	199	81.829	310.7
Bus28	0.4	Gen	100	635	311	1020
Bus29	0.4	Load	99.76	633	310	1020

Table 4. All branches information during load flow analysis

Cable ID	Type	kW Flow	Kvar Flow	Amp Flow	% PF	% Loading	% Voltage Drop	kW Losses	kvar Loss
Cable1	Cable	257	111	403.6	91.81	80.7	2.13	6.397	0.231
Cable2	Cable	193	82.963	310.1	91.89	77.5	1.64	3.777	0.137
Cable4	Cable	62.361	30.013	103.8	90.11	51.9	0.54	0.423	0.015
Cable14	Cable	29.868	-1.531	43.17	-99.87	21.6	0.24	0.073	0.003
Cable18	Cable	29.868	-1.531	43.17	-99.87	8.6	0.24	0.073	0.003
Cable19	Cable	90.64	29.573	138	95.07	34.5	0.75	0.747	0.027
Cable20	Cable	90.64	29.573	138	95.07	69	0.75	0.747	0.027
Cable23	Cable	635	311	1020	89.81	53.7	0.24	1.482	0.894

Table 5. Short Circuit reading for 3-phase fault occurs at Bus22

Short Circuit Report						
3-Phase fault at Bus: Bus22						
Pre-fault voltage = 0.400 = 100.00 % of nominal bus kV (0.400 kV) i.e. 100.00 %of base (0.400 kV)						
Contribution			1/2 Cycle			
From Bus ID	To Bus ID	% V from Bus	kA Real	kA Imaginary	Imaginary/Real	kA Symm Magnitude
Bus22	Total	0.00	2.335	-12.856	5.5	13.066
Bus21	Bus22	2.32	0.227	-0.341	1.5	0.409
Bus23	Bus22	2.83	0.205	-0.455	2.2	0.499
Agriculture Department	Bus22	100.00	0.165	-0.393	2.4	0.426
Bus15	Bus16	2.32	0.227	-0.341	1.5	0.409
CMS Loads	Bus16	100.00	0.103	-0.245	2.4	0.266
Bus28	Bus29	2.32	0.790	-9.645	12.2	9.677
CS&IT Department	Bus29	100.00	0.165	-0.393	2.4	0.426
Bus23	Bus24	2.83	0.205	-0.455	2.2	0.499
Mechanical Department	Bus24	100.00	0.247	-0.589	2.4	0.639
*Bus16	Bus22	0.00	1.738	-11.667	6.7	11.796
*Bus29	Bus16	0.00	1.408	-11.081	7.9	11.170
*Bus24	Bus29	0.00	0.453	-1.044	2.3	1.138
*Bus15	Bus1	2.32	-0.195	-0.107	0.6	0.223
*Bus1	Bus21	2.32	0.588	-4.013	6.8	4.056
*Bus21	Bus28	2.32	0.576	-6.658	11..6	6.683
No AC Decrement (NACD) Ratio = 0.13						

