Symmetrical and Asymmetrical Fault Currents: Evaluation to Enhance the Performance of 220KV Grid Station

M. J. Tahir[1,2], I. A. Latiff[1], M. U. Gul[2], M. Alam[3,4], M. S. Mazliham[5]
[1]*Universiti Kuala Lumpur-BMI, Batu 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia*
[2]*The University of Lahore,1km Raiwind Road 53700 Lahore, Punjab, Pakistan*
[3]*Institute of Business and Management (IoBM), Korangi Creek, 74900 Karachi, Pakistan*
[4]*Universiti Kuala Lumpur, IPS, 1016, Jalan Sultan Ismail, 50250 Kuala Lumpur, Malaysia*
[5]*Universiti Kuala Lumpur, Malaysia France Institute(MFI), Jalan Teras Jernang,*
43650 Bandar Baru Bangi, Selangor, Malaysia
muhammad.junaid@s.unikl.edu.my

***Abstract*— The studies of the electrical system need to assess the output of the power system at development phase as well as daily situations. This paper presents fault current study of a 220KV grid station at the standard of IEC 60909 and IEC 61363. In order to support the power system, fault current study can be done at design & development phase to conclude the system design, determine voltage magnitude, shielding apparatus, circuit breakers, conductor length, step up and step-down power equipment and solid grounding. A grid station is simulated using real system facts and Figures in the ETAP software and fault current analysis is executed at different voltage levels. With the help of results achieved from the simulations, it is likely to assess the dynamic pressure yield to the equipment of the power system in the existence of faults. However, evaluation of installed apparatus in the situation of power system enhancement that can significantly influence the fault current level. The study shows the significance of the symmetrical and asymmetrical fault currents investigation for the description of the apparatus rating, which must upkeep these currents.**

***Index Terms*—Fault Current Study; ETAP; IEC 60909; IEC 61363.**

I. INTRODUCTION

The grid station studies predominantly lie on the methods used for size and selection of apparatus and enhance /estimate the outcome of a standing or proposed power system under the stated situations. As compare to other essential power network topics, Short Circuit (SC) topics are the most important as compared to other fundamental power system studies [1]. Third world countries are facing severe energy crisis due to which forced load shedding is done on the substation side. Due to this rapid switching process, instruments are losing their strength with the passage of time. On the other side, electricity demand is increasing day by day, so it is the time to change the old equipment rating into a new equipment rating of the substation. This can only be done by offline grid Short Circuit analysis compliance to International Electrotechnical Commission (IEC)-60909 and (IEC)-61363.

In Short Circuits, the system contains large magnitude of currents which are too much higher than load currents. For short circuit analysis of electrical grid, it can broadly classify as [2]:

- Three phase Short Circuit or Symmetric fault
- Asymmetrical fault

The consequences of these Short Circuit current study depend upon the type and duration of fault which determines various characteristics of Short Circuit, three-phase, line-to-line, line-to-line-to-neutral and line-to-neutral. All major sources of fault currents should be represented in Short Circuit calculation model. The key fault current sources are lumped load (both Static load and motor load) and utility/grid supply.

In this paper, the short circuit response of the 220KV grid station has been analyzed for various fault conditions at different fault locations using ETAP for the offline grid monitoring purpose. Since ETAP is the most effective and user-friendly tool to perform the power system studies [8], it has been chosen in this paper to simulate the grid station. IEC 60909 and IEC 61363 standards are used to analyze the Short Circuit behavior of the system. The results of short circuit studies identify the value of sub-transient, transient and steady state currents and these faults current magnitude are valuable to find out network arrangement, network voltage profiles, shielding apparatus, circuit breakers, conductor length, step up and step-down power equipment and solid grounding.

Renuka et al. [1] presented a fault current analysis of an industrial distribution system in compliance to IEC60909. The fault current studies should be performed at scheduling phase as well as operating situations has been purposed. ETAP software for the evaluation of different faults in industrial supply system has been used.

