Short Circuit Analysis of 33/11/0.4 kV Distribution System Using ETAP

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***Abstract*— There are two major problems that can occur in power system; these are open circuits fault and short circuits fault. Of the two, short circuit is the most dangerous because it can lead to very high fault currents and these currents can have very substantial effects such as electromechanical forces and thermal heating on equipment that may need replacement of equipment and may even cause fires and other similar ensuing effects in the power system. Building systems are particularly at risk. To prevent problems from short circuits, it is required to design electrical protection systems that will be able to detect abnormal fault currents that may occur and then take remedial action to isolate the faulty section of the system in as short a time as is consistent with the magnitude of the short circuit fault current level. This requires that the fault current be predicted for a fault in any particular location of the power system. This paper described the short circuit analysis of 33/11/0.4 kV Maubin distribution system for various types of symmetrical and unsymmetrical faults at different locations. This analysis is done by using Electrical Transient Analyzer Program (ETAP) and has been performed based on International Electrotechnical Commission (IEC) – 60909, IEC 61363-1 standards. All the data is collected from 33/11/0.4 kV substation under Ese Maubin.**

***Keywords*— short circuit, fault current, ETAP, IEC-60909, IEC 61363-1, Maubin distribution system**

I. INTRODUCTION

A fault on a power system is an abnormal condition that includes an electrical failure of power system equipment operating at one of the primary voltages within the system. Generally, two types of failure can occur. The first is an insulation failure that results in a short-circuit fault and can occur as a result of overstressing and degradation of the insulation over time or due to a sudden overvoltage condition. The second is a failure that results in a cessation of current flow or an open-circuit fault. A short circuit may lead to stability problem, electromagnetic interference, mechanical and thermal stress.

Short circuit faults can take place between phases, or between phases and earth, or both. Short circuits may be one-phase to earth, phase to phase, two-phase to earth, three-phase clear of earth and three-phase to earth. The three-phase fault that symmetrically affects the three phases of a three-phase circuit is the only balanced fault whereas all the other faults are unbalanced. Short circuit analysis is carried out to ensure the safety of the general public, and to determine the ratings of protective equipment to ensure the stability of the power system. The maximum steady-state short circuit current is used to determine minimum device ratings. The minimum steady-state short circuit value is used for relay coordination purposes in preventing the occurrence of nuisance trips and loading deviations.

In this paper, the short circuit characteristic of 33/11/0.4 kV distribution system (Maubin) has been analyzed for various fault conditions at different fault locations using IEC 60909 and IEC 61363-1 standards in ETAP. The detailed descriptions about the short circuit current calculations are presented in this paper. ETAP is the most comprehensive solution for the simulation, design and analysis of generation, transmission, distribution, and industrial power systems.

II. GENERAL DESCRIPTION OF CALCULATION METHODOLOGY

In IEC short circuit calculation method; an equivalent voltage source at the fault location replaces all voltage sources.

A voltage factor c is used to adjust the value of the equivalent voltage source for minimum and maximum current calculation. All machines are represented by their internal impedances. Transformer tap can be set at either an operating position or at the nominal position, and different schemes are available to correct system voltages and transformer impedance if off-nominal tap setting exists. System impedances are assumed to be balanced three phase, and the method of symmetrical components is applied for unbalanced fault calculations. Zero sequence capacitances of transmission lines, shunt admittances and cables can be considered for unbalanced fault calculations (LG and LLG) if the option in the study case is selected to involve branch Y and static load. This means that the capacitances of static load and branches are considered based on IEC 60909-0. The calculations consider electrical distance from the fault location to synchronous generator. For a far-from generator fault, calculations assume that the steady-state value of the short-circuit current is equal to the initial symmetrical short-circuit current and only the DC component decays to zero. However, for a near-to-generator fault, calculations count for decaying in both AC and DC components. The equivalent (R/X) ratios determine the rates of decay of both components, and different values are taken for generator and loads near the fault.

