Analyses and Monitoring of 132 kV Grid using ETAP Software

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Abstract

Power System study and analyses are important parts of power system engineering. This innovative concept deals with a 132 kV Grid simulation in Electrical Transient Analyzer Program (ETAP). Existing power distribution system in Pakistan consists of approximately 6000 11 kV feeders, which are mainly analyzed by software FDR-ANA (Feeder Analyses). This software does not have capability to provide comprehensive analyses for integrated power system which is essential. This research paper focused on the detailed analyses and monitoring by using the most modern software ETAP, which performs numerical calculations of large integrated power system with fabulous speed besides, generating output reports. In a developing country like Pakistan it is first time that Off-line monitoring is made which includes current flowing in every branch, power factor, active and reactive power flow, harmonic distortion etc. of large power system. Based upon the recorded data obtained from an actual 132 kV grid which has been implemented in ETAP for Off-line monitoring and analyses.

1. Introduction

For the last few years electrical engineers have been focusing on the power system studies using software tools. Recent advances in engineering sciences have brought a revolution in the field of electrical engineering after the development of powerful computer based software. This research work high-lights the effective use of Electrical Transient Analyzer Program (ETAP) software for analyses and monitoring of large electrical power system which comprises of large power distribution network emanating from 132 kV Grid [1-3].

Pakistan Electric Power Company (PEPCO) has been experiencing severe power shortage for last many years. Resultantly, the country is facing repeated and astonishing black outs. Despite the shortage of electricity, one of the main reasons of this energy crisis is deficiency in the field of analyses and monitoring of electrical power network. Keeping in view the above scenario, Rachna College of Engineering & Technology (RCET) Pk, has analyzed the complete 132 kV Grid network which contain 11 kV feeders and rest of distribution network. This 132 kV Grid is situated at the hub of Pakistan's thickly populated city Gujranwala where different analyses like load flow, harmonic load flow, motor starting are performed in ETAP based upon practical data and complete off-line monitoring are also made to predict the actual effects of load on the entire power system.

The data used for analyses purpose is in the form of one line diagram of complete power system network starting from Power transformer at Grid up till the load. The rating of power/distribution transformers are taken as they actually exist. Moreover, the conductors/cables, circuit breakers, CT's, PT's, and rest of power system elements are also modelled according to their actual ratings in ETAP.

This 132 kV Grid located in Gujranwala Electrical Power Company (GEPCO) region, having 6 power transformers, 32 feeders, 48 circuit breakers, 42 current transformers, 8 potential transformers and 2 incoming lines. Practical power system under study is a very antique grid which is formed in 1952 and a centralized grid which feeds power supply to the other grids in this region, all the analyses and monitoring are concentrated on this grid [4].

This paper represents a novel approach to analyze the power system network by using ETAP with the help of one line diagram. This diagram is implemented in ETAP to perform load flow study, harmonic load flow and motor starting studies. 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. During the motor starting period, the motor appears to the system as small impedance connected to a bus as it draws a large current from the system (about ten times the motor rated current), which, therefore, results in voltage drops in the system and possess disturbances to the normal operation of other system are revealed respectively during analyses of the power system [5].

Section 2 is the complete single line diagram of the system under consideration; this diagram is implemented based upon practical data in ETAP for simulation purpose in Section 3. Section 4 and 5 are Feeder and Load Modelling in ETAP respectively. Section 6 contains analyses which include load flow, harmonic and motor starting. Section 7 deals with monitoring of this large power system. Section 8 is the Conclusion of this research work.

2. Single line diagram of case under study

Fig. 1 shows the single line diagram of the complete power system which is under study. It is clear from the Fig. 1 that there are two incoming lines of 132 kV supplying power to six power transformers of different ratings at 132 kV grid station, and these power transformers are connected with 11 kV power distribution network (11 kV feeders).

The load connected with the system is industrial load, offices load, plazas, shops and domestic load. The load can also 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 modelling is performed in ETAP based upon original system data.

