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Selection of Circuit Breaker Rating for Symmetrical Fault Analysis on Transmission Lines

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Abstract: ***Fault studies play a significant role in the power system analysis for stable and economical operations of a power system. Faults on power system are broadly divided into symmetrical and unsymmetrical faults. The paper describes the short circuit analysis for three phase symmetrical fault for finding the short circuit rating of circuit breaker. Circuit breakers serve as interrupting devices which interrupt the operating and short circuit currents. MATLAB based programs were written for load flow studies to determine prefault conditions and three phase short circuit studies. In this paper short circuit studies done on the IEEE 14 bus system which gives us maximum fault current and fault MVA rating which help in settings of relay.***

Keywords: Symmetrical fault, Circuit breaker, Fault, Short circuit current, Power system

1. Introduction

The normal operation of a power system is balanced steady state three phase operation. This condition can be temporarily troubled by a number of undesirable and unavoidable incidents. A short circuit or fault is said to occur if the insulation of the system fails at any location due to system over voltages caused by lighting or switching surges, insulation contamination or other mechanical causes etc[1]. When short circuit occurs, high currents; several times higher than normal operating currents flows in the system depending on the nature and location of the fault. The fault current if allowed to persist may cause thermal damage to the equipment. It is therefore necessary to remove faulty section of a power system from service as soon as possible. Standard extra high voltage protective equipment is designed to clear faults within three cycles. Low voltage protective equipment operates more slowly and may take 5-20 cycles. Fault studies form an important part of power system analysis. The problem consists of determining bus voltages and line currents during various types of faults. Based on these studies the short circuit MVA at various points in the network can be calculated. These short circuit levels provide the basis for specifying interrupting capacities of circuit breakers. Changes in the configuration of the transmission network alter both the short circuit levels and short circuit currents in the system. Hence, when any major modifications to the power system are made these computations must be repeated to determine the adequacy of the protective equipment. The magnitude of the fault current, dependents on the internal impedance of the generators, plus the impedance of the intervening circuit. The reactance of the generator under short circuit condition is not constant [2]. The bus impedance matrix by the building algorithm is employed for the symmetrical computation of bus voltages and line currents during a three phase fault. MATLAB programmes to compute the node voltages and line currents, under a three phase fault condition have been developed and included.

2. Approach to Quantify the Fault

Faults may occur at different points in a power system. We mostly concerned with faults on transmission lines. Faults that occur on transmission lines are broadly classified as: Three Phase Short Circuit and Unsymmetrical Faults.

A. Three Phase Short Circuit: In three phase short circuits three phases are short circuited to each other and often to earth also. Such faults are balanced and symmetrical in the sense that the system remains balanced even after the fault. A three phase short circuit occurs rarely but it is most severe type of faults involving largest currents. For this reason, the balanced short circuit calculations are performed to determine these large currents to be used to determine the rating of circuit breaker.

B. Effects of Fault: Faults can damage or disrupt power system in several ways. Fault can give rise to abnormal operating conditions, usually excessive voltages and currents at certain points on the system. Large voltage stress insulation beyond their breakdown value while large currents result in over heating of power system components. Faults can cause the three phase system to become unbalanced with the result that three phase equipment operate improperly and block the flow of power. Hence, it is necessary that, upon occurrence of the fault, the faulty section should be disconnected as rapidly as possible in order that the normal operation of the rest of the system is not affected. The relays should immediately detect the existence of the fault and initiate circuit breaker operation to disconnect the faulty section.

C. Fault Analysis: Fault analysis is also known as short circuit study or short circuit analysis. A fault analysis includes; to determine the values of voltages and currents at different points of the system during the fault, determination of rating of required circuit breakers, selection of appropriate scheme of protective relaying.

Circuit breaker is capable of interrupting fault current and of reclosing. Modern circuit breaker standards are based on symmetrical interrupting current. It is usually necessary to calculate only symmetrical fault current at a system location, and then select a breaker with a symmetrical interrupting capability equal to or above the calculated current. The breaker has the additional capability to interrupt the asymmetrical or total fault current if the dc offset is not too large[3].

D. Calculation of Sub Transient Fault Current: A three phase symmetrical short circuit is caused by the application of three equal fault impedances Z_f between each phase and ground. In order to calculate the sub transient fault current or initial symmetrical current for a three phase short circuit in a power system, we make the following assumptions for the simplicity:

- Transformers are represented by their leakage reactances. Winding resistances shunt admittances and delta-star phase shifts are neglected.
- Transmission lines are represented by their equivalent series reactances. Series reactances and shunt admittances are neglected.
- Synchronous machines are represented by constant voltage sources behind sub transient reactances. Armature resistance, saliency, and saturation are neglected.
- All non rotating impedances loads are neglected.
- Induction motors are either neglected or represented in the same manner as synchronous machines.