In this paper, IEC 60909 and 61363-1 are being employed to study the short circuit performance of 33/11/0.4 kV radial distribution system. The initial symmetrical current (I''_k) is calculated by using the norminal voltage V_n, voltage factor (C) and equivalent impedance at the fault location (Z_k). The peak current (I_p) is calculated by using the initial symmetrical current (I''_k) and a fuction of system $\frac{R}{X}$ value at fault location k.

$$I''_k = \frac{CVn}{\sqrt{3Z_k}} \quad \text{, (in kA)} \qquad (1)$$

$$I_p = \sqrt{2}\ k\, I''_k \quad \text{, (in kA)} \qquad (2)$$

IEC Standards provide three methods for calculating the *k* factor: Method (A)- Uniform ratio $\frac{R}{X}$. The value of the k factor is determined from taking the smallest ratio of $\frac{R}{X}$ of all the branches of the network. Only branches that contain a total of 80 percent of the current at the nominal voltage corresponding to the short circuit location are included. Branches may be a series combination of several elements. Method B - $\frac{R}{X}$ ratio at the short circuit location. The value of the k factor is determined by multiplying the k factor by a safety factor of 1.15, which covers inaccuracies caused after obtaining the $\frac{R}{X}$ ratio from a network reduction with complex impedances. Method C - Equivalent frequency. The value of the *k* factor is calculated using a frequency altered $\frac{R}{X}$. $\frac{R}{X}$ is calculated at a lower frequency and then multiplied by a frequency-dependent multiplying factor.

For a far from generator fault, the symmetrical short circuit breaking current (I_b) is equal to the initial symmetrical short circuit current.

$$I_b = I''_k \quad \text{, (in kA)} \qquad (3)$$

For a near to generator fault, I_b is obtained by combining contributions from each individual machine. I_b for different types of machines is calculated by using the following formula:

$$I_b = \mu I''_k \quad \text{, (in kA) for synchronous machine} \qquad (4)$$

$$I_b = \mu q I''_k \quad \text{,(in kA) for asynchronous machine} \qquad (5)$$

where μ and q are factors that account for AC decay.

The DC component of the short circuit current for the minimum delay time of a protective device is calculated based on initial symmetrical short circuit current and system $\frac{X}{R}$ ratio:

$$I_{dc} = I''k \text{ x } \sqrt{2} \text{ x } \exp\left(\sqrt{\frac{2\pi f t_{min}}{\frac{X}{R}}}\right) \text{, in kA} \qquad (6)$$

Where f is the system frequency, t_{min} is the minimum delay time of the protective device under concern, and $\frac{X}{R}$ is the system value at the faulted bus.

Steady-state short circuit current I_k is a combination of contributions from synchronous generators and power grid. I_k for each synchronous generator is calculated using the following formula:

$$I_{kmax} = \lambda_{max} I_{rG} \quad \text{, in kA} \qquad (7)$$

$$I_{kmin} = \lambda_{min} I_{rG}\text{, in kA} \qquad (8)$$

where λ is a function of a generator's excitation voltage, ratio between its initial symmetrical short circuit current and rated current, other generator parameters, and I_{rG} is the generator's rated current.

III. TERMINOLOGY OF SHORT CIRCUIT CURRENT WAVEFORM

In order to calculate short circuit current duties on power system equipment, it is important to define the terminology used in characterizing the short circuit current waveform. Short circuit faults are characterized by the short circuit current and its components. These are the ac or symmetrical root mean square (rms) short-circuit current, dc short-circuit current or dc time constant or *X*/*R* ratio, and the overall asymmetrical short-circuit current. Fig. 1 shows a simple balanced three-phase electric circuit where *L* and *R* are the circuit inductance and resistance for each phase, and *L*e and *R*e are the earth return path inductance and resistance, respectively.

$$v_i(t) = \sqrt{2}V_{rms}\sin(\omega t + \varphi_i) \quad \text{i = r,y,b} \quad (9)$$

where V_{rms} is rms voltage magnitude, $\omega = 2\pi f$ in rad/s, f is power frequency in Hz and ϕi is voltage phase angle in rad given by $\varphi_y = \varphi_r - \frac{2\pi}{3}$, $\varphi_b = \varphi_r + 2\pi/3$

If a solid three-phase to earth connection or short-circuit fault is made simultaneously between phases r, y, b and earth e at $t = 0$,

$$L\frac{d_i(t)}{dt} + Ri_i(t) + L_e\frac{d_{ie}(t)}{dt} + R_e i_e(t) = v_i(t) \qquad (10)$$