The Short Circuit analysis conducted in Komag Sarawak Operations (KSO) has been discussed. The factory to re-examine the protection system and enhance the system's dependability has been investigated. It has been decided to do so because the current power system was very old and never revised before. ETAP for reconsideration of the power system has been used [2].

A power system has been considered which is interconnected with different types of distributed generators. IEC 60909 standard to calculate the consequential fault magnitude for the medium and low voltage system has been applied [3].

A dynamic and standard based calculation of Short Circuit currents has been given using different approaches. The approaches have been compared, offered by ANSI/IEC standards for current fault analysis at different voltage levels. They compared the calculated results with EMTP software results [4].

The pattern of IEC 60909 has been explained and purposed that in this standard for the exact place, period highest and lowest potential fault current has been driven. That has been reported using a sequence of factors which relate to the evaluated fault current of apparatus and the tests required on apparatus to prove that evaluation [5].

A typical 2×30 MW thermal power plant has been taken to analyze the fault current study, using electrical transient analyzer program (ETAP) software. Fault current analysis based on American National Standards Institute (ANSI) - C37 and International Electrotechnical Commission (IEC) 60909, IEC 61363-1 standards has been performed. The symmetrical and unsymmetrical faults at different locations in the power plant have been evaluated and also investigated the effect of fault location on the Short Circuit response [6].

The expected fault currents of the test equipment have been simulated and computed. The model after calculating the impedances of the test system has been created. The influencing aspects have been analyzed, which distinguish the actual yield current from the predictable value, using the computed calculation results. For the enhancement of new test tool, the results offer a theoretical basis [7].

In the network, Short Circuit can't be permanently avoided, but at the time of design and development, its impact can only be minimized by keeping in view its penalties on the network. The network equipment's, step up and step-down power equipment, conductors, circuit breakers, shielding apparatus etc need to be considered and designated to have to unbalance resistive competency to match network maximum unbalance current AC value.

These faults are analyzed and represented by modeling 220KV electrical power grid. In a power network, Short Circuit generates large-scale currents which are several times larger than normal load currents. Therefore, Short Circuit current need to be calculated at each voltage level for determining the characteristics of the equipment required to withstand the fault.

II. SHORT CIRCUIT ANALYSIS

The substation is normally a multi-appliance system because it contains both industrial and domestic load. Industrial loads are much considerable because they have feasibly more than one generator and many electric motors, all interlinked with transformers, lines and cables. The utility/grid generally demonstrated a continuous voltage source along with equivalent impedance. The AC factor is constant for the abnormal current distributed by utility/grid as presented in Figure-1, due to the greater impedances of the transformers, connecting lines and cables having reasonably constant and large values. Induction motor and synchronous machine delivered an abnormal current which reduces with time until a normal magnitude is approached. The AC factor of fault current delivered by the utility is also presented in Figure 1.

In fault current studies, two kinds of fault currents must be considered:

- The peak/maximum fault current Ip which decides the capability of the electrical equipment.
- The steady-state/minimum fault current IK which is essential for the setting of switchgear.

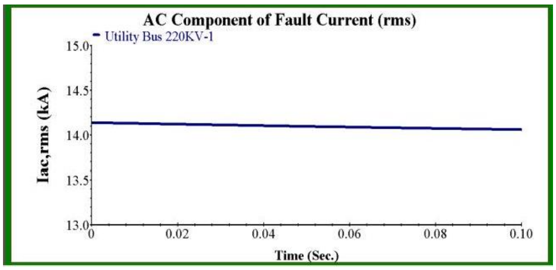

Figure 1: AC component of fault current.

There are several methods to do Short Circuit analysis: the impedance method, the conventional method, the composition method, all these methods can calculate fault current for low voltage power system, but IEC 60909 method can be used up to 550KV [5]. Power system using IEC 60909, IEC 61363 standards the Short Circuit study is executed in ETAP for 3-phase fault, line-to-neutral (L-G) fault, line-to-line (L-L) fault and line-to-line-to-neutral (L-L-G) fault and I_k'' (initial AC symmetrical fault current), I_P (peak fault current) and I_k (steady-state fault current) is determined [6]. I_k'' is the rms value of initial AC symmetrical fault current is calculated by Equation (1).

$$I_k'' = \frac{cU_n}{\sqrt{3}|Z_k|} \tag{1}$$

where Z_k = At the fault location, Short Circuit impedance and c = voltage factor.