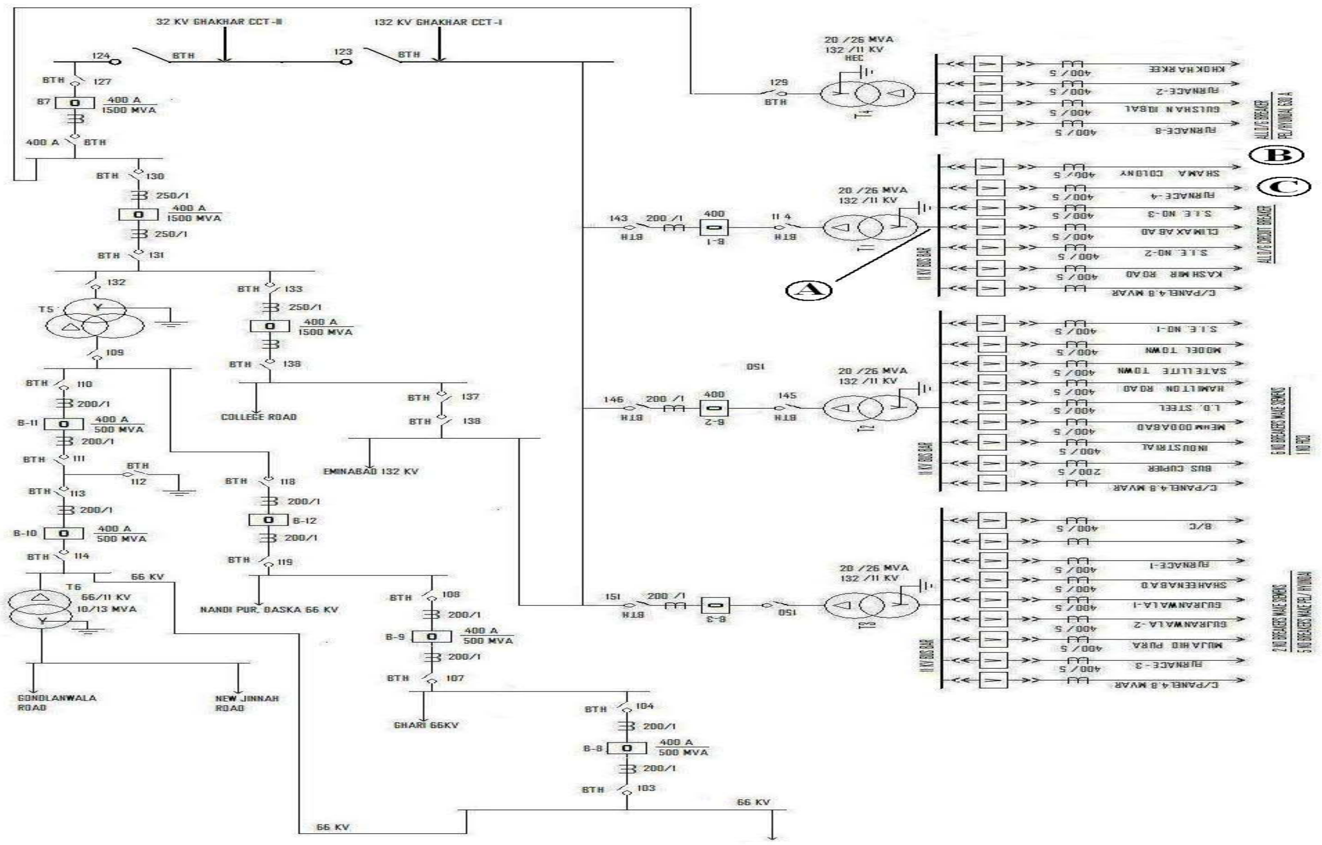

Fig. 1. Single line diagram of 132 kV Grid

Monitoring Points are also marked on the same single line diagram. Point A is taken at secondary of power transformer, point B is taken at primary distribution side (i.e. 11 kV feeder) and point C is taken on a feeder where furnace load is connected (common point of three furnaces). This large system is sub divided into sections according to their load behavior for analyses and monitoring purpose.

