Middle-East Journal of Scientific Research 23 (8): 1617-1625, 2015
ISSN 1990-9233
© IDOSI Publications, 2015
DOI: 10.5829/idosi.mejsr.2015.23.08.22406

ANSI and IEC Standards Based Short Circuit Analysis of a Typical 2×30 MW Thermal Power Plant

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Abstract: Power system network becomes very complex and wide spread because of the industrial growth. It may subject to various disturbances and hence the stability and quality of the electrical energy supplied are affected. In grid connected operation, the stability plays a major role in providing the reliable power to the customers. Even if any disturbances occur it needs to be resolved quickly. To ensure the stability of the power system network, the protective devices should be selected in an appropriate manner which can be obtained by performing the short circuit analysis. In this paper, an attempt has been made to analyze the short circuit study of a typical 2×30 MW thermal power plant using Electrical Transient Analyzer Program (ETAP) software. The short circuit analysis has been performed based on American National Standards Institute (ANSI) - C37 and International Electrotechnical Commission (IEC) – 60909, IEC 61363-1 standards. The short circuit responses of the typical 2 × 30 MW thermal power plant for various types of symmetrical and unsymmetrical faults at different locations are obtained. The effect of fault location on the short circuit response has also been investigated in this paper.

Key words: American National Standards Institute (ANSI) · Electrical Transient Analyzer Program (ETAP) · International Electrotechnical Commission (IEC) · Short circuit

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INTRODUCTION

Electric Power System is the interconnected network to generate and supply the electrical power to the customers in an economical and reliable manner [1-4]. Electrical power consumption has been increased due to the technological and industrial growth which makes the power system network very complex [1, 2]. Power system Network is a dynamic system and it may subject to various disturbances which includes the short circuit fault that affects the reliability of the power system [1]. The fault current level in the power system is affected by the addition of new generators, transmission lines and sub-stations. The fault current has to be identified by performing short circuit analysis and the effect of the same on the power system components can be prevented by the proper selection of protective devices [2, 4]. The power system components such as generators, power cables, transformers and transmission lines should be designed to withstand the momentary short circuit current at the time of fault [5]. The fault current can be determined by the intervening reactance of the power components such as generator, transmission line, power cable and transformer [5]. The perspective short circuit current (PSCC) in a system during a fault is of large interest to the design engineers, to design the electrical insulation and the protective system [6]. Short circuit may lead to instability, mechanical and thermal stresses on electrical insulations and it may also cause for fire hazard and electric shock to the working personnel [6]. The short circuit faults in the power system can be classified into two major categories namely symmetrical and unsymmetrical faults [1, 2-4, 7]. Three phase short circuit fault is very rare but most severe fault and it is of most concern from the transient stability point of view [8]. The protective system should be designed properly to maintain the reliability of the electric energy supplied under normal as well as contingency cases [1, 5]. The

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results of fault analysis are used to determine the protective device settings and MVA rating of circuit breakers [3, 9, 10]. Rated MVA of the circuit breaker can also be determined based on the three phase fault which is higher in magnitude than other types of faults [11, 12].

In this paper, the short circuit response of the typical 2×30 MW thermal power plant has been analyzed for various fault conditions at different fault locations using ETAP. Since ETAP is the most effective and user friendly tool to perform the power system studies [13-15], it has been chosen in this paper to simulate the typical 2×30 MW thermal power plant. ANSI- C37, IEC 60909 and IEC 61363-1 standards are used to analyze the short circuit behavior of the system. From the short circuit responses, it is identified that the fault current magnitude is affected by the intervening circuit reactance of the power system components. It is found that the double line to ground fault contributes high magnitude of the fault current among all the unsymmetrical faults and it is also identified that the three phase fault contributes huge fault current than any other fault. The sections in this paper are organized as follows. Section II presents the complete description of the typical 2×30 MW thermal power plant. The detailed description of the short circuit analysis using ANSI and IEC standards has been presented in Section III. The simulation results of the system for various types of fault occurred at different locations are furnished and discussed in section IV. The major findings based on the short circuit responses are highlighted in section V.