Substituting i = r, y, b in Equation (10) and adding the three equations,

$$L\frac{d}{dt}\left[i_r(t) + i_y(t) + i_b(t)\right] + R\left[i_r(t) + i_y(t) + i_b(t)\right] + 3L_e\frac{d_{ie}(t)}{dt} + 3R_e i_e(t) = v_r(t) + v_y(t) + v_b(t) \qquad (11)$$

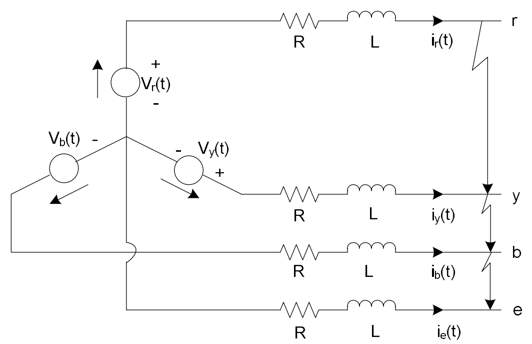

Fig. 1 Basic balanced three-phase electric circuit with earth return

Since the three-phase voltage sources are balanced,

$$v_r(t) + v_y(t) + v_b(t) = 0 \quad , \quad i_r(t) + i_y(t) + i_b(t) = i_e(t)$$

Therefore, substituting in Equations (11),

$$(L + 3L_e)\frac{d_{ie}(t)}{dt} + (R + 3R_e)i_e(t) = 0 \quad (12)$$

The solution of Equation (12) is given by

$$i_e(t) = Kx \exp\left[\frac{-t}{\left(\frac{L+3L_e}{R+3R_e}\right)}\right] \quad (13)$$

where K is a constant that satisfies the initial conditions. Since the three-phase system is symmetrical and balanced, $i_e(t)=0$. Thus, Equation (13) gives $K = 0$ and $i_e(t) = 0$. That is, following a simultaneous three-phase short circuit, no current will flow in the earth return connection and the three fault currents $i_i(t)$ will flow independently as in single-phase circuits. Therefore, with $i_e(t) = 0$, the solution of Equation (10) is given by

$$i_i(t) = \sqrt{2}\, I_{rms}\left\{sin\left[\omega t + \varphi_i - tan^{-1}\left(\frac{\omega L}{R}\right)\right] - \sin\left[\varphi_i - tan^{-1}\left(\frac{\omega L}{R}\right)\right] x \exp\left[\frac{-t}{\left(\frac{L}{R}\right)}\right]\right\} \quad (14)$$

Where,

$$I_{rms} = \frac{V_{rms}}{\sqrt{R^2 + (\omega L)^2}}$$

Equation (14) can be written as the sum of an ac component and a unidirectional dc component as follows,

$$i_i(t) = i_{i(ac)}(t) + i_{i(dc)}(t) \quad (15)$$

Where,

$$i_{i(ac)}(t) = \sqrt{2}\, I_{rms} \sin\left[\omega t + \varphi_i - tan^{-1}\left(\frac{\omega L}{R}\right)\right] \quad (16)$$

$$i_{i(dc)}(t) = -\sqrt{2}\, I_{rms} \sin\left[\varphi_i - tan^{-1}\left(\frac{\omega L}{R}\right)\right] x \exp\left[\frac{-t}{\left(\frac{L}{R}\right)}\right] \quad (17)$$

Fig. 2 shows a general asymmetrical short-circuit current waveform and the terminology used to describe the various current components as well as the short circuit current interruption.

t_F = Instant of short-circuit fault
Δt_1 = Protection relay time.
t_A = Instant of 'initial peak' of short-circuit current.
t_1 = Instant of energisation of circuit-breaker trip circuit
Δt_2 = Circuit-breaker opening time
t_2 = Instant of circuit-breaker contact separation
Δt_3 = Circuit-breaker current arcing time
t_3 = instant of short-circuit current interruption
t_B = Instant of peak of major current loop