3. Simulation of System in ETAP

Fig. 1 shows two 132 kV incoming lines from 220 kV Grid and six power transformers. The same system is simulated in ETAP as shown in Fig. 2.

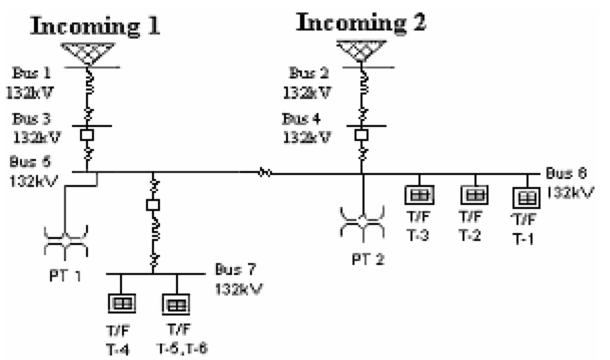

Fig. 2. Simulated diagram of 132kV Grid using ETAP

4. Feeder Modelling in ETAP

For simplicity of analyses and lack of space available, only one power transformer named T1 has been selected for simulation purpose. Feeders during simulation are divided into two different categories, one for furnace load and other for usual distributed load which may include static, inductive, dynamic and dc load etc.

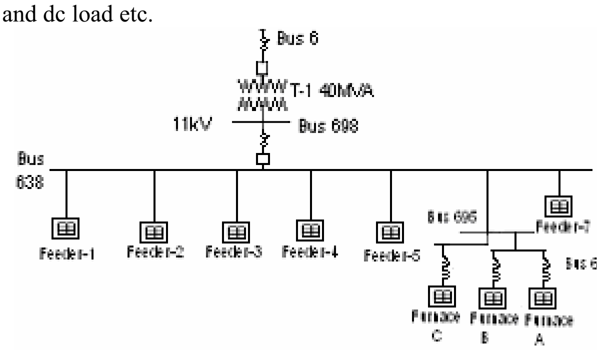

Fig. 3. Simulated diagram of Power Transformer T1

Fig. 3 shows that 7 Feeders are emanating from power transformer T1. Three furnaces are being supplied from feeder 6 resulting in significant generation of harmonics being large non-linear load.

The simulated network for general purpose feeder (domestic and some small industry) is shown in Fig. 4.

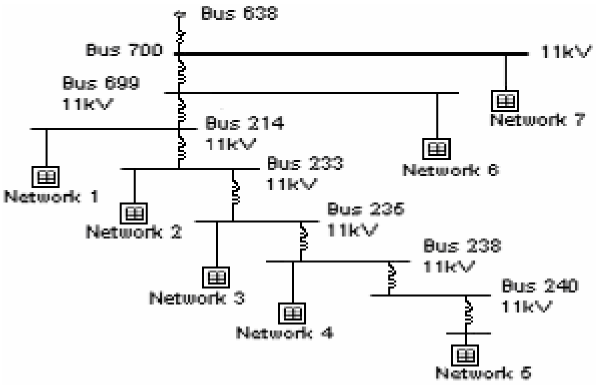

Fig. 4. Distributed Network in ETAP for general purpose feeder

5. Load Modelling in ETAP

Keeping in view the on ground reality, load modelling is performed by considering 70 % static and dynamic load in addition to 30 % dc load. Fig. 5 shows the simulated model of load connected with 200 kVA distribution transformer.

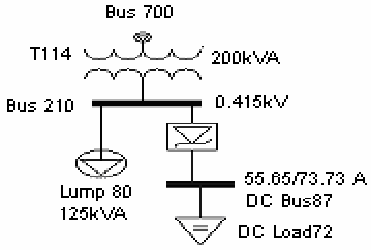

Fig. 5. Load modelling for 200 kVA distribution transformer

For furnace load modelling, ETAP provides the provision for exact modelling of such large electronic load in which rectification and inversion phenomenons are involved. Fig. 6 shows one of the three furnaces connected to the feeder which is implemented in ETAP.