System Description: Thermal power plants play an important role in the total power generation in supplying the reliable power. The reliability of the plant can by the proper design of the protective devices. Therefore, a typical 2×30 MW thermal power plant has been considered in this paper for analyzing the short circuit responses which is very much required for designing the protective devices. The description about the major components of the typical 2×30 MW thermal power plant is given in this section. The single line diagram of the typical 2×30 MW thermal power plant having all the major components is shown in Fig. 1 and the details of which are listed in Table 1.

The electrical parameter of various components of the typical 2×30 MW thermal power plant considered in this paper is given in Appendix. The typical 2×30 MW thermal power plant is evacuating 75 MVA power at 132 KV to the grid through the over-head (OH) line of Lychee Aluminum Conductor Steel Reinforced (ACSR) conductor connected between GT bus and Grid bus. Cross Linked Polyethylene (XLPE) armored cables namely Gen cable and Aux cable 1 and 2 are connected between Gen bus and Gen cable and Gen bus and Aux trans bus 1 and 2 to supply the power to the grid and auxiliary equipments respectively.

Short Circuit Analysis: The short circuit is an accidental or intentional conductive path between two or more conducting part, caused by the breakdown of insulation, high surge voltage and human error [5]. It leads to large magnitude of fault current which is greater than full load current [2, 6], [7, 9]. Short circuit current depends on the intervening circuit reactance up to the fault point [5-6]. A short circuit may lead to electromagnetic interference, stability problem, mechanical and thermal stress [6]. The results of short circuit analysis are used for the selection of protective devices and their coordination [3, 9, 10]. In this paper, the short circuit characteristic of the typical 2×30 MW thermal power plant has been analyzed using ANSI C-37, IEC 60909 and IEC 61363-1 standards in ETAP. The detailed description about the short circuit current calculations are presented in this section.

Ansi Standard (C37): The short circuit current calculations based on the ANSI standard has been performed in three different networks namely $\left(\frac{1}{2}\right)$ cycle, $\left(1\frac{1}{2}\right)$ to 4 cycle and 30 cycle. In $\left(\frac{1}{2}\right)$ cycle network, the sub-transient reactance of the network components is used to calculate the fault current and the corresponding network is called as sub-transient network. Here, the momentary short circuit current is calculated after $\left(\frac{1}{2}\right)$ cycle of the fault occurrence. In $\left(1\frac{1}{2}\right)$ to 4 cycle network, the transient reactance of the network components is used to calculate the fault current and the corresponding network is called as transient network. In this network, the interrupting short circuit current is calculated after 4 cycles of the fault occurrence. In 30 cycle network, the steady state reactance of the network components is used to calculate the fault current and it is used to calculate the steady state short circuit current [11, 12]. The device duty settings for the various protective devices obtained from the various ANSI calculation network are givenin Table 2.

Table 1: Major Components Of The Typical Thermal Power Plant

S.No.	Name of the component	Notation
1	Steam turbine generator	Gen 1, Gen 2
2	Generation transformer (GT)	GT-1, GT-2
3	Auxiliary transformer	Aux Trans 1, Aux Trans 2
4	HT motors	BFP-1, ID-1, PA-1, CCWP-1, BFP-2,ID-2, PA-2, CCWP-2
5	LT motors	SA Fan-1, SA Fan-2
6	Power cables	Gen cable, Aux cable 1, Aux cable 2
7	APFC panel	APFC panel-1, APFC panel-2
8	Boiler MCC	-
9	Water Treatment Plant (WTP) MCC	-
10	Electrical Overhead Travelling (EOT) MCC	-
11	AC and Ventilation MCC	-
12	Lube MCC	-