$2\sqrt{2}\ I''_k$ = Theoretical current at the instant of short-circuit fault t_F where I''_k is the rms short-circuit current at $t = t_F$

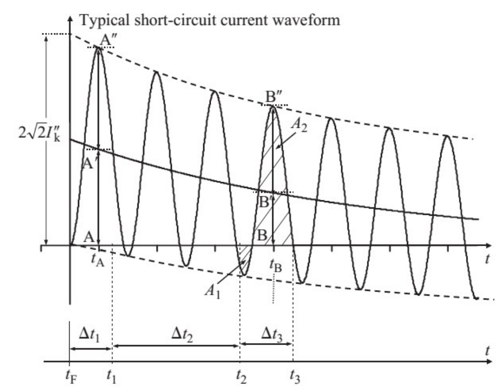

Fig. 2 Asymmetrical short circuit current waveform

IV. SHORT CIRCUIT ANALYSIS RESULTS OF MAUBIN DISTRIBUTION SYSTEM

Fig. 3 shows single line diagram of 33/11/0.4 kV Maubin distribution system. In this system, there has one number of 10 MVA main transformer, 3 feeders and the power grid is supplied by Kyaiklat substation. The current flow under normal operating condition can be seen in Fig. 4. This load flow analysis is based on Newton- Raphson method under normal operating condition. In Fig. 4, the total ampere flow at bus 1 is 133.2 A, the branch current flow at feeder 1 is 180.6 A, at feeder 2 is 118 A , and at feeder 3 is 101.4 A respectively.