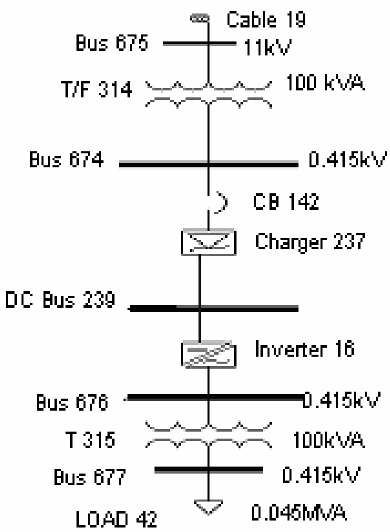

Fig. 6. Load modelling for furnace load

All the three furnaces are of different ratings, Furnace-1 which takes a load of 62.2 A from the system similarly Furnace-2 and Furnace-3 take loads of 161.2 A and 136.5 A respectively [6, 7].

6. Analyses of the System using ETAP

6.1. Load Flow Analysis

Load flow studies have been performed at various monitoring points using ETAP, in which Newton–Raphson (NR) method is used. Consequent results are given in Table 1 and Table 2 accordingly.

Table 1. Load flow results

Monitoring Points	kV	MW	MVAR	% PF
Grid (Bus 3)	132	36.68	23.10	84.6
A	11	5.520	3.793	83.1
B	11	0.379	0.253	83.0
C	11	0.717	0.471	83.6

Table. 2 clearly shows that real power on swing buses is 42.09MW while reactive power is 26.70Mvar. Power factor is 84 % which is less than the standard set by the utility i.e. 92 %.

Table 2. Summary report of total demand and losses

Points for Discussion	MW	Mvar	MVA	% PF
Swing Bus	16.789	11.970	20.619	81.4 (lag)
Total Demand	16.789	11.970	20.619	81.4 (lag)
Total Motor Load	15.413	7.068	16.956	90.9 (lag)
Total Static Load	0.555	0.393		
Apparent Losses	0.821	4.510		

6.1.1. ETAP Alerts during Load Flow Analysis

Table 3. ETAP Alerts during Load Flow Results

Device ID	Rating	Calculated	% Value	Condition
Bus 210	0.415 kV	0.314 kV	73.2	Under Voltage
Bus 675	11 kV	10.531 kV	96	Under Voltage
Bus 674	0.415 kV	0.387 kV	93.2	Under Voltage
Bus 700	11 kV	10.615 kV	96.5	Under Voltage
Bus 238	11 kV	11 kV	10.604	Under Voltage
Bus 239	0.415 kV	0.391 kV	94.1	Under Voltage
Bus 698	11 kV	10.671 kV	97	Under Voltage
Bus 638	11 kV	10.623 kV	96.6	Under Voltage
Bus 695	11 kV	10.558 kV	96	Under Voltage

While performing load flow analysis ETAP provides various alerts which need immediate attention for smooth running of the system, their detail is given in Table 3.

6.2. Harmonic Analysis

After performing harmonic analysis on the entire power system under consideration in ETAP, the obtained information includes Total Harmonic Distortion in voltage (% THDv) and Total Harmonic Distortion in current (% THDi). Table 4 shows the different results which are monitored after harmonic studies on different monitoring points. % THDv standard set by IEEE is 5% which is violated.

Table 4. % THDv & % THDi at monitoring points

Monitoring Points	% THDv	%THDi
A	2.13	3.41
B	3.0	2.25
C	13.1	15

The current waveform and its harmonic spectrum captured at the monitoring point A are shown in Fig. 7 and Fig. 8 respectively.

