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A Comparison of Short-circuit Current Decaying Calculation between PSS/E BKDY and Computational Curve

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Abstract. The calculations of short-circuit current decrement with PSS/E BKDY and computational curve were compared with the one by the dynamic simulation of PSS/E. Calculation shows that the accuracy of the result by PSS/E BKDY is quite good while the one by computational curve is so conservative that it makes larger errors. The reasons for the above results have been analyzed theoretically.

Introduction

Short-circuit is severe fault in power system. It is very important to calculate the short-circuit current for selecting electrical equipment, configurating protective relaying and automatic device. Conventional short-circuit current calculation that only needs the network structure data, power flow data and sub-transient reactance of generators is based on the steady-state power flow or the classical assumptions, calculating the periodic component of short-circuit current at the instant of fault application. The calculation is so convenient that it is now available in most power system simulation software such as PSASP, BPA, PSS/E. However, it just calculates the initial value of the periodic component of short-circuit current and unable to calculate its decrement. In fact, the short-circuit current will decay to a certain extent before the circuit breaker trips. If the short-circuit current decrement before circuit breaker tripping is calculated, it will be able to make full use of existing circuit breaker on the basis of security, to delay or avoid replacing circuit breaker in a large amount due to short of interrupting capacity.

Computational curve is often used to estimate the periodic component of short-circuit current at any time after fault to make up for the fact that conventional short-circuit current calculation just calculates the initial value. The short-circuit computational curve currently used in China was formulated with reference to the ones made by the former Soviet Union in the early 1980s [1]. However, there are many differences between early 1980s and today in generator parameters, load distribution in power system and so on, which make large errors when computational curve is used to estimate the decaying periodic component of short-circuit current in actual power systems [2,3].

The PSS/E simulation software developed by PTI company in the United States provides a method of calculating the short-circuit current decrement named BKDY besides conventional short-circuit current calculation.

In addition to the periodic component of short-circuit current, BKDY is able to estimate other components of short-circuit current, such as the DC component and its decrement, the total root-mean-square(RMS) value and peak value of short-circuit current. BKDY is used for simulation in small network and actual power system in reference [4,5]. Calculation shows that BKDY which is quite good in the research of short-circuit current decaying and circuit breaker interrupting duty is able to work out the decaying periodic and DC components of short-circuit current accurately.

In this paper, the calculations of short-circuit decrement in IEEE9 system [6] with PSS/E BKDY and computational curve were compared with the results by the dynamic simulation of PSS/E in the same condition.

PSS/E BKDY Module

Method of Calculating Short-circuit Current Decrement. The impact of sudden short-circuit in power system on generator is related to the interaction of current in stator and rotor windings, so it is very complicated to carry out rigorous analysis of the process that needs a set of non-linear differential equations of mechanical, electrical and magnetic effect. The theory of flux linkage conservation in superconducting loop is often used in calculation of short-circuit current in power system to avoid complicated mathematical calculations, which changes differential equations into algebraic equations to simplify the problem. However, the actual stator and rotor windings in machines are not superconductors because of existing resistance and the current and the flux in windings will decay after fault application. Take the d-axis for example, the periodic d-axis component of short-circuit current is shown as Eq. 1 [7], and the equivalent for the q-axis, where the unisource system excludes load, line charging capacitance, compensating capacitance, resistance of all elements, magnetizing branches of transformers and the increment by forced excitation.

$$i_{d(a\omega)}(t)=\frac{E_{q[0]}}{X_d+X_e}+\left(\frac{E'_{q[0]}}{X'_d+X_e}-\frac{E_{q[0]}}{X_d+X_e}\right)e^{-\frac{t}{T'_d}}+\left(\frac{E''_{q[0]}}{X''_d+X_e}-\frac{E'_{q[0]}}{X'_d+X_e}\right)e^{-\frac{t}{T''_d}} \tag{1}$$

Where, $E_{q[0]}, E'_{q[0]}, E''_{q[0]}$ is the prefault no-load steady-state, transient and subtransient potential of the generator, respectively; X_d, X'_d, X''_d is the synchronous, transient and subtransient reactance of the generator, respectively; X_e is the reactance between generator and short-circuit location, that is the external reactance; T'_d, T''_d is the time constant of transient and subtransient component decaying, respectively.