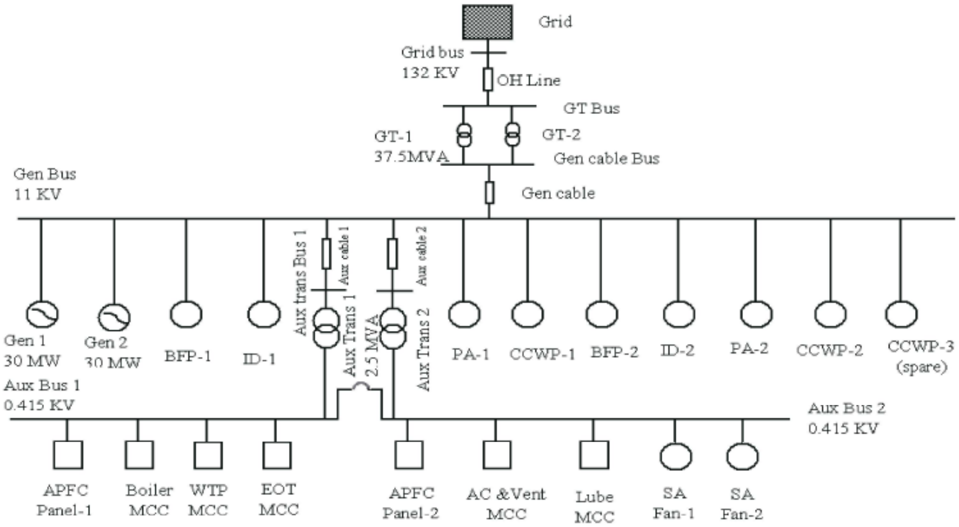

Fig. 1: Single line diagram of the typical thermal power plant

Table 2: Device Duty Settings Obtained From Different Ansi Network

Protective device	$\frac{1}{2}$ cycle network	$1\frac{1}{2}$ - 4 cycle network	30 cycle network
HVCB	Closing and latching capability	Interrupting capability	NA
LVCB	Interrupting capability	NA	NA
Fuse	Interrupting capability	NA	NA
Switch Gear & MCC	Bus bracing	NA	NA
Relay	Instantaneous settings	NA	Over Current settings

Iec Standards: In this paper, two IEC standards namely IEC 60909 and IEC 61363-1 are being used to analyze the short circuit performance of the typical 2×30 MW thermal power plant. In IEC 60909 standard, the initial symmetrical current (I_k'') is obtained by using the nominal voltage (V_n), voltage factor (C) and equivalent impedance at the fault location (Z_k) and peak current (I_p) is obtained by using the initial symmetrical current $\left(I_k''\right)$ and function of system $\left(\frac{R}{X}\right)$ value at fault location (k) as expressed in Equations (1) and (2) respectively.

Initial symmetrical current, $I_k'' = \frac{CV_n}{\sqrt{3}Z_k} in\ KA$ in KA (1)

Peak current, $i_p = \sqrt{2}kI_k'' in\ KA$ in KA (2)

In order to calculate the value of 'k', three methods namely method-A, method-B, method-C are used and the peak current magnitudes are obtained. Method-A which is known as uniform $\left(\frac{R}{X}\right)$ ration, 'k' is determined by taking the smallest of $\left(\frac{R}{X}\right)$ ratio from all the branches of network with 80% of current at nominal voltage is only included. In method-B which is otherwise called as $\left(\frac{R}{X}\right)$ ratio at short circuit location, the value of 'k' is obtained by multiplying $\left(\frac{R}{X}\right)$ with a safety factor of 1.15 to account the inaccuracies in the calculation. In method-C which is known as equivalent frequency method, the value of 'k' is obtained by using the frequency altered $\left(\frac{R}{X}\right)$. Here in this method, $\left(\frac{R}{X}\right)$ is calculated at lower frequency and it is multiplied by a frequency dependent multiplying factor. The breaking current (I_b), DC component of fault current (I_{dc}) and the steady state fault current (I_k) for various fault locations are expressed below [11, 12, 16]. 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 Equations (3) - (5) respectively.

$$I_b = I_k'' \text{ in KA} \tag{3}$$

$$I_b = \mu\, I_k'' \text{ in KA for synchronous machine} \tag{4}$$

$$I_b = \mu\, qI_k'' \text{ in KA for asynchronous machine} \tag{5}$$

where,

μ, q – Factors that accounts for AC decay

The DC component of fault current (I_{dc}) is obtained by using the frequency of the system (f), minimum delay of protective devices (t_{min}) as expressed in Equation (6).