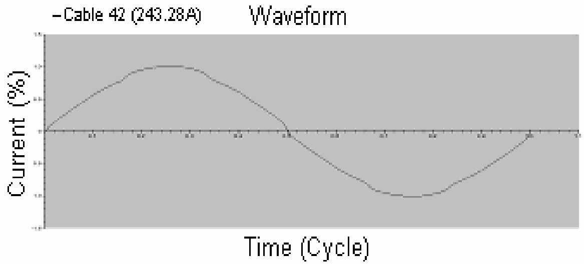

Fig. 7. Current Waveform at point A

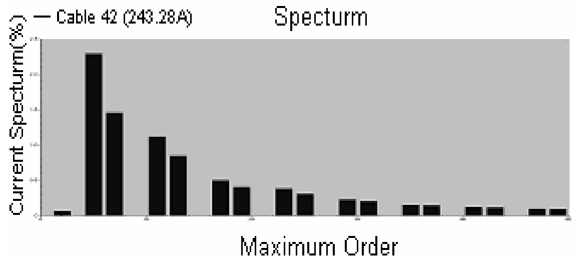

Fig. 8. Current Spectrum at point A

Similarly, the current waveform and harmonic spectrum captured at point B are shown in Fig. 9 and Fig. 10 respectively.

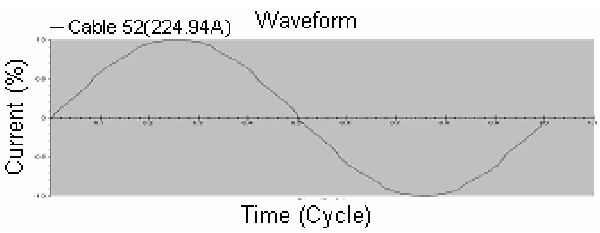

Fig. 9. Current Waveform at point B

Fig. 10. Current Spectrum at point B

Fig. 11 and Fig. 12 are the current waveform and its harmonic spectrum at point C which is more distorted as compared to points A and B. The reason behind this distorted pattern is significant presence of 5^{th}, 7^{th}, 11^{th} and 13^{th} etc. harmonic contents in the current waveform drawn by the furnace load.

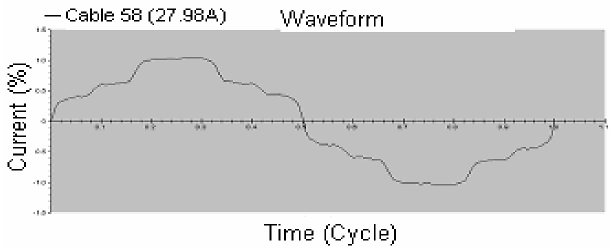

Fig. 11. Current Waveform at point C

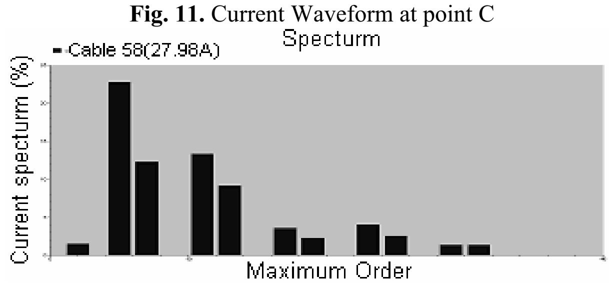

Fig. 12. Current Spectrum at point C

6.3. Motor Starting Analysis

Motor starting analysis is performed on Induction motor and different effects like % slip, starting current, starting torque, terminal voltage, bus voltage and accelerated torque on the power system under study are recorded during the starting of the motor. Fig. 13 shows the single line representation of induction motor when simulated in ETAP for motor starting analysis.