To calculate sub transient fault currents for three phase faults in an N-bus power system. The system is modelled by its positive sequence network, where lines and transformers are represented by series reactances and synchronous machines are represented by constant voltage sources behind sub transient reactances. For simplicity we also neglect pre fault load currents [4].

E. Selection of Short Circuit Current (SCC) Rating of Circuit Breaker:

A simplified method for breaker selection is called the "E/X simplified method". The maximum symmetrical short circuit current at the system location in question is called the pre fault voltage and system reactance characteristics, using computer programs. Resistances shunt admittances, non rotating impedance loads and pre fault load currents are neglected. The two ratings of the circuit breaker which require the computations of SCC are: Rated Momentary Current & Rated Symmetrical Interrupting Current.

Symmetrical SC current is obtained by using sub transient reactance for synchronous machines, Momentary current (RMS) is then calculated by multiplying the symmetrical momentary current by a factor of 1.6 to account of DC off set current. Symmetrical current to be interrupted is computed by using sub transients reactance for synchronous generators and transient's reactance for synchronous motor. The DC offset value to be added to obtain the current to be interrupted is accounted for by multiplying the symmetrical SC current by a factor as tabulated below:

C B Speed	Multiplying Factor
8cycles or slower	1.0
5cycles	1.1
3cycles	1.2
2cycles	1.4

If SC MVA is more than 500, the above multiplying factors are increased by 0.1 each. The multiplying factor for air breakers rated 600V or lower is 1.25. The current that a circuit breaker can interrupt is inversely proportional to the operating voltage over a certain range that is;

Amperes at Operating Voltage= Amperes at Rated Voltage /Operating Voltage

As the operating voltage cannot exceed the maximum design value. Also no matter how low the voltage is the rated interrupting current cannot exceed the rated maximum interrupting current. Over this range of voltages, the product of operating voltages and interrupting current is constant. It is therefore logical as well as convenient to express the circuit breaker rating in terms of SC MVA that can be interrupted, and defined as

Rated Interrupting MVA (Three Phase) Capacity = $\sqrt{3}|V(line)| \times |I(line)|$

where V (line) is rated voltage in kV and I (line) is rated interrupting current in kA.

Thus instead of computing the SC current to be interrupted, we compute three phase SC MVA to be interrupted, where

SC MVA (3-Phase) = $\sqrt{3} \times prefault\ line\ voltage\ in\ kV \times SC\ curent\ in\ kA$

If voltage and current are in per unit values on a three phase basis

SC MVA (3-phase) = $|V|prefault \times |Isc| \times (MVA)base$

Obviously, rated MVA interrupting capacity of a circuit breaker is to be more than or equal to the SC MVA required to be interrupted.

For the selection of a circuit breaker for a particular location, we must find the maximum possible SC MVA to be interrupted with respect to type and location of fault and generating capacity connected to the system. A three phase fault through rare is generally the one which gives the highest SC MVA and a circuit breaker must be capable of interrupting it. An exception is an LG (line to ground) fault close to a synchronous generator. In a simple system the fault location which gives the highest SC MVA may be obvious but in a large system various possible locations must be tried out to obtain the highest SC MVA requiring repeated computations[5].

F. Algorithm for Short Circuit Studies: For short circuit computation of large system, a systematic general algorithm has been developed.

Step I: Consider N bus system with operating at steady load. Obtain pre fault voltages and currents in all the lines 'L' through load flow study. Suppose K^{th} bus is faulted through a fault impedance Z_f. Calculate post fault bus voltage with ΔV represent the changes in bus voltages at caused by fault.

Step II: Make passive Thevenin network of the system with generators replaced by transient or sub transient reactance with their e.m.fs shorted.

Step III: Excite the passive Thevenin network with $-V_{k0}$ in series with Z_f. ΔV comprises the bus voltages of this network.

Step IV: Calculate voltage at K^{th} bus under fault and fault current I_f.

G. Objective: The main objective of this work is to determine the Short Circuit Capacity of the bus bar / transmission line and to determine the Rating of Circuit Breaker related to these lines.