$$I_{dc} = I_k'' \times \sqrt{2} \times \exp\left(\sqrt{\frac{2\Pi f t_{min}}{\frac{X}{R}}}\right) in\ KA \tag{6}$$

The maximum steady state fault current (I_{kmax}) and minimum steady state fault current (I_{kmin}) is obtained by using the rated generator fault current (I_{rG}) and the function of generator excitation voltage and ratio between i_b'' and rated current (λ) as expressed in Equations (7) and (8) respectively.

$$I_{kmax} = \lambda_{max} I_{rG} \text{ in KA} \tag{7}$$

$$I_{kmin} = \lambda_{min} I_{rG} \text{ in KA} \tag{8}$$

In addition, the short circuit performance is analyzed using IEC 61363-1 standard. Based on IEC 61363-1 standard in ETAP, the transient short circuit current waveforms are represented as a function of time from 0 second to 0.1 second with a time increment of 0.001 second by considering various factors that affect the short circuit current. The factors considered includes transient reactance, sub-transient reactance, steady state reactance, transient time constant, sub-transient time constant and DC time constant. In this paper, the short circuit analysis for the typical 2×30 MW thermal power plant have been performed in ETAP by both these standards viz. ANSI and IEC standards for symmetrical and unsymmetrical faults at various fault locations such as grid bus and gen bus. The ETAP based simulation responses on these standards are furnished and discussed in Section IV.

RESULTS AND DISCUSSION

The short circuit analysis for the typical 2×30 MW thermal power plant have been performed in ETAP by both the ANSI and IEC standards for all the types of symmetrical and unsymmetrical faults at various fault locations. The short circuit results of the typical plant using different ANSI networks for the occurrence of symmetrical fault at grid bus and gen bus are given in Tables 3 and 4 respectively.

The short circuit results using different ANSI networks for the occurrence of various unsymmetrical faults at Grid bus and Gen bus are given in Tables 5 and 6 respectively.

In addition, the short circuit responses of the system have been analyzed using various IEC standards namely IEC 60909 and IEC 61363-1. The short circuit calculations based on IEC standard calculates the total initial symmetrical short-circuit rms current (I_k'') as well as the initial symmetrical short-circuit rms current of a synchronous machine (I''_{KG}) in each contributing source [11-12]. 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 grid bus and gen bus are obtained and given in Tables 7 and 8 respectively.

The current envelope of the transient fault current when the fault is occurred at grid bus and gen bus is obtained using IEC 61363-1 standard as shown in Fig. 2 and Fig. 3 respectively.