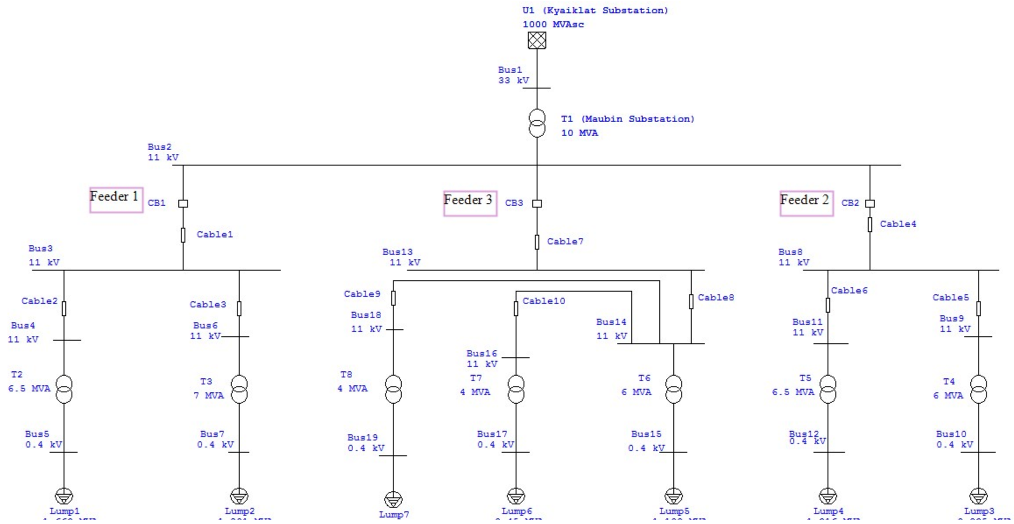

Fig. 3 Illustrate single line diagram of Maubin distribution system

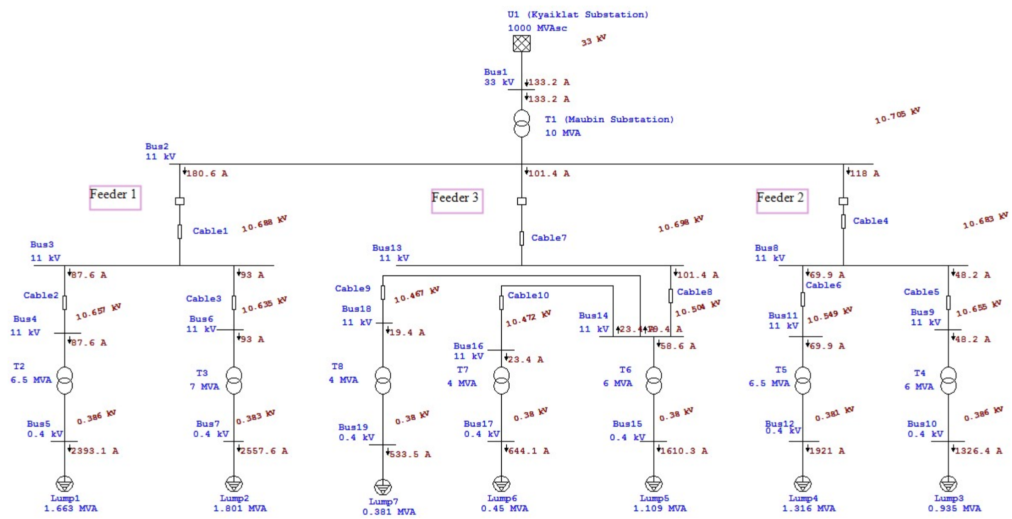

Fig. 4 Illustrate load flow analysis of Maubin Distribution System under normal operating condition

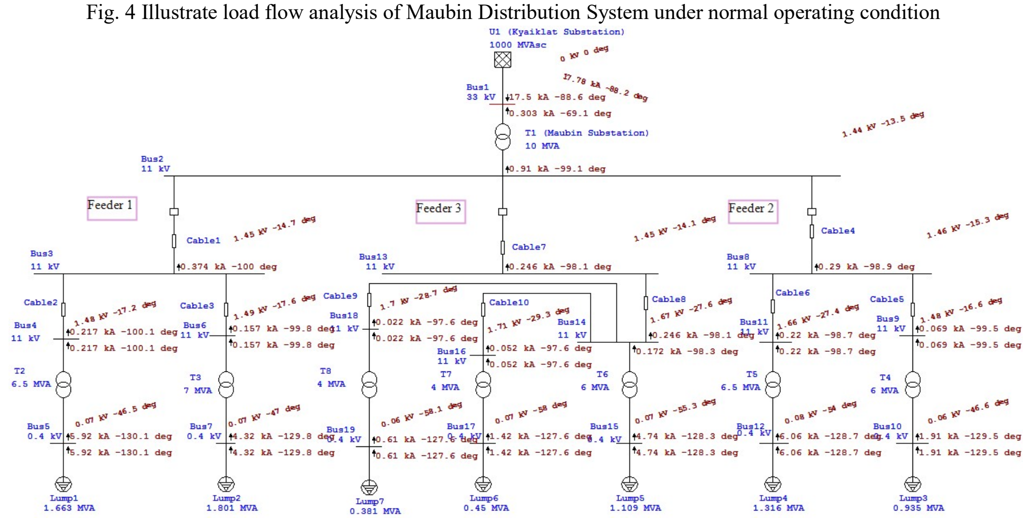

Fig. 5 Illustrates three phase balanced short circuit fault at bus 1 of Maubin Distribution System

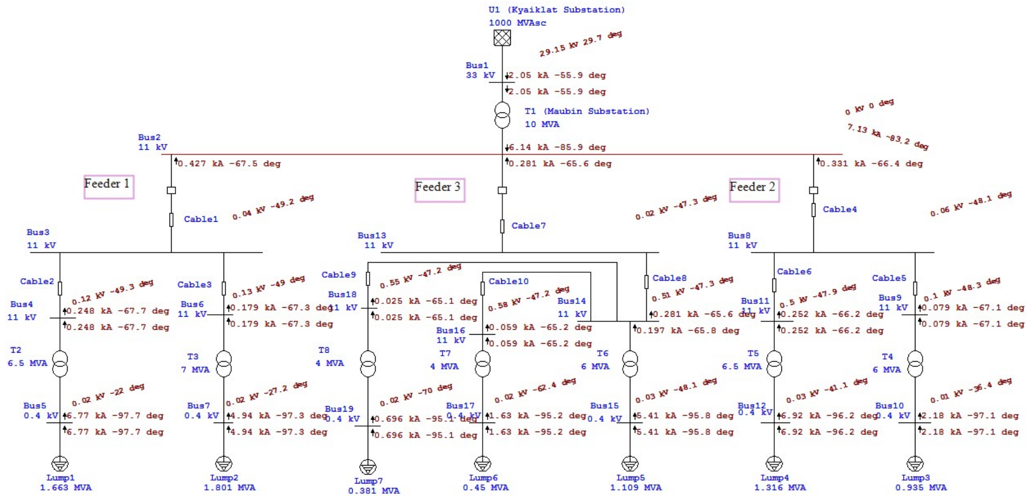

Fig. 6 Illustrates three phase balanced short circuit fault at bus 2 of Maubin Distribution System