Calculation Theory of PSS/E BKDY. The calculation theory of short-circuit current decaying by PSS/E BKDY is similar to the method above, assuming that the flux linkages in generator windings keep constant at the instant of fault application and latter decay at the time constant of transient and subtransient component, and the generator d-axis flux is expressed as Eq. 2 [8,9], and the the equivalent for the q-axis.

$$\begin{aligned}\psi''_d=&\psi''_{d0}(X''_d+X_e)[(\frac{1}{X''_d+X_e}-\frac{1}{X'_d+X_e})e^{-\frac{t}{T''_d}}+(\frac{1}{X'_d+X_e}-\frac{1}{X_d+X_e})e^{-\frac{t}{T'_d}}+\frac{1}{X_d+X_e}]\\&+i_{d0}(X''_d+X_e)[\frac{X_d-X''_d}{X_d+X_e}(1-e^{-\frac{t}{T'_d}})+\frac{X'_d-X''_d}{X'_d+X_e}(e^{-\frac{t}{T'_d}}-e^{-\frac{t}{T''_d}})]\end{aligned} \tag{2}$$

Where, ψ''_{d0} is the linear combination of initial flux in rotor exciter winding and d-axis damper winding of the generator, that is subtransient potential; i_{d0} is the d-axis component of initial current in stator winding; X_e is the value calculated by dividing the voltage at each terminal by the current flowing at the terminals at fault initiation; the remaining parameters are the same as Eq. 1. In the unisource system, Eq. 1 and Eq. 2 can be duduced from each other when all the elements except series reactance are neglected.

So, besides the network structure data, it is necessary to get the generator dynamic parameters for calculation by PSS/E BKDY, including the d-axis and q-axis synchronous, transient and subtransient reactance as well as the time constant of transient and subtransient component which are saved in the *Breaker Duty Data File* (suffix *bkd*) being added into BKDY for calculation.

Short-circuit Current Computational Curve

Formulation of Short-circuit Current Computational Curve. According to Eq. 1, when the generator (including the excitation system) parameters and initial state are determined, the periodic component of short-circuit current is the function of the time and the electrical distance between power source and short-circuit location, named short-circuit current computational curve. The electrical distance between power supply and short-circuit location is expressed by operational reactance, a per unit based on the rated capacity of the generator, shown as Eq. 3.

$$X_{js} = X_d'' + X_e \tag{3}$$

Fig. 1 is a typical connection diagram used for formulating computational curve on the assumption that the generator is operating at normal full-load state before fault application, 50% of the load distributed to the high-voltage bus (the power-factor is 0.9, in the form of constant impedance). The generator is equipped with field forcing device where the peak value of forced excitation voltage is 1.8 times that of the nominal state, the equivalent time constant of excitation system is set to 0.25s for turbo-generator and 0.02s for hydroelectric generator [1].

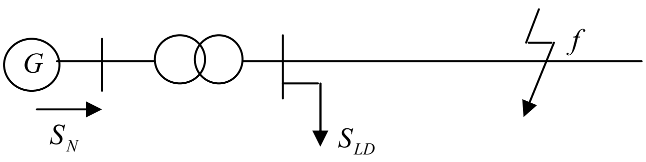

Fig. 1 Typical Connection Diagram Used for Formulating Computational Curve

In order to expand the applicability of computational curve, the prototype generators connected as Fig. 1, for which the periodic components of short-circuit current at any time after fault application are calculated, are selected from 18 different types of turbo-generator from 12MW to 200MW in capacity and 17 different types of hydroelectric generator from 12.5 MW to 225 MW in capacity. To get the typical computational curve of turbo-generator and hydroelectric generator, the values of periodic component of short-circuit current of different prototypes with the same operational reactance at the same instant are classified according to steam and hydraulic turbine to work out the arithmetic mean value which is the function of operational reactance and time. The short-circuit computational curve currently used in power system was formulated in the early 1980s.

Usage of Short-circuit Current Computational Curve. There are many differences between the power system with only one generator used for formulating computational curve shown in Fig. 1 and the the actual ones with many generators connected to form a complex network. In order to use the computational curve in actual power system, first it is necessary to convert the actual complex network into radial network where the short-circuit location *f* is the center and all the power sources are the ends, while each source branch is assumed to be the typical connection above.

And then the transfer reactance of each source branch and the corresponding operational reactance are calculated, respectively. According to the operational reactance, the periodic component of short-circuit current supplied by the relevant power source is obtainable in computational curve and the total short-circuit current is also available by summing all the practical values of short-circuit current supplied by each power source.

Comparisons between PSS/E BKDY and Computational Curve. PSS/E BKDY and computational curve are different methods of simplifying the complicated physical process and reducing the computation for engineering. With BKDY the differential equations are changed into algebraic equations, and network structure data and generator dynamic parameters are directly used for calculation, which reflects the short-circuit current changing after fault application. With computational curve the arithmetic mean values from typical parameters and prototype generators are used, and it is necessary to convert the actual network into typical connection to get the corresponding values of short-circuit current from computational curve. In this paper, the calculation results by the two methods above are compared.