Results and Discussions of Standard IEEE 14 Bus Test System

In the present work IEEE-14 bus system analysed to determine the short circuit behaviour of power system under loading conditions. In IEEE -14 buses, symmetrical fault is applied on each bus and calculated the Short circuit MVA of each bus/line through programming. 100 MVA and 220 kV are kept as base values and Mat lab tool is used for analyze the system. During calculations the, SCC level is calculated for all buses. Short circuit capacity of bus determines the strength of bus bar. These calculations are very essential for designing any power system because if fault MVA values are above the designing level, then the bus bars will damage and disturb the whole supply. This may lead damage of equipments such as conductor, breaker, isolators etc. The calculations for short circuit capacity on short circuit current in each line &from these results, calculations the circuit breaker design parameters namely-Breaking Capacity, Making Capacity, Operating Time cycles, Short time rating in Amp/Sec have been done.

Table 1: Exciter Data of Network

Exciter No.	1	2	3	4	5
K_A	200	20	20	20	20
T_A	.02	.02	.02	.02	.02
T_B	0.0	0.0	0.0	0.0	0.0
T_C	0.0	0.0	0.0	0.0	0.0
V_{Rmax}	7.32	4.38	4.38	6.81	6.81
V_{Rmin}	0.0	0.0	0.0	1.395	1.395
K_E	1.0	1.0	1.0	1.0	1.0
T_E	0.19	1.98	1.98	0.70	0.70
K_F	.0012	.0001	.0001	.0001	.0001
T_F	1.0	1.0	1.0	1.0	1.0

Table 2: Generator Data of Network

Generator Bus No.	1	2	3	4	5
MVA	615	60	60	25	25
X_l(p.u)	0.2396	.00	.00	.134	.134
Ra(p.u)	0.00	.0031	.0031	.0014	.0014
Xd(p.u)	.8979	1.05	1.05	1.25	1.25
Xd'(p.u)	.2995	.1850	.1850	.232	.232
Xd''(p.u)	0.23	.13	.13	.12	.12
Tdo'	7.4	6.1	6.1	4.75	4.75
Tdo"	.03	.04	.04	.06	.06
Xq(p.u)	.646	.98	.98	1.22	1.22
Xq'(p.u)	.646	.36	.36	.715	.715
Xq" (p.u)	.4	.13	.13	.12	.12
Tqo'	.00	.3	.3	1.5	1.5
Tqo"	.033	.099	.099	.21	.21
H	5.148	6.54	6.54	5.06	5.06
D	2	2	2	2	2

Table 3: Bus Data of Network

Bus No.	P Gen (p.u)	Q Gen (p.u)	P Load (p.u)	Q Load (p.u)	Bus Type	Q Gen Max (p.u)	Q Gen Min (p.u)
1	2.32	0.00	0.00	0.00	2	10	-10
2	0.4	-0.42	.2170	.2170	1	.5	-0.4
3	0.00	0.00	.9420	.1900	2	0.4	0.00
4	0.0	0.0	.4780	0.00	3	0.0	0.0
5	0.0	0.0	.0760	.0160	3	0.0	0.0
6	0.0	0.0	.1120	.0750	2	.24	-.06
7	0.0	0.0	0.0	0.0	3	0.0	0.0
8	0.0	0.0	0.0	0.0	2	.24	-.06
9	0.0	0.0	.2950	.1660	3	0.0	0.0
10	0.0	0.0	.0900	.0580	3	0.0	0.0
11	0.0	0.0	.0350	.0180	3	0.0	0.0
12	.0	0.0	.0610	.0160	3	0.0	0.0
13	0.0	0.0	.1350	.0580	3	0.0	0.0
14	0.0	0.0	.1490	.0500	3	0.0	0.0

Table 4: Line Data of Network

From Bus	*To bus*	*Resistance (p.u)*	*Reactance (p.u)*	*Line charging (p.u)*	*Tap ratio*
1	2	.01938	.05917	.05917	1
1	5	.05403	.22304	.22304	1
2	3	.04699	.19797	.19797	1
2	4	.05811	.17632	.17632	1
2	5	.05695	.17388	.17388	1
3	4	.06701	.17103	.17103	1
4	5	.01335	.04211	.04211	1
4	7	0.00	.20912	.20912	.978
4	9	0.00	.55618	.55618	.969
5	6	0.00	.25202	.25202	.932
6	11	.09498	.1989	.1989	1
6	12	.12291	.25581	.25581	1
6	13	.06615	.13027	.13027	1
7	8	0.00	.176215	.17615	1
7	9	0.00	.11001	.11001	1
9	10	.03181	.08450	.08450	1
9	14	.12711	.27038	.27038	1
10	11	.0825	.19207	.19207	1
12	13	.22092	.19988	.19988	1
13	14	.17093	.34802	.34802	1