Fig. 5 and Fig. 6 show three phase balanced short circuit fault at bus 1, and at bus 2 of the Maubin distribution system. The short circuit analysis of this system has been carried out using ETAP by IEC 60909 standards for all the types of symmetrical and unsymmetrical faults at buses 1, 2, 3, 8 and 13. The IEC 60909 standard based short circuit results namely initial symmetrical current (I''_k), peak current (I_p), breaking current (I_b) and steady state current (I_k) for the occurrence of fault at buses 1, 2, 3, 8 and 13 are obtained and described in Tables I to V respectively.

TABLE I
FAULT CURRENT WHEN SHORT CIRCUIT FAULT OCCURS AT BUS 1

Fault Current	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	17.782	17.685	15.399	17.763
Peak Current (kA, method C)	48.279	48.017	48.810	48.228
Breaking Current (kA, rms, symm)		17.685	15.399	17.763
Steady State Current (kA, rms)	17.495	17.685	15.399	17.763

TABLE II
FAULT CURRENT WHEN SHORT CIRCUIT FAULT OCCURS AT BUS 2

Fault Current	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	7.125	7.066	6.170	7.181
Peak Current (kA, method C)	17.596	17.450	15.238	17.735
Breaking Current (kA, rms, symm)		7.066	6.170	7.181
Steady State Current (kA, rms)	6.136	7.066	6.170	7.181

TABLE III
FAULT CURRENT WHEN SHORT CIRCUIT FAULT OCCURS AT BUS 3

Fault Current	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	6.981	6.848	6.045	6.940
Peak Current (kA, method C)	16.310	15.999	14.125	16.215
Breaking Current (kA, rms, symm)		6.848	6.045	6.940
Steady State Current (kA, rms)	6.018	6.848	6.045	6.940

TABLE IV
FAULT CURRENT WHEN SHORT CIRCUIT FAULT OCCURS AT BUS 8

Fault Current	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	6.815	6.616	5.902	6.741
Peak Current (kA, method C)	15.132	14.689	13.105	14.967
Breaking Current (kA, rms, symm)		6.616	5.902	6.741
Steady State Current (kA, rms)	5.895	6.616	5.902	6.741

TABLE V
FAULT CURRENT WHEN SHORT CIRCUIT FAULT OCCURS AT BUS 13

Fault Current	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	7.002	6.887	6.064	6.984
Peak Current (kA, method C)	16.515	16.243	14.303	16.473
Breaking Current (kA, rms, symm)		6.887	6.064	6.984
Steady State Current (kA, rms)	6.043	6.887	6.064	6.984

Fig. 7 shows the current envelope of the transient fault current when the fault is occurred at bus 1(grid bus) is obtained using IEC 61363-1 standard. The IEC 61363-1 standard based simulation result namely total fault current (i), DC component of fault current (I_{dc}), top envelope of fault current (i_{env}), AC component of fault current (I_{ac}) and percentage DC component of fault current (I_{dc} %) when transient fault is occurred at grid bus is obtained and described in Table VI.