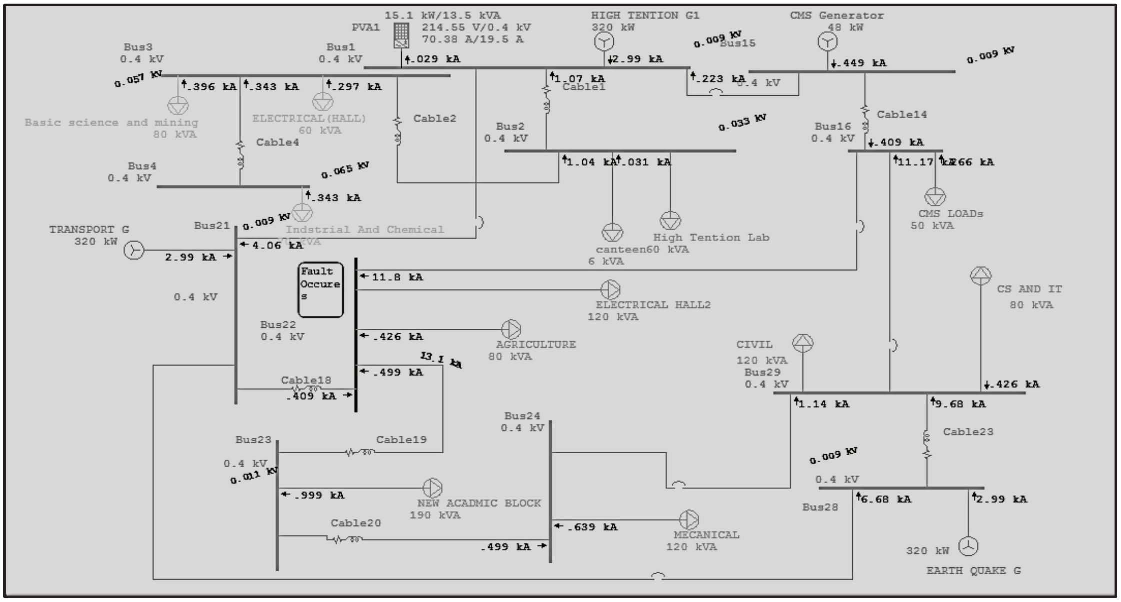

Fig. 4. Short circuit analysis

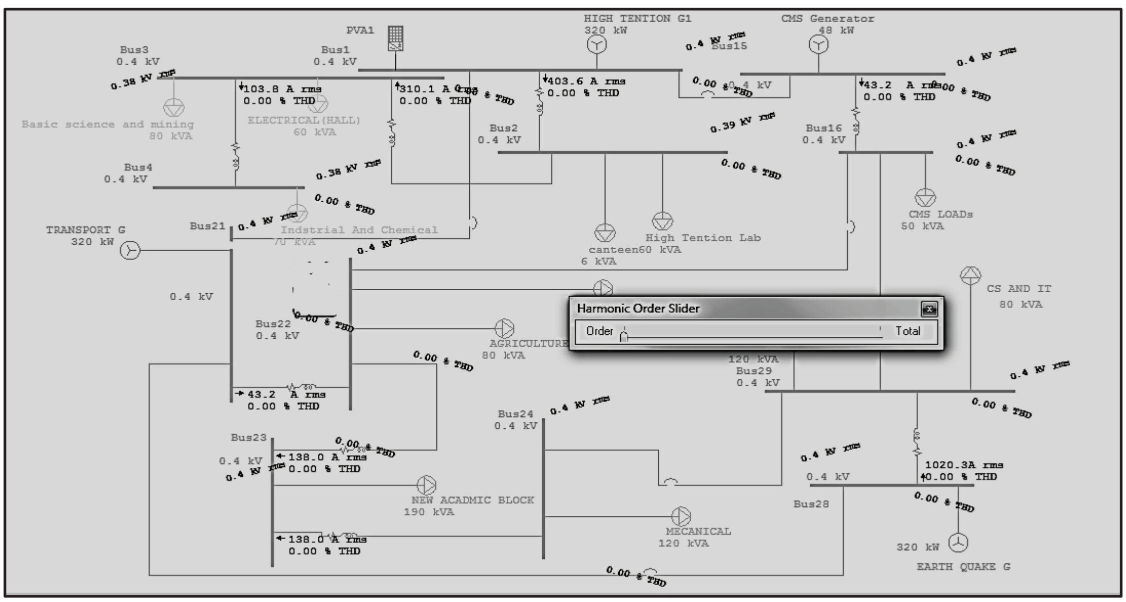

Fig. 5. Harmonic analysis of UET Microgrid

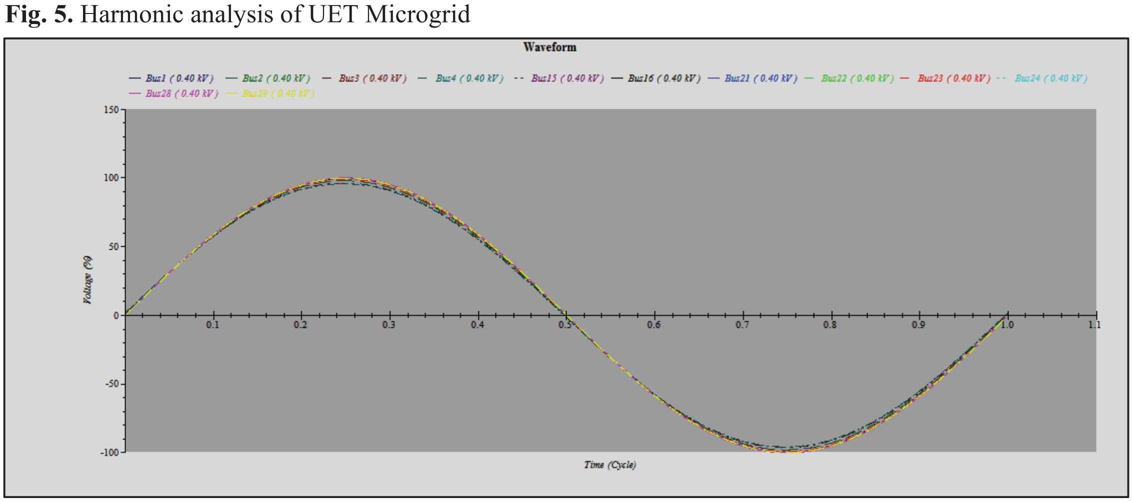

Fig. 6. Bus voltage harmonics waveform

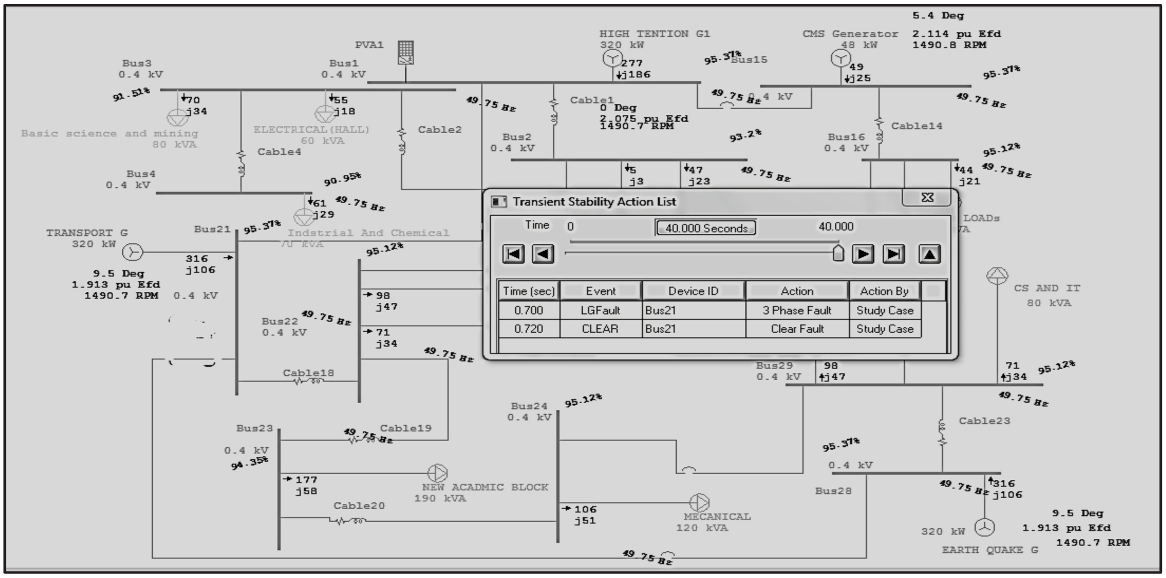

Fig. 7. Transient stability analysis of UET Microgrid

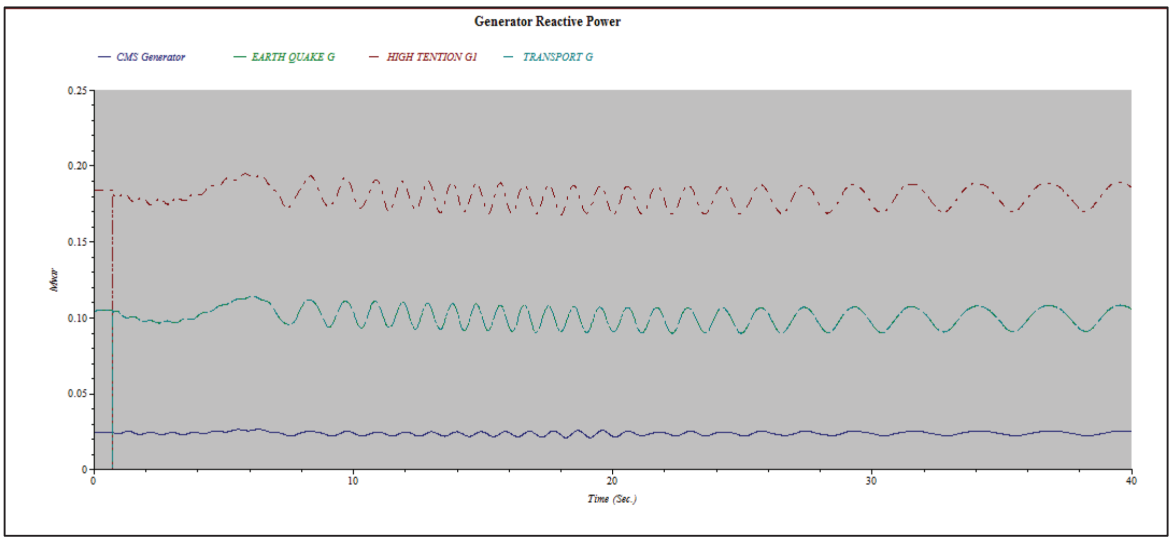

Fig. 8(a). Generator reactive power

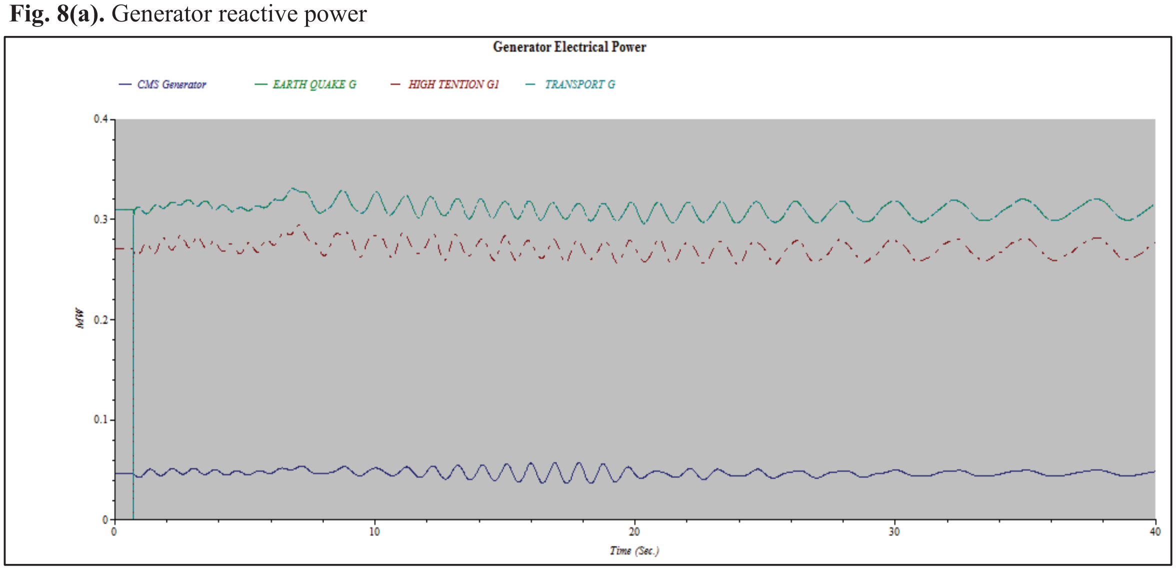

Fig. 8(b). Generator electrical power

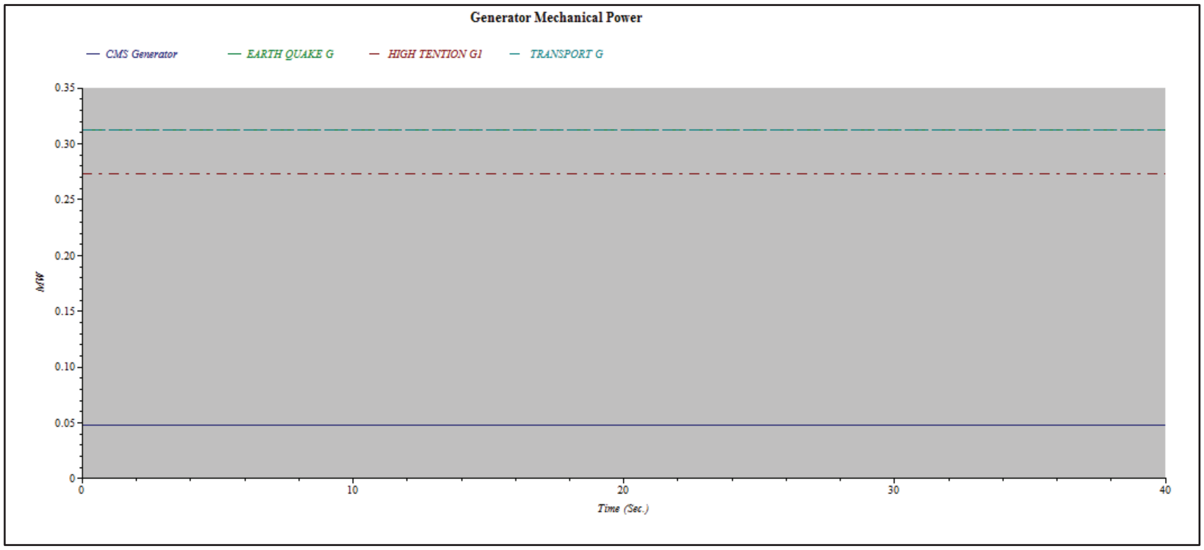

Fig. 8(c). Generator mechanical power

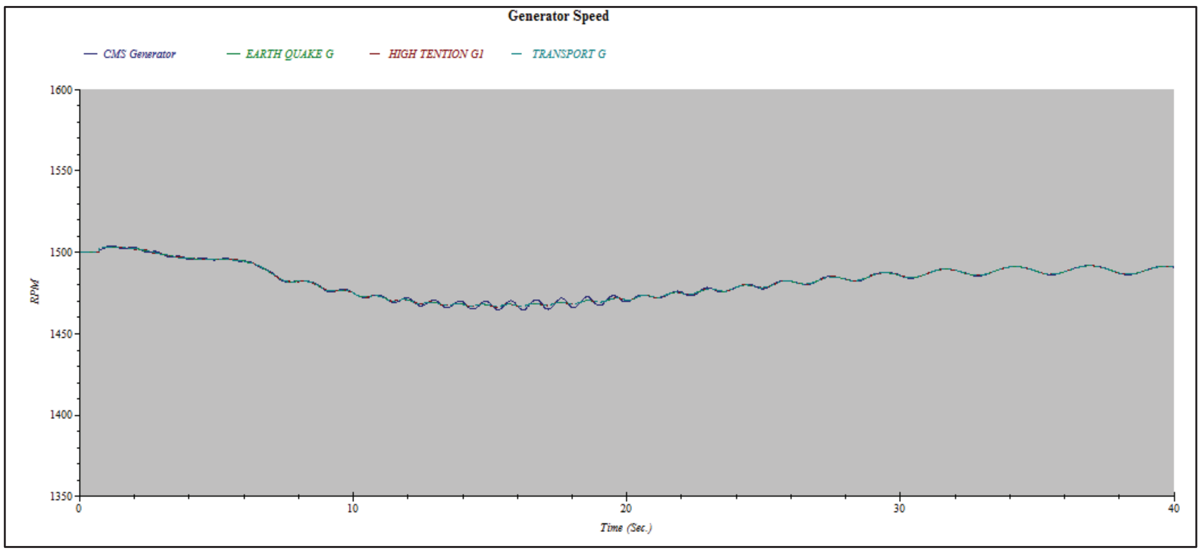

Fig. 8(d). Generator speed

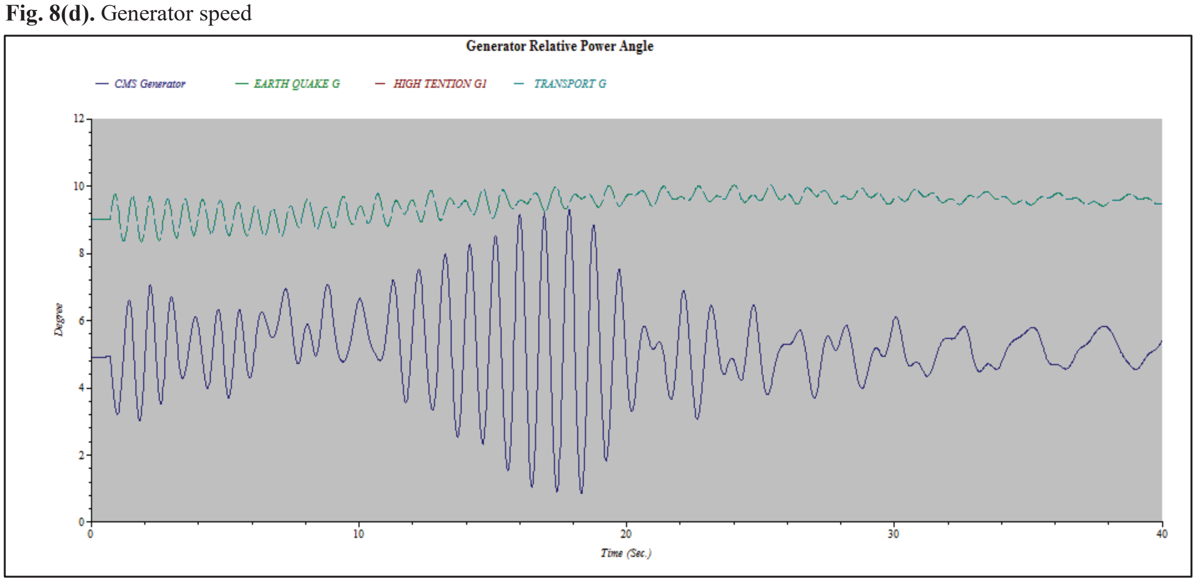