The c factor or voltage factor is the ratio of equivalent voltage to nominal voltage and required to account for variation due to time and place, transformer taps, static load and capacitance, generator & motor sub-transient behaviour. The peak current I_P can be calculated by Equation (2) where k is a function of system X/R ratio at the fault location.

$$I_P = \sqrt{2} * k * I_k'' \tag{2}$$

where k is a function of the system R/X ratio at the fault location. IEC Standards provide three methods for calculating the k factor [5]:

(i) Method A - Uniform ratio R/X. The magnitude of the k factor is obtained by choosing the lowest ratio of R/X of all the branches of the power system.
(ii) Method B - At Short Circuit place ratio of R/X. The magnitude of the k factor is obtained by multiplying a safety factor of 1.15 by the k factor, which includes inaccuracies resulted after determining the R/X ratio from a power system minimization with complex impedances.
(iii) Method C - Equivalent frequency. The magnitude of the k factor is determined using a frequency-varied R/X. R/X is computed at least frequency and then multiplied by a frequency-dependent factor.

The breaking current (I_b) for the fault occurred far away from the generator terminal and for the fault occurred near the generator terminals are obtained as expressed in Equation (3) to (5) respectively.

$$I_b = I_k'' \tag{3}$$

$$I_b = \mu * I_k'' \tag{4}$$

$$I_b = \mu * q * I_k'' \tag{5}$$

where q, μ are the coefficients that accounts for AC decay.

By using the frequency of the network (f), least delay of shielding devices (t_{min}) the dc factor of fault current (I_{dc}) is achieved as expressed in Equation (6).

$$I_{dc} = I_k'' * \sqrt{2} * exp\left[\frac{\sqrt{2\pi f t_{min}}}{\frac{X}{R}}\right] \tag{6}$$

The objective to perform Short Circuit analysis for offline grid monitoring, there are some guidelines:

- To evaluate the Installed respective protective devices with parameter as per IEC standard.
- To define the switchgear setting.
- To evaluate and make sure that the systems are withstood capability of installed protective equipment for such particular fault.
- To determine the fault magnitude using Short Circuit analysis such as line-to-line-to-line, line-to-line, line-to-line-neutral, line-to-neutral etc at any bus bar. To determine sub-transient, transient, steady-state currents on different bus-bar levels.

III. SYSTEM DESCRIPTION AND SIMULATION

To enhance the performance and making power network stable here an NTDC 220KV grid model having three different voltage levels with loads having a different rating is proposed. To conclude the actual outcome of a power network, appropriate computational models and the exact factors of the power systems, power grid and load synoptic have to be nominated. The single line diagram (SLD) of the power grid is illustrated in Figure-2; the power grid station is simulated on ETAP software. To enhance the power quality and consistency of the grid, the Band Road Grid Station (BRGS) have network connectivity with NTDC at four points NTDC power is available at 220KV voltage level through utility ties U1, U2, U3 and U4. To deliver nonstop power supply and improve the grid power double line conductor has installed for incoming lines. These lines are placed parallel to feed station and they can perform as a source and sink according to the power required. One and a half circuit breaker scheme is used for the grid protection at 220KV level. Using transformers firstly voltage is step down to 132KV then further it was step down to 11KV for industrial and domestic distribution.