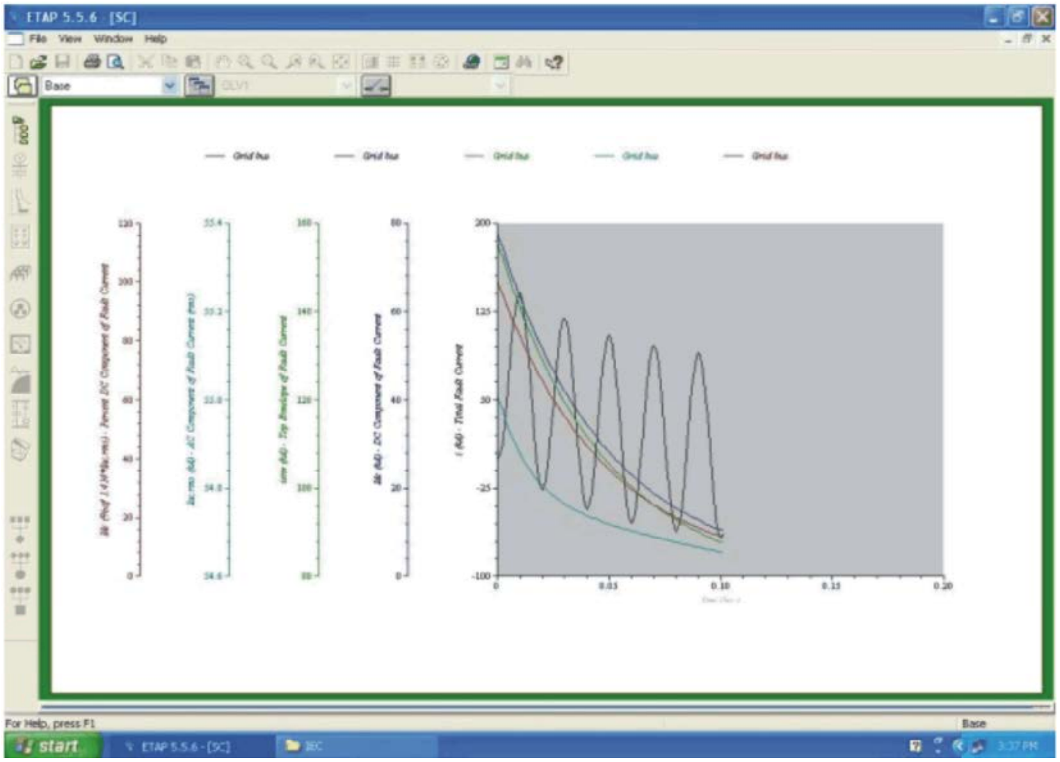

Fig. 2: Fault current envelope during grid bus fault

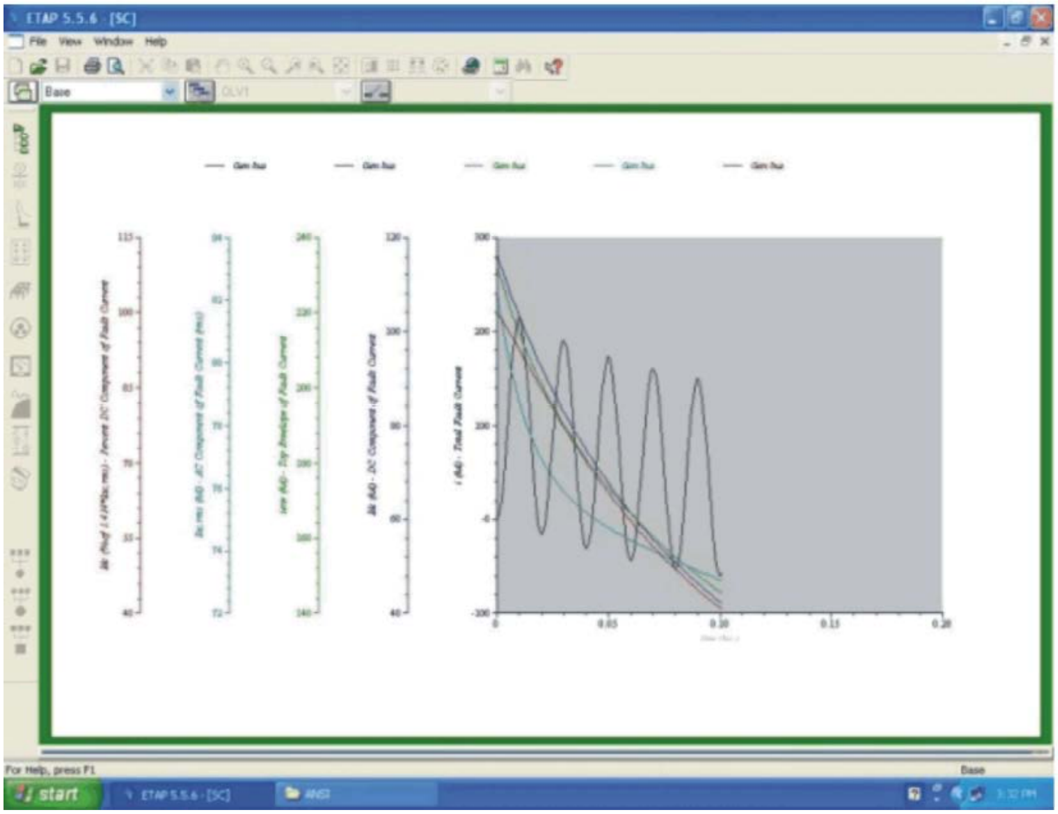

Fig. 3: Fault Current Envelope during Gen Bus Fault

Table 3: Fault Current When The Symmetrical Fault Occurs At Grid Bus

	Bus code		Fault current		
ANSI Network	From bus	To bus	KA real	KA imag	KA sym rms
$\frac{1}{2}$ cycle	Grid bus	Total	49.693	-49.887	49.994
	GT Sec	Grid bus	0.042	-1.475	1.476
	Grid	Grid bus	3.227	-48.412	48.519
$1\frac{1}{2}$ to 4 cycle	Grid bus	Total	3.264	-49.845	49.952
	GT Sec	Grid bus	0.037	-1.434	1.434
	Grid	Grid bus	3.227	-48.412	48.519
30 cycle	Grid bus	Total	14.187	3.254	-49.586
	GT Sec	Grid bus	0.026	-1.175	1.175
	Grid	Grid bus	3.227	-48.412	48.519

Table 4: Fault Current When The Symmetrical Fault Occurs At Gen Bus

	Bus code		Fault current		
ANSI Network	From bus	To bus	KA real	KA imag	KA sym rms
0.5 cycle	Grid bus	Total	2.639	-74.344	74.391
	GT Sec	Grid bus	2.072	-47.4	47.455
1.5 to 4 cycle	Grid bus	Total	2.523	-73.2	73.244
	GT Sec	Grid bus	2.072	-47.4	47.445
30 cycle	Gen	Total	2.37	-66.787	66.829
	Gen cable	Gen	2.072	-47.4	47.455

Table 5: Fault Current When The Unsymmetrical Fault Occurs At Grid Bus

		Fault current		
Type of fault	ANSI Network	KA real	KA imag	KA sym rms
Line to Ground	$\frac{1}{2}$ cycle	3.49	-53.336	53.45
	$1\frac{1}{2}$ - 4 cycle	3.49	-53.317	53.431
	30 cycle	3.481	-53.190	53.303