Fig. 8(e). Generator relative power angle

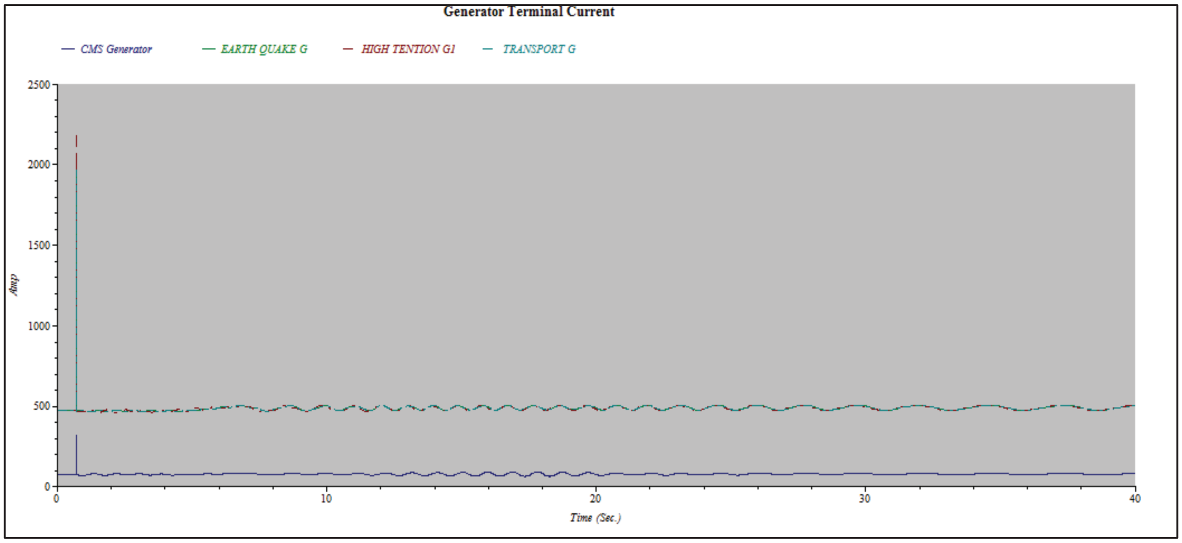

Fig. 8(f). Generator terminal current

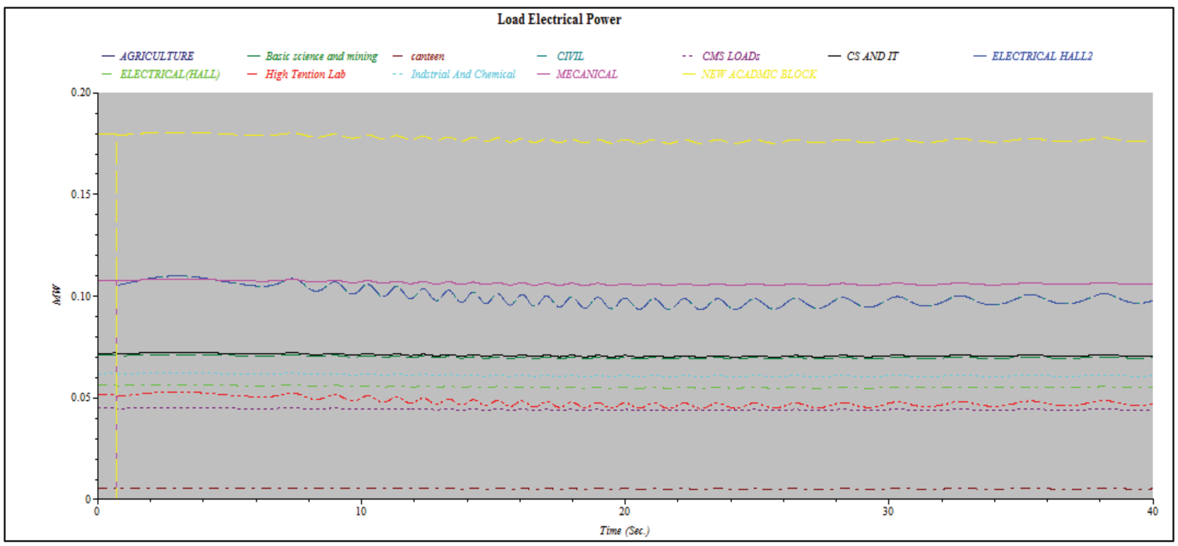

Fig. 9(a). Load electrical power

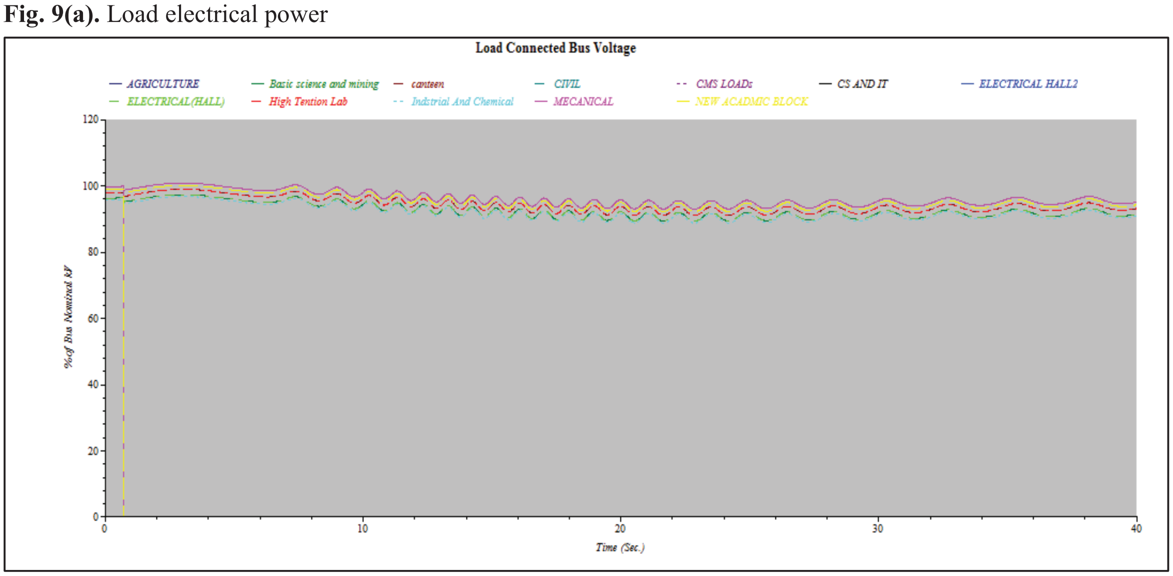

Fig. 9(b). Load connected bus voltage

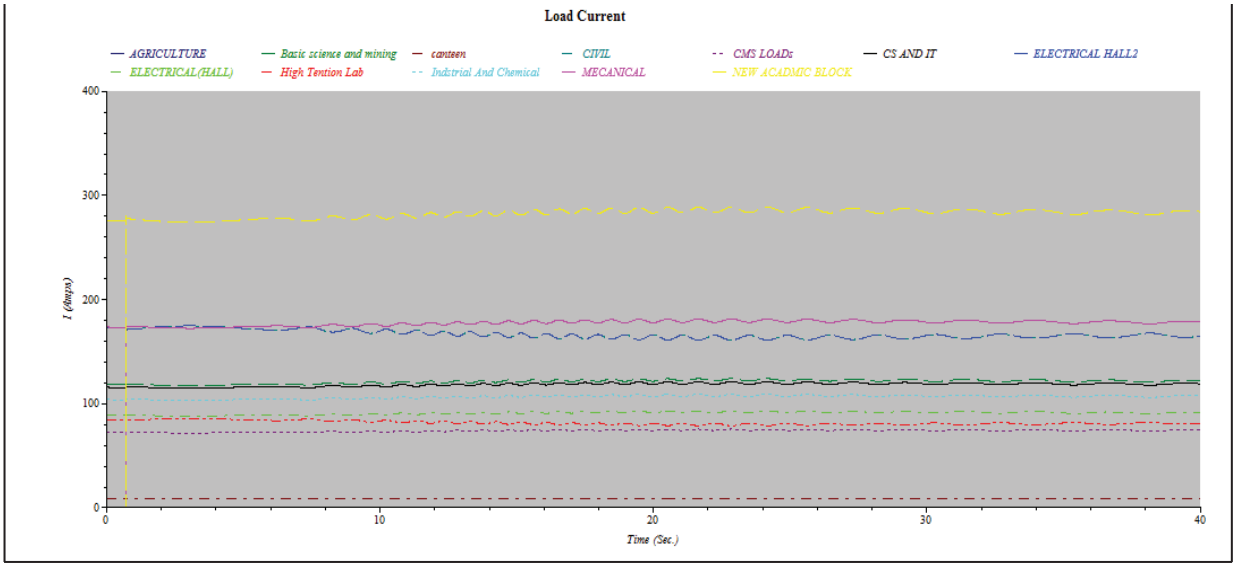

Fig. 9(c). Load current

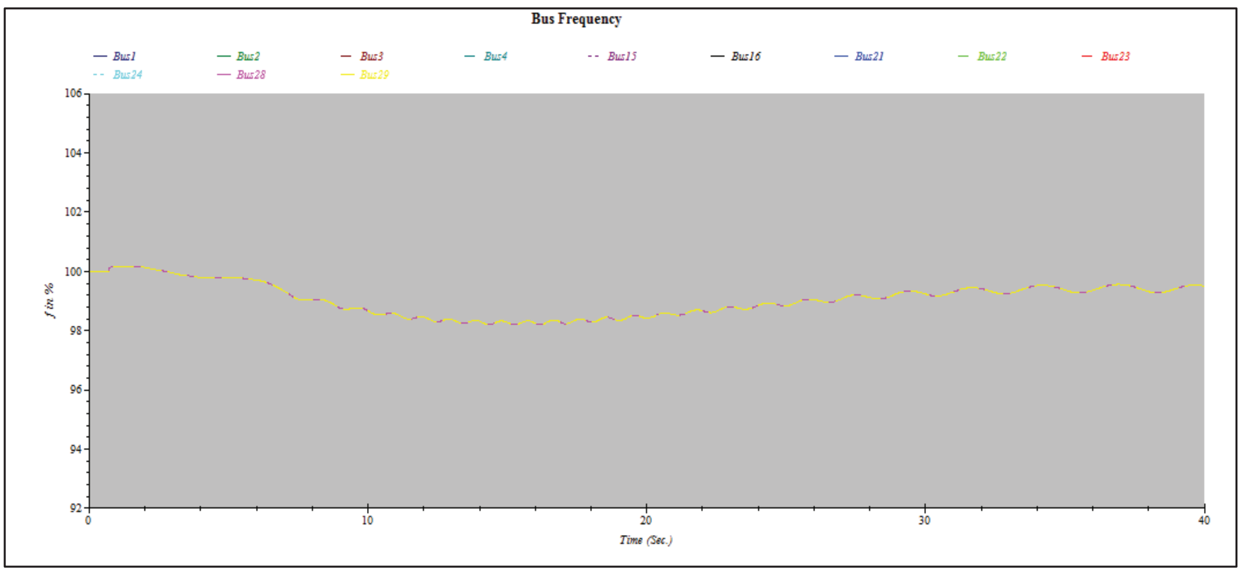

Fig. 10. Stability of the frequency of UET Microgrid

loading, percentage terminal voltage is shown in Table 7 while the total connected load and total generation is shown by Table 8.

3.2 Mode of operation (With Microgrid)