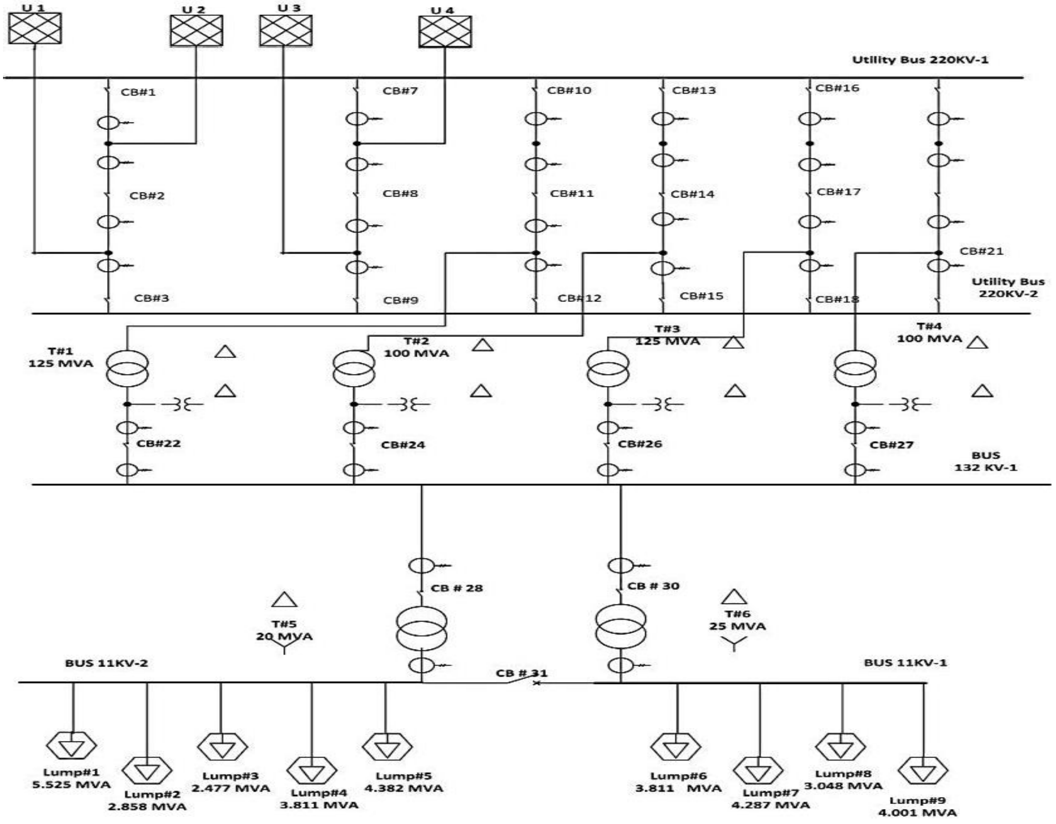

Figure 2: Single line diagram of grid station

To represent the 11KV feeder load current, lumped loads having 70 percent motor and 30 percent static characteristics are placed. Method C is used for modeled 220kv power grid as it is a non-meshed grid.

IV. RESULTS AND DISCUSSION

For selected domestic/industrial power network at different time intervals, the results of the Short Circuit analysis are given in Table 1, 3 and 5. Its graphical representation at different buses for various cases are shown in Figure 4, 5 and

6. Here, three time intervals; peak load time, shoulder peak time and low load time are selected to properly evaluate the power system to enhance its performance.

Table 1, 3 and 5 show the fault currents evaluation at different voltage levels for the symmetrical or three phase networks along with a double line to ground, line to line and line to the ground network for the sub-transient, transient and steady- state states at peak load, shoulder peak and low load time.

Normally 3-phase fault have greater magnitude as compare to the other faults and it can be seen from the Table 1, 3 and 5, that 3-phase fault having 29.012 magnitude which is greater as compared to L-G fault magnitude which is zero, L-L fault and L-L-G fault having 25.125 magnitudes at 220kv voltage bus. Similarly, this pattern can see for the 132kv and 11kv buses in Table 1.

As utility 220kv bus and 132kv bus have delta connection, that is way line to ground fault shows zero value, line to line and double line to ground fault shows similar values. Table-2, 4 and 6 explains well about the comparison between the rating of the installed device and fault magnitude for peak load, shoulder peak and low load time.