Line to Line	$\frac{1}{2}$ cycle	43.199	2.831	43.291
	$1\frac{1}{2}$ - 4 cycle	43.178	2.831	43.271
	30 cycle	43.033	2.819	43.125
Double Line to ground	$\frac{1}{2}$ cycle	41.328	31.486	51.956
	$1\frac{1}{2}$ - 4 cycle	41.304	31.469	51.926
	30 cycle	41.132	31.368	51.728

The IEC 61363-1 standard based simulation results namely total fault current (I), DC component of fault current (I_{dc}), Peak envelope 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 and gen bus are obtained and listed in Tables 9 and 10 respectively.

On analyzing the short circuit results of the typical 2×30 MW thermal power plant, it is found that the fault current magnitude is decreased by the intervening reactance of the power system components connected between the fault location and sources. It is identified that the fault current when the double line to ground fault occurs is very large than any other unsymmetrical fault.

Table 6: Fault Current When The Unsymmetrical Fault Occurs At Gen Bus

		Fault current		
Type of fault	ANSI Network	KA real	KA imag	KA sym rms
Line to Ground	$\frac{1}{2}$ cycle	0.2	-0.001	0.2
	$1\frac{1}{2}$ - 4 cycle	0.2	-0.001	0.2
	30 cycle	0.2	-0.001	0.2
Line to Line	$\frac{1}{2}$ cycle	64.25	2.282	64.291
	$1\frac{1}{2}$ - 4 cycle	63.679	2.285	63.72
	30 cycle	59.95	2.054	59.985
Double Line to ground	$\frac{1}{2}$ cycle	-64.3	-2.282	64.341
	$1\frac{1}{2}$ - 4 cycle	-63.729	-2.285	63.77
	30 cycle	-59.998	-2.053	60.033