Here, the analysis of the proposed Microgrid is performed when supply from main grid is off. The Microgrid in this state feeds all loads of UET Peshawar campus. Cons equently, one small generator is switched off and other extra load is connected to the main generator while in islanded mode. Two operational modes of our Microgrid with economic benefits are described here.

3.2.1 One generator is switched off

The ability of the main Generator to meet all the demand forces the small generator of 60kVA to shut down. The load flow analysis of UET Peshawar Microgrid without the 60KVA generator is performed and depicted in Figure 12. The percentage generation of generators is shown in Table 9. The percentage loading, percentage terminal voltage is shown in Table 10 and the total connected load and the total generation are shown in Table 11. So in this way, cost of operation of extra generator is removed. The 60 kVA generator will be available for meeting the peak load or any eventuality in the islanded mode. Diesel consume by 60KVA generator per hour when it is running at full load i.e. generating 48KWh is 13.5 litre/hr. So,

If one litre diesel price = Rs 100 Rupees
For 13.5 litre diesel price = Rs 1350 Rupees
One Unit or KWh price = Rs 28.125 Rupees
If the generator is running for three hours in a day, then total cost saving per day = Rs 4050 Rupees
Total cost saving for one month = Rs 121500 Rupees
Total cost saving in one year = Rs 1458000 Rupees

3.2.2 Addition of load to the Microgrid

As the High Tension lab generator shown in Figure 10 is generating at 48% so it's mean that additional load can be connected to the Microgrid. In this way the extra load of 160 kVA can be feed by the UET Peshawar Microgrid. The load flow analysis when the extra load is connected to UET Peshawar Microgrid is shown in Figure 13.

Moreover, balanced load of nearby houses is also connected to the generator. The percentage generation of generators is given in Table 12. The percentage loading, percentage terminal voltage as shown in Table 13 while the total connected load and the total generation is shown in Table 14.