Comparison is given between device peak making rated current $I_{P(device)}$ having 108kA verses fault top envelope $I_{P(fault)}$ 29.012kA, device symmetrical 40kA and Asymmetrical 42.689kA rated $I_{b(device)}$ verses system fault symmetrical 10.776kA and Asymmetrical fault 13.428kA current $I_{b(fault)}$, device rated dc component $I_{dc(device)}$ 14.911kA verses fault current dc component $I_{dc(fault)}$ 8.012kA for peak load time at 220kv bus in Table 2, which have maximum values as compare to shoulder peak load time in Table 4 and low load time in Table 6.

A comparison is presented in the Figure 3 for the 3-phase. Short Circuit(KA) for the peak or transient fault current in power system at different buses for various cases i.e. peak load, shoulder peak load and low load time and it can be seen that for peak load 3-phase having 62.895kA maximum fault magnitude at 11kv bus.

Similarly, Figure 4, 5 and 6 simultaneously shows the comparison at different buses for various loading conditions for double line to ground Short Circuit (KA), double line Short Circuit (KA) and line to ground Short Circuit (KA) for the transient fault current. The comparison of peak parameters is expressed very well in the Figures.

Table 1
Phase and Ground Short Circuit Analysis Results at Peak Load

Bus ID	3-Phase Fault			L-G Fault			L-L Fault			L-L-G Fault		
	I''_k	I_p	I_k	I''_k	I_p	I_k	I''_k	I_p	I_k	I''_k	I_p	I_k
Utility 220KV Bus-1	10.776	29.012	10.497	0	0	0	9.333	25.125	9.333	9.333	25.125	9.333
Utility 220KV Bus-2	10.776	29.012	10.497	0	0	0	9.333	25.125	9.333	9.333	25.125	9.333
132KV Bus-1	9.694	26.216	9.218	0	0	0	8.396	22.704	8.396	8.396	22.704	8.396
132KV Bus-2	9.694	26.216	9.218	0	0	0	8.396	22.704	8.396	8.396	22.704	8.396
11KV Bus-1	24.092	62.895	15.810	20.864	54.468	20.864	21.863	57.076	21.863	23.276	60.763	23.276
11KV Bus-2	24.092	62.895	15.810	20.864	54.468	20.864	21.863	57.076	21.863	23.276	60.763	23.276

Table 2
Device Rating Short Circuit Analysis Results at Peak Load

BUS ID	Device Capacity (kA)				Short Circuit Capacity			
	Making Peak	Sym	Asym	I_p	I_b	Sym	I_b	Asym
Utility BUS 220 KV-1	108	40	42.689	14.911	29.012	10.776	13.428	8.012
Utility BUS 220 KV-2	108	40	42.689	14.911	29.012	10.776	13.428	8.012
132 KV BUS-1	108	40	42.689	14.911	26.216	9.617	12.335	7.724
132 KV BUS-2	108	40	42.689	14.911	26.216	9.617	12.335	7.724
11KV BUS-1	100	40	34.482	17.812	62.895	21.934	26.670	15.172
11 KV BUS-2	100	40	34.482	17.812	62.895	21.934	26.670	15.172

Table 3
Phase and Ground Short Circuit Analysis Results Aat Shoulder Peak Load

Bus ID	3-Phase Fault			L-G Fault			L-L Fault			L-L-G Fault		
	I''_k	I_p	I_k	I''_k	I_p	I_k	I''_k	I_p	I_k	I''_k	I_p	I_k
Utility 220KV Bus-1	10.699	28.810	10.497	0	0	0	9.266	24.950	9.266	9.266	24.950	9.266
Utility 220KV Bus-2	10.699	28.810	10.497	0	0	0	9.266	24.950	9.266	9.266	24.950	9.266
132KV Bus-1	9.560	25.865	9.218	0	0	0	8.279	22.400	8.279	8.279	22.400	8.279
132KV Bus-1	9.560	25.865	9.218	0	0	0	8.279	22.400	8.279	8.279	22.400	8.279
11KV Bus-1	21.090	55.399	15.810	18.264	47.977	18.264	20.129	52.876	20.129	20.743	54.488	20.743
11KV Bus-1	21.090	55.399	15.810	18.264	47.977	18.264	20.129	52.876	20.129	20.743	54.488	20.743