Table 7: Fault Current When The Fault Occurs At Grid Bus

	Fault type			
Fault Current	Three phase	Line to Ground	Line to Line	Double line to ground
(I_k'')	50.15	53.667	43.42	52.154
(i_p)	129.43	138.506	112.061	134.603
(I_b)	49.787	53.667	43.420	52.154
(I_k)	50.048	53.667	43.42	52.154

Table 8: Fault Current When The Fault Occurs At Gen Bus

	Fault type			
Fault Current	Three phase	Line to Ground	Line to Line	Double line to ground
(I_k'')	81.634	0.22	70.39	70.445
(i_p)	218.438	0.589	168.351	188.499
(I_b)	68.725	0.22	70.39	70.445
(I_k)	78.875	0.22	70.39	70.445

Table 9: Transient Fault Current For The Grid BusFault

	Fault current				
T (Cycle)	I (KA)	I_{dc} (KA)	I_{env} (KA)	I_{ac} (KA)	$I_{dc\%}$ (%)
0	0	77.796	155.592	55.010	100
0.1	11.746	76.646	152.395	54.977	96.01
0.2	47.617	71.63	149.337	54.947	92.18
0.3	92.741	68.739	146.41	54.922	88.5
0.4	128.78	65.969	143.608	54.899	84.97
0.5	140.924	63.314	140.924	54.879	81.58
0.6	123.535	60.763	138.352	54.861	78.32
0.7	82.294	58.326	135.889	54.845	75.20
0.8	32.024	55.986	133.528	54.831	72.2
0.9	-8.978	53.741	131.265	54.818	69.32
1.0	-25.92	51.588	129.097	54.807	66.56
1.1	-13.17	49.524	127.018	54.797	63.91

Table 10: Transient Fault Current For The Gen Bus Fault

	Fault current				
T (Cycle)	I (KA)	I_{dc} (KA)	I_{env} (KA)	I_{ac} (KA)	I_{dc} (%)
0	0	116.292	232.585	82.231	100
0.1	20.376	113.431	228.455	81.334	98.62
0.2	75.50	110.704	224.621	80.552	97.18
0.3	142.996	108.092	221.044	79.809	95.7
0.4	196.28	105.584	217.69	79.271	94.18
0.5	214.534	103.168	214.534	78.747	92.64
0.6	190.408	100.838	211.552	78.287	91.08
0.7	132.623	98.587	208.727	77.88	89.51
0.8	62.532	96.41	206.042	77.521	87.94
0.9	5.973	94.302	203.483	77.203	86.37
1.0	-16.521	92.259	201.039	76.919	84.81
1.1	2.563	90.278	198.699	76.665	83.27

It is also witnessed from the responses obtained by both ANSI and IEC standards that the three phases to ground fault contributes the largest fault current among all the faults. By analyzing the short circuit results of the typical 2×30 MW thermal power plant, it is identified that the short circuit current values obtained through simulation can be used to determine the instantaneous current settings of the relay, momentary short circuit current rating, breaking capacity, interrupting capacity and fault MVA of the circuit breaker.

CONCLUSION

In this paper, the short circuit response of the typical 2×30 MW thermal power plant has been analyzed by ANSI C-37, IEC 60909 and IEC 61363-1 standards using ETAP. The short circuit characteristics of the system for symmetrical and unsymmetrical faults at grid bus and gen bus are analyzed. It is found from the results based on the ANSI and IEC standards that the fault current is influenced by the intervening reactance of the power system components connected between the fault location and the source. The short circuit result of all the unsymmetrical faults conveys that the double line to ground fault contributes huge fault current than the other faults. The three phase fault is found to cause for very large fault current among all the types of symmetrical and unsymmetrical faults. It is identified that the short circuit current values obtained through simulation can be used to determine the instantaneous current settings of the relay, momentary short circuit current rating, breaking capacity, interrupting capacity and fault MVA of the circuit breaker, which are very much essential for the design of protective devices. In future, the work can be extended to design the protective system for the typical power plant and the same can be coordinated to ensure the proper operation of protective system.

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