Table 5: Results of Fault Current & SCC of IEEE-14 Bus Network

Bus No.	*Fault Current (P.U)*	*Bus Angle*	*Fault Current (kA)*	*SCC (MVA)*
1	10.6068	-83.46	2.78	1060.71
2	3.5571	-84.98	0.93	355.72
3	5.2468	-79.70	1.38	524.70
4	6.9595	-81.27	1.83	695.97
5	7.1652	-81.78	1.88	716.54
6	3.4925	-83.70	0.92	349.26
7	3.8731	-84.95	1.02	387.32
8	2.4014	-87.38	0.63	240.15
9	3.7234	-84.06	0.98	372.35
10	3.1924	-81.44	0.84	319.25
11	2.8643	-72.38	0.75	286.44
12	2.3707	-74.61	0.62	237.08
13	2.8635	-78.89	0.75	286.36
14	2.4902	-76.80	0.65	249.03

Table 6: Results of Short Circuit Current, Breaking Capacity, Making Capacity, Rated Symmetrical Breaking Current and Short Time Ratings.

The results are at: 3-Phase balanced fault, voltage level of system is 220kV, and operating time cycle is 3 sec.

Fault location	*Name of the circuit*	*Short Circuit current in KA*	*Breaking Capacity in MVA*	*Rated symmetrical braking current in AMP*	*Making capacity in MVA*	*Short time ratings AMP/SEC*
Fault at bus no .1	2-1	0.4	152.42047	400	388.6722	400/3
	5-1	0.09	34.294606	90	87.451245	90/3
Fault at bus no .2	3-2	0.01	3.8105118	10	9.716805	10/3
	1-2	0.3	114.31535	300	291.50415	300/3
	4-2	0.02	7.6210235	20	19.43361	20/3
	5-2	0.04	15.242047	40	38.86722	40/4
Fault at bus no .3	3-3	0.3	114.31535	300	291.50415	300/3
	4-3	0.24	91.452282	240	233.20332	240/3
Fault at bus no .4	2-4	0.24	91.452282	240	233.20332	240/3
	3-4	0.12	45.726141	120	116.60166	120/3
	5-4	0.32	121.93638	320	310.93776	320/3
	7-4	0.01	3.8105118	10	9.716805	10/3
Fault at bus no .5	1-5	0.21	80.020747	210	204.0529	210/3
	2-5	0.24	91.452282	240	233.20332	240/3
Fault at bus no .6	5-6	0.22	83.831259	220	213.76971	220/3
	11-6	0.07	26.673582	70	68.017635	70/3
	12-6	0.01	3.8105118	10	9.716805	10/3
	13-6	0.04	15.242047	40	38.86722	40/3
Fault at bus no .7	9-7	0.15	57.157676	150	145.75207	150/3
Fault at bus no .8	7-8	0.24	91.452282	240	233.20332	240/3
Fault at bus no .9	4-9	0.09	34.294606	90	87.451245	90/3
	7-9	0.16	60.968188	160	155.46888	160/3
	10-9	0.06	22.863071	60	58.30083	60/3
	14-9	0.04	15.242047	40	38.86722	40/3
Fault at bus no .10	9-10	0.23	87.64177	230	223.48651	230/3
	11-10	0.09	34.294606	90	87.451245	90/3
Fault at bus no .11	10-11	0.13	49.536653	130	126.31846	130/3
	6-11	0.15	57.157676	150	145.75207	150/3
Fault at bus no .12	6-12	0.13	49.536653	130	126.31846	130/3
	13-12	0.01	3.8105118	10	9.716805	10/3
Fault at bus no .13	12-13	0.04	15.242047	40	38.86722	40/3
	14-13	0.06	22.863071	60	58.30083	60/3
Fault at bus no .14	13-14	0.09	34.294606	90	87.451245	90/3

Fault analysis on power system involves knowing the system performance at steady state and calculating the values of current flowing in the system when fault occurs. Fault analysis was subsequently carried out to determine the voltage and current when fault occurs, results shows excessively high current flow. On the basis of the current calculation the appropriate rating of circuit breaker is required to protect the transmission lines from symmetrical fault.

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