Table 4
Device Rating Short Circuit Analysis Results at Shoulder Peak Load

BUS ID	Device capacity (kA)				Short Circuit Current (kA)			
	Making Peak	Sym	Asym	I_p	I_b	sym	I_b	Asym
Utility BUS 220 KV-1	108	40	42.689	14.911	28.810	10.699	13.347	7.980
Utility BUS 220 KV-2	108	40	42.689	14.911	28.810	10.699	13.347	7.980
132 KV BUS-1	108	40	42.689	14.911	25.865	9.560	12.257	7.671
132 KV BUS-2	108	40	42.689	14.911	25.865	9.560	12.257	7.671
11KV BUS-1	100	40	34.482	17.812	55.399	19.504	24.135	14.215
11 KV BUS-2	100	40	34.482	17.812	55.399	19.504	24.135	14.215

Table 5
Phase and Ground Short Circuit Analysis Result at Low Load

BUS ID	3-Phase Fault			L-G Fault			L-L Fault			L-L-G Fault		
	I_k''	I_p	I_k	I_k''	I_p	I_k	I_k''	I_p	I_k	I_k''	I_p	I_k
Utility BUS 220 KV-1	10.625	28.609	10.497	0	0	0	9.201	24.776	9.201	9.201	24.776	9.201
Utility BUS 220 KV-2	10.625	28.609	10.497	0	0	0	9.201	24.776	9.201	9.201	24.776	9.201
132 KV BUS-1	9.432	25.522	9.218	0	0	0	8.169	22.103	8.169	8.169	22.103	8.169
132 KV BUS-2	9.432	25.522	9.218	0	0	0	8.169	22.103	8.169	8.169	22.103	8.169
11KV BUS-1	18.799	49.478	15.810	16.281	42.849	16.281	18.681	49.167	18.681	18.825	49.546	18.825
11 KV BUS-2	18.799	49.478	15.810	16.281	42.849	16.281	18.681	49.167	18.681	18.825	49.546	18.825

Table 6
Device Rating Short Circuit Analysis Results at Low Load

BUS ID	Device capacity (kA)				Short Circuit Current (kA)			
	Making Peak	Sym	I_bAsym	I_{dc}	I_p	$I_b$sym	I_bAsym	I_{dc}
Utility BUS 220 KV-1	108	40	42.689	14.911	28.609	10.625	13.270	7.950
Utility BUS 220 KV-2	108	40	42.689	14.911	28.609	10.625	13.270	7.950
132 KV BUS-1	108	40	42.689	14.911	25.522	9.432	12.128	7.624
132 KV BUS-2	108	40	42.689	14.911	25.522	9.432	12.128	7.624
11KV BUS-1	100	40	34.482	17.812	49.478	17.747	22.241	13.405
11 KV BUS-2	100	40	34.482	17.812	49.478	17.747	22.241	13.405