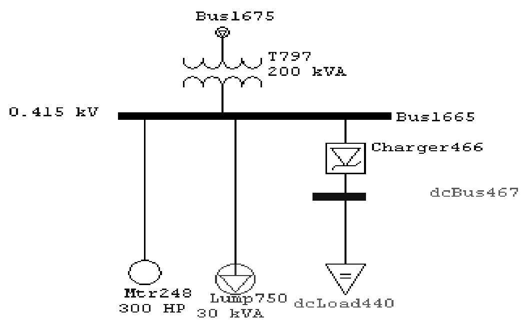

Fig. 13. Simulated model for Motor starting study

Detail of Induction motors used for simulation are given in the Table 5.

Table 5. Different Induction motors used for simulation

Motor ID	HP	kV	RPM	%PF	% EFF	FLA
Mtr17	1000	0.415	1500	92.4	93.6	1200
Mtr133	200	0.415	1500	91.7	92.8	243.9
Mtr132	400	0.415	1500	92.0	93.1	484.4
Mtr131	300	0.415	1500	91.9	93.1	363.4
Mtr134	150	0.415	1500	91.6	92.6	183.5

The graphical results of motor starting analysis for bus voltage, current drawn, reactive power, real power demand, % slip, terminal voltage and % torque are shown in Fig.'s 14, 15, 16, 17, 18, 19 and 20 respectively which are self explanatory.