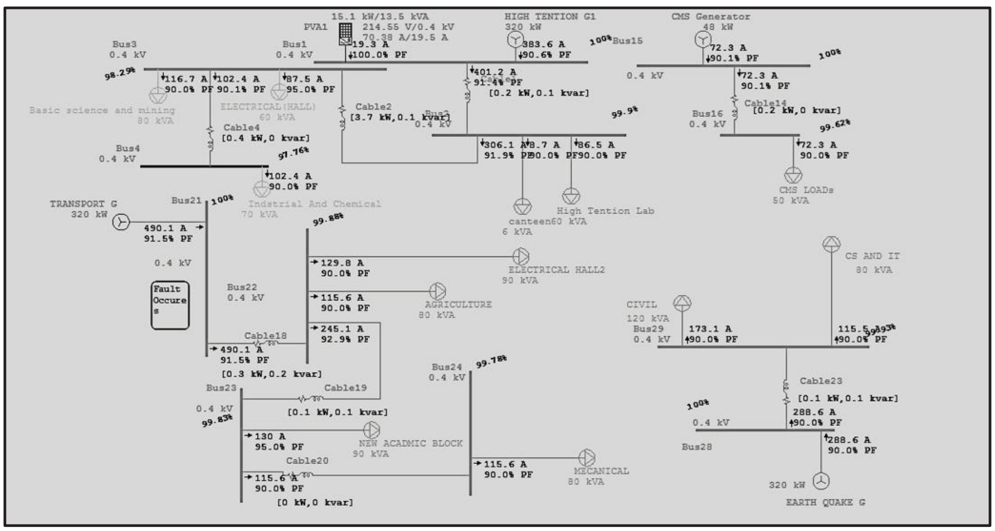

Fig. 11. Without Microgrid state

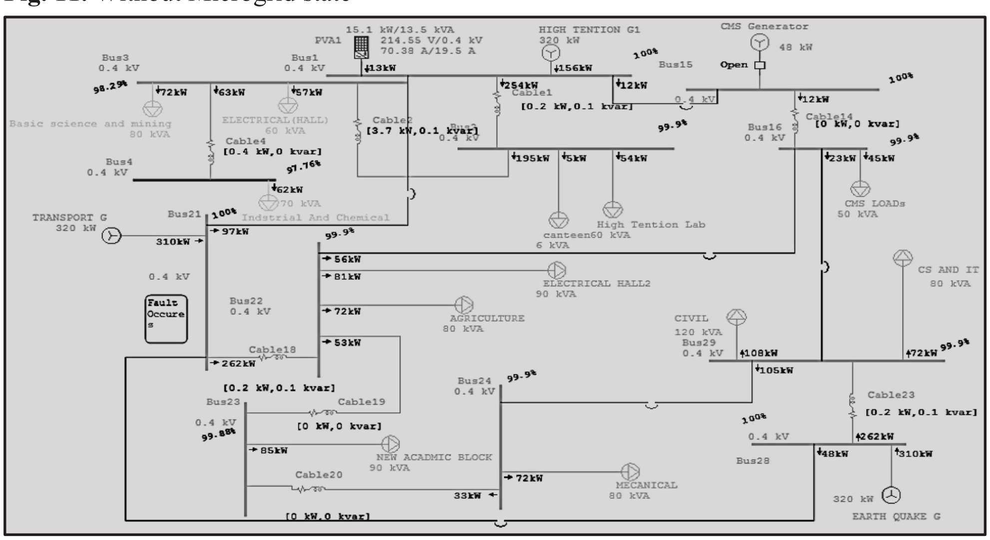

Fig. 12. Load flow analysis without the 60KVA generator

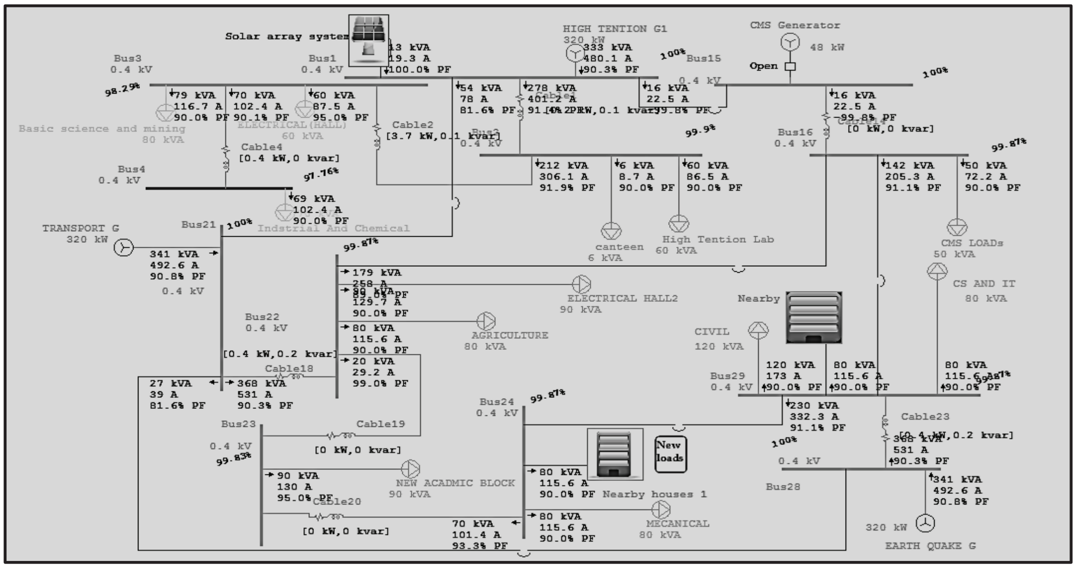

Fig. 13. Load flow analysis when the extra load is connected

Table 6. Generators percentage generation

Generator ID	Rating (kW)	Rated (kV)	kW	kvar	Amp	%PF	% Generation
CMS Generator	48	0.4	45.138	21.469	72.33	90.07	94
Earth Quake G	320	0.4	180	87.168	288.6	90	56.2
High Tension G1	320	0.4	241	112	383.6	90.6	75.2
Transport G	320	0.4	311	137	490.1	91.48	97.1