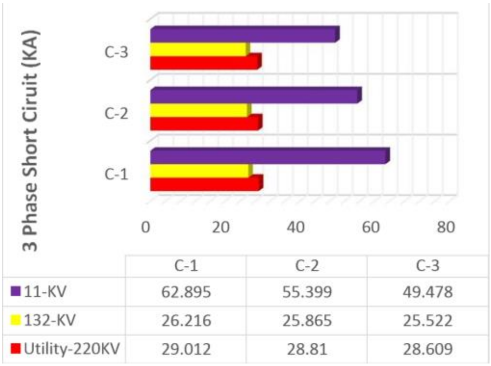

Figure 3: 3-phase Short Circuit (KA) at different buses for various cases

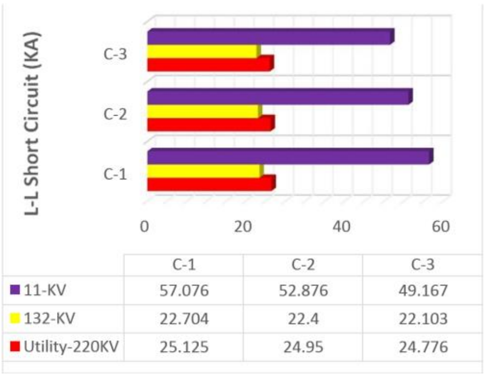

Figure 5: Double line Short Circuit (KA) at different buses for various cases

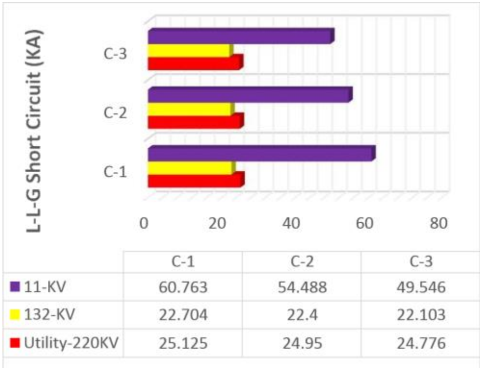

Figure 4: Double line to ground Short Circuit (KA) at different buses for various cases

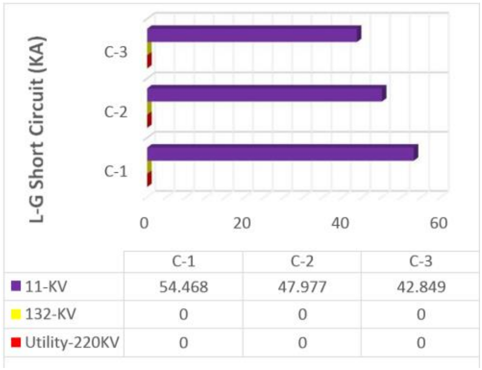

Figure 6: Line to ground Short Circuit (KA) at different buses for various cases

V. CONCLUSION

The simulation and fault study analysis have been performed on the ETAP software for the offline grid monitoring purpose. The fault studies have been done by placing the fault at different voltage levels. Their impact in the form of magnitude is calibrated and plotted for sub-transient, transient and steady-state currents. These results are beneficial to decide the power system equipment withstand capability against fault and the resizing and enhancement of the installed apparatus. The comparison for peak Short Circuit at different buses for various loading conditions are expressed very well in the figures.

REFERENCES

[1] Renuka K., Mukesh K. K., Manoj K., and Ganga A. 2013. Short Circuit Analysis of an Industrial Distribution System", *Proceedings of The Second International Conference on Advances In Computer, Electrics And Electrical Engineering* (IEEE), pp. 199-202.

[2] M. H. Hairi, H. Zainuddin, M. H. N. Talib, A. Khamis, and J. Y. Lichun. 2009. An Investigation of Short Circuit Analysis in Komag Sarawak Operations (KSO) Factory. *World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, 3(11): 1940-1945.

[3] T. N. Boutsika, and S. A. Papathanassiou. 2008. Short-circuit calculations in networks with distributed generation. *Electric Power Systems Research*, 78(7): 1181-1191.

[4] A. Berizzi, S. Massucco, A. Silvestri, and D. Zaninelli. 1994. Short-circuit current calculation: a comparison between methods of IEC and ANSI standards using dynamic simulation as reference. *IEEE Transactions on Industry Applications*, 30(4): 1099-1106.

[5] Sweeting D. 2011. Applying IEC 60909, short-circuit current calculations. In *Petroleum and Chemical Industry Conference*, 2011 *Record of Conference Papers Industry Applications Society 58th Annual IEEE*, pp. 1-6.

[6] S. L. Sankar, and M. M. Iqbal. 2015. ANSI and IEC standards based short circuit analysis of a typical 2× 30 MW thermal power plant. *Middle-East Journal of Scientific Research*, 23(8): 1617-1625.

[7] Wang F., Yanpeng Qi. and Zhengcai Fu. 2012. Calculation of peak output current of short circuit test equipment used for the low-voltage switching devices. *International Conference on High Voltage Engineering and Application (ICHVE)*, pp. 72-75.

[8] R. Agrawal, S. K. Bharadwaj, and D. P. Kothari. 2013. An educational and professional simulation tools in power systems and facts controllers-an overview. *International Journal of Electrical, Electronics and Computer Engineering*, 2 (2): 91-96.