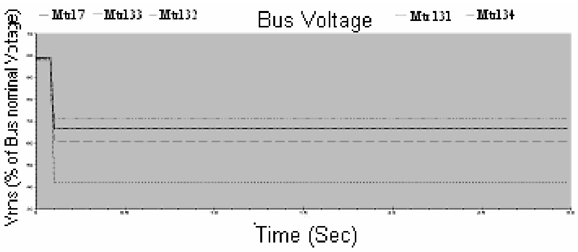

Fig. 14. Different Motors Bus voltage

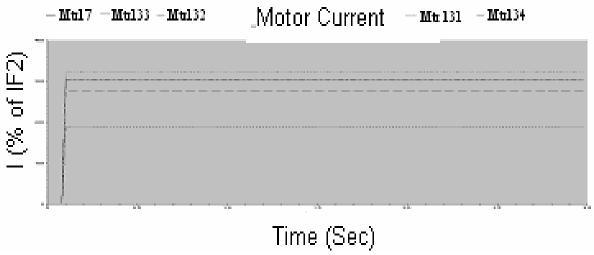

Fig. 15. Different Motors Current

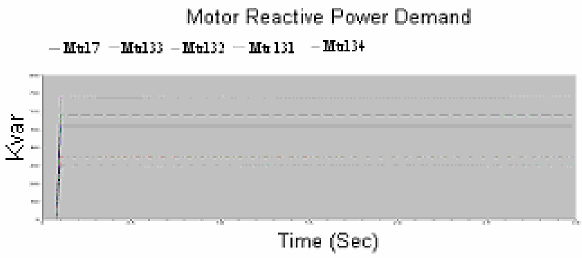

Fig. 16. Different Motors Reactive Power Demand

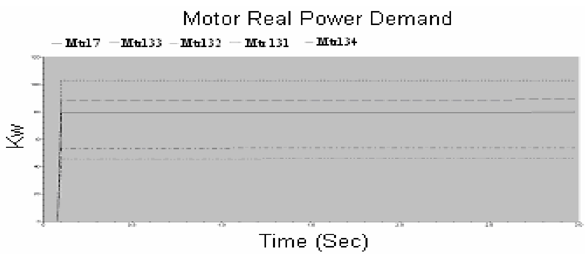

Fig. 17. Different Motors Real Power Demand

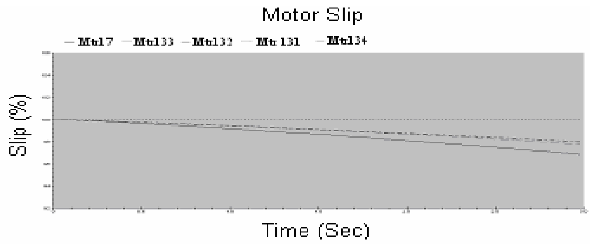

Fig. 18. Different Motors % Slip

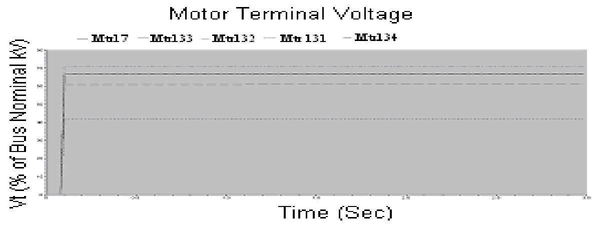

Fig. 19. Different Motors Terminal Voltage

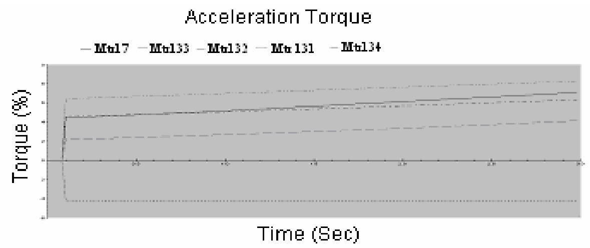

Fig. 20. Different Motors % Torque

These are different characteristics which are observed on the power system during motor starting analysis.

7. Monitoring of the System under Study

7.1. Over Loaded Transformers

Loading wise power system under study was normal (not over loaded) but it is interesting due to involvement of large electronic load (i.e. furnace) another loss is involved in the system which is known as distortion power loss due to which system becomes over loaded in some branches, these over loaded transformers are indicated in Table 6. (Note: due to lack of space available here only few transformers are listed).

Table 6. Some over loaded Transformers in the system

T/F ID	Capability (MVA)	Loading (input) MVA	Loading (input) %	Loading (output) MVA	Loading (output) %
T114	0.200	1.251	625.3	0.952	476.2
T797	0.200	0.352	175.8	0.330	165.12
T122	0.200	0.452	225.9	0.416	208.231
T605	0.200	0.328	164.1	0.310	154.9
T618	0.200	0.352	175.8	0.330	165.1
T803	0.200	0.452	225.9	0.416	208.3
T807	0.200	1.195	597.3	0.926	462.3
T809	0.2000	0.352	175.8	0.330	165.3

7.2. Voltage Drop

Table 7 shows the % voltage drop in different distribution transformers. Voltage drop standard set by utility is 5 % which is significantly violated here.

Table 7. % Voltage Drop in few sections/branches

CKT/Branch ID	% Bus Voltage from	% Bus Voltage to	%Voltage drop (Mag.)
T114	73.7	96.8	23.08
T624	89.1	96.12	7.58
T625	90.4	96.2	6.27
T628	75	96.7	21.77
T797	90.8	96.7	5.89
T803	89.1	96.12	7.58
T804	90.4	96.2	6.27
T807	75	96.7	21.77
T819	75	96.7	21.77
T821	90.7	96.8	5.88
T831	75	96.7	21.77
T833	90.7	96.8	5.88
T839	89.1	96.12	7.58

7.3. Technical Losses (I^2R Losses)

Technical losses calculated while performing simulation are given in Table 8 at few branches.

Table 8. Losses in KW & KVAR in few sections/branches

CKT/Branch ID	Losses KW	Losses KVAR
T114	83.6	426.3
T624	10.9	55.7
T625	6.7	19.5
T628	76.2	388.7
T797	6.6	33.7
T803	10.9	55.7
T807	76.2	388.7
T819	76.2	388.7
T821	6.6	33.7
T831	76.2	388.7
T833	6.6	33.7
T839	10.9	55.7

Table 8 shows the losses in KW and KVAR at different distribution transformers, but as system under study is a very large system so it is not possible to mention losses at all the transformers, buses, transmission lines and cables. But it is recorded that the total losses in KW and KVAR at all the distribution networks is 820.7 kW and 4509.2 KVAR respectively.

8. Conclusions

Simulation of large electrical power system performed in this research paper for monitoring and analyses purpose has opene 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.

9. References

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