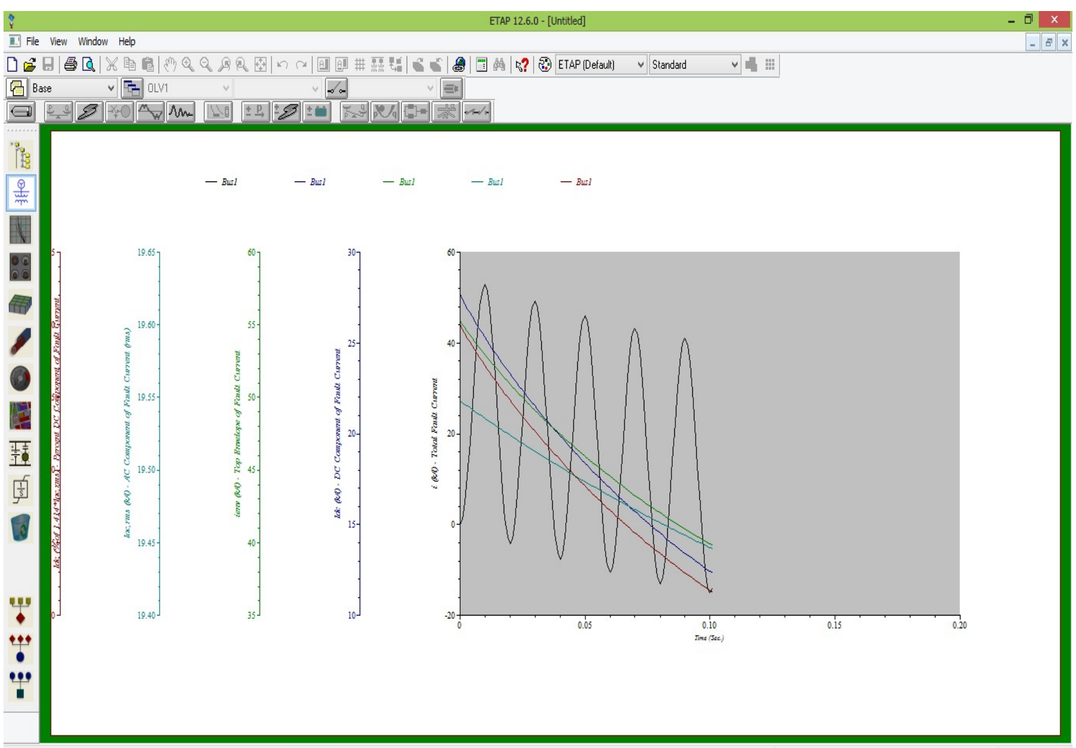

Fig. 7 Illustrates fault current envelop during grid bus fault of Maubin Distribution System

TABLE VI
TRANSIENT FAULT CURRENT AT GRID BUS

T (cycle)	i (kA)	I_{dc} (kA)	i_{env} (kA)	I_{ac} (kA,rms)	I_{dc} (%)
0.000	0.000	27.644	55.289	19.548	100.00
0.100	4.770	27.132	54.773	19.545	98.16
0.200	18.104	26.644	54.282	19.543	96.41
0.300	34.717	26.178	53.812	19.540	94.73
0.400	48.083	25.729	53.360	19.538	93.12
0.500	52.923	25.296	52.923	19.535	91.56
0.600	47.224	24.876	52.500	19.533	90.05
0.700	33.003	24.468	52.088	19.531	88.58
0.800	15.536	24.070	51.688	19.528	87.16
0.900	1.342	23.682	51.296	19.526	85.76
1.000	-4.308	23.303	50.914	19.524	84.40
1.100	0.596	22.932	50.539	19.522	83.06

V. CONCLUSION

A power system is not only able to meet the present load but also has the flexibility to meet the future demands. A power system is planned to generate electric power in sufficient quantity, to meet the present and estimated future demands of the users in a particular area, to transmit it to the areas where it will be applied and then distribute it within that area, on a continuous basis. To make sure the maximum return on the great investment in the equipment, which goes to make up the power system and to keep the users satisfied with reliable service, the whole system must be maintained in operation continuously without major breakdowns. Therefore, Short circuit studies are important for planning future expansion of power systems as well as in determining the best operation of protective systems.

In this paper short circuit analysis of 33/11/0.4 kV distribution system using ETAP software based on IEC 60909 is carried out with an approach to calculate short circuit current for various types of symmetrical and unsymmetrical faults at different locations. In addition, this paper described the current envelope of the transient fault current when the fault is occurred at grid bus is obtained using IEC 61363-1 standard. This short circuit analysis results can be provided to determine the optimum size of protective equipments to keep the users satisfied with reliable service. Short circuit analysis using ETAP software is an excellent tool for system planning and its protection.

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