Table 7. Percentage loading, percentage terminal voltage

Load ID	Rating (kVA)	Rated (kV)	kW	kvar	Amp	%PF	% Loading	% V(terminal)
Agriculture Department	80	0.4	71.966	34.855	115.6	90	100.1	99.88
Basic Sciences Department	80	0.4	71.511	34.634	116.7	90	101.1	98.29
Canteen	6	0.4	5.398	2.614	8.665	90	100.1	99.9
Civil Department	120	0.4	108	52.235	173.1	90	99.9	99.93
CMS Loads	50	0.4	44.933	21.762	72.33	90	100.2	99.62
CS&IT Department	80	0.4	71.98	34.862	115.5	90	100	99.93
Electrical Department Hall 1	90	0.4	80.811	39.139	129.8	90	99.9	99.88
Electrical Department Hall 2	60	0.4	56.613	18.608	87.51	95	101.1	98.29
High Tension Laboratory	60	0.4	53.897	26.103	86.52	90	99.9	99.9
Industrial & Chemical Departments	70	0.4	62.441	30.241	102.4	90	101.4	97.76
Mechanical Department	80	0.4	71.936	34.84	115.6	90	100.1	99.78
New Academic Block	90	0.4	85.44	28.083	130	95	100.1	99.83

Table 8. Total connected load and total generation

Buses	12
Branches	8
Generators	4
Power Grids	0
Loads	12
Load-MW	0.79
Load-Mvar	0.359
Generation-MW	0.79
Generation-Mvar	0.359
Loss-MW	0.005
Loss-Mvar	0.001

Table 9. Generators percentage generation

Generator ID	Rating (kW)	Rated (kV)	kW	kvar	Amp	%PF	% Generation
Earth Quake G	320	0.4	310	120	479.6	93.3	96.9
High Tension G1	320	0.4	156	120	284	79.43	48.8
Transport G	320	0.4	310	120	479.6	93.3	96.9

Table 10. Percentage loading, percentage terminal voltage

Load ID	Rating (kVA)	Rated (kV)	kW	kvar	Amp	%PF	% Loading	% V(terminal)
Agriculture Department	80	0.4	71.971	34.857	115.5	90	100.1	99.9
Basic Sciences Department	80	0.4	71.511	34.634	116.7	90	101.1	98.29
Canteen	6	0.4	5.398	2.614	8.665	90	100.1	99.9
Civil Department	120	0.4	108	52.203	173	90	99.9	99.9
CMS Loads	50	0.4	44.982	21.786	72.21	90	100.1	99.9
CS&IT Department	80	0.4	71.971	34.857	115.5	90	100.1	99.9
Electrical Department Hall 1	90	0.4	80.839	39.152	129.8	90	99.9	99.9
Electrical Department Hall 2	60	0.4	56.613	18.608	87.51	95	101.1	98.29
High Tension Laboratory	60	0.4	53.897	26.103	86.52	90	99.9	99.9
Industrial & Chemical Departments	70	0.4	62.441	30.241	102.4	90	101.4	97.76
Mechanical Department	80	0.4	71.971	34.857	115.5	90	100.1	99.9
New Academic Block	90	0.4	85.459	28.089	130	95	100.1	99.88

Table 11. Total connected load and total generation

Load-MW	0.79
Load-Mvar	0.359
Generation-MW	0.79
Generation-Mvar	0.359
Loss-MW	0.005
Loss-Mvar	0.001

Table 12. Generators percentage generation

Generator ID	Rating (kW)	Rated (kV)	kW	kvar	Amp	%PF	% Generation
Earth Quake G	320	0.4	310	143	492.6	90.83	96.9
High Tension G1	320	0.4	300	143	480.1	90.31	93.9
Transport G	320	0.4	310	143	492.6	90.83	96.9

Table 13. Percentage loading, percentage terminal voltage

Load ID	Rating (kVA)	Rated (kV)	kW	kvar	Amp	%PF	% Loading	% V(terminal)
Agriculture Department	80	0.4	71.963	34.854	115.6	90	100.1	99.87
Basic Sciences Department	80	0.4	71.511	34.634	116.7	90	101.1	98.29
Canteen	6	0.4	5.398	2.614	8.665	90	100.1	99.9
Civil Department	120	0.4	108	52.174	173	90	99.9	99.87
CMS Loads	50	0.4	44.977	21.783	72.22	90	100.1	99.87
CS&IT Department	80	0.4	71.963	34.854	115.6	90	100.1	99.87
Electrical Department Hall 1	90	0.4	80.795	39.131	129.7	90	99.9	99.87
Electrical Department Hall 2	60	0.4	56.613	18.608	87.51	95	101.1	98.29
High Tension Laboratory	60	0.4	53.897	26.103	86.52	90	99.9	99.9
Industrial & Chemical Departments	70	0.4	62.441	30.241	102.4	90	101.4	97.76
Mechanical Department	80	0.4	71.963	34.854	115.6	90	100.1	99.87
Nearby Houses	80	0.4	71.963	34.854	115.6	90	100.1	99.87
Nearby Houses 2	80	0.4	71.963	34.854	115.6	90	100.1	99.87
New Academic Block	90	0.4	85.443	28.084	130	95	100.1	99.83

Table 14. Total connected load and total generation

Load-MW	0.934
Load-Mvar	0.428
Generation-MW	0.934
Generation-Mvar	0.428
Loss-MW	0.005
Loss-Mvar	0.001

4. DISCUSSION & CONCLUSION

From the preceding analysis, a Microgrid is proposed for our local campus of UET, Peshawar while in islanding mode when power is not available due to load shedding or faults occurring in the distribution system. As per our backup resources, three diesel generators with solar system can be interconnected to form such a proposed Microgrid for UET Peshawar. The load flow analysis, short circuit analysis, total harmonic analysis, transient stability analysis of our proposed Microgrid are shown in this paper and are carried out using the ETAP simulation software. The results vividly show that a reduction in number of engaged diesel generating units on campus that normally operate in parallel greatly reduces the per annum cost paid by the University. It is also shown in this paper that by implementing the proposed Microgrid, the optimum units will dispatch power to the load in an effective way without overloading the operating units.

This will greatly decrease the cost of operating an extra diesel generator at full capacity. Thus, the efficiency of the system will increase and this arrangement will also be eco-friendly due to reduction in diesel related carbon emissions. Furthermore, this proposed arrangement with added features such as precision smart switches can be implemented for further efficiency improvement in future. Finally, it is concluded that a smart Microgrid such as proposed in this paper is an efficient and cost effective way of running on campus power generating resources while in islanding mode.

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