Case Analysis

Introduction of the Case. Take the IEEE9 system for example, the network structure and the steady-state power flow are shown in Fig. 2. Given the dynamic parameters of the generators, the salient pole machine model is used for Gen1 while the round-rotor machine model is used for Gen2 and Gen3 for simulation with PSS/E; Gen1 is supposed to be hydraulic turbine while Gen2 and Gen3 is supposed to be steam turbine for calculation with computational curve.

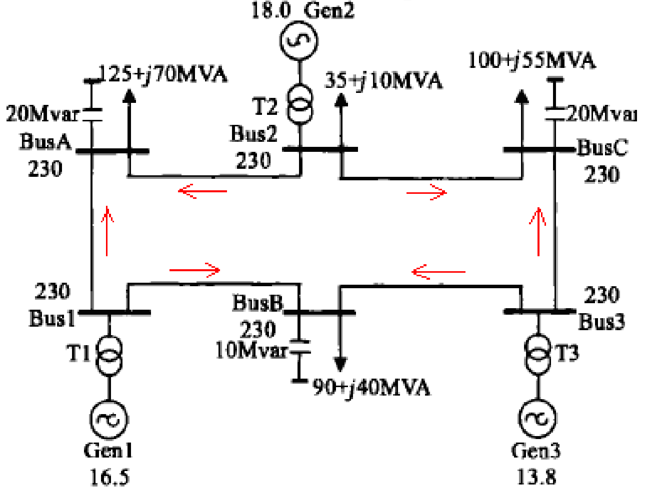

Fig. 2 IEEE9 System

Comparisons between Calculation Results. Supposing Bus1 and BusA are the three-phase short-circuit locations separately, the calculation results by PSS/E BKDY based on power flow, computational curve and dynamic simulation of PSS/E are shown in Table 1 and Table 2, the decaying curves shown in Fig. 3 and Fig. 4. The method of linear interpolation is applied to the values unobtainable from the digital table for calculation with computational curve. The calculation results by dynamic simulation in which the generator is expressed by differential equations without algebraic simplification are used to check the accuracy of the results by PSS/E BKDY and computational curve as reference.

Table 1 Decrement of the periodic component of fault current when Bus1 is three-phase short-circuited.

Faulted Time/s	BKDY		Computational Curve		Dynamic Simulation/A
	Value/A	Rate of Tolerance /%	Value/A	Rate of Tolerance /%	
0.00	3753.1	0.00	4189.2	11.62	3753.2
0.01	3579.8	-1.14	4052.2	11.91	3621.0
0.02	3446.9	-0.38	3974.5	14.87	3460.0
0.03	3344.1	-1.47	3896.8	14.81	3394.1
0.04	3263.9	-2.05	3819.1	14.62	3332.0
0.05	3200.6	-2.60	3741.4	13.85	3286.2
0.06	3150.1	-3.10	3663.7	12.70	3250.8
0.07	3109.3	-3.52	3629.8	12.63	3222.6
0.08	3075.7	-3.87	3595.9	12.39	3199.6
0.09	3047.7	-4.17	3561.9	12.00	3180.2
0.10	3024.1	-4.41	3528.0	11.52	3163.5

Note: $Rate\ \ of\ \ Tolerance\,(\%) = \frac{Value\ \ by\ \ BKDY\ (or\ \ Computational\ \ Curve) - Value\ \ by\ \ Dynamic\ \ Simulation}{Value\ \ by\ \ Dynamic\ \ Simulation} \times 100\%.$

Table 2 Decrement of the periodic component of fault current when BusA is three-phase short-circuited.

Faulted	BKDY		Computational Curve		Dynamic
Time/s	Value/A	Rate of Tolerance /%	Value/A	Rate of Tolerance /%	Simulation/A
0.00	2451.3	0.00	2544.9	3.81	2451.4
0.01	2370.6	-1.20	2509.6	4.60	2399.3
0.02	2305.8	-1.18	2487.5	6.60	2333.4
0.03	2253.1	-2.19	2465.3	7.02	2303.6
0.04	2210.0	-2.88	2443.2	7.36	2275.7
0.05	2174.3	-3.59	2421.1	7.35	2255.2
0.06	2144.4	-4.19	2399.0	7.18	2238.3
0.07	2119.1	-4.72	2388.0	7.37	2224.0
0.08	2097.5	-5.16	2377.0	7.47	2211.7
0.09	2078.7	-5.55	2366.0	7.50	2200.8
0.10	2062.3	-5.87	2355.0	7.49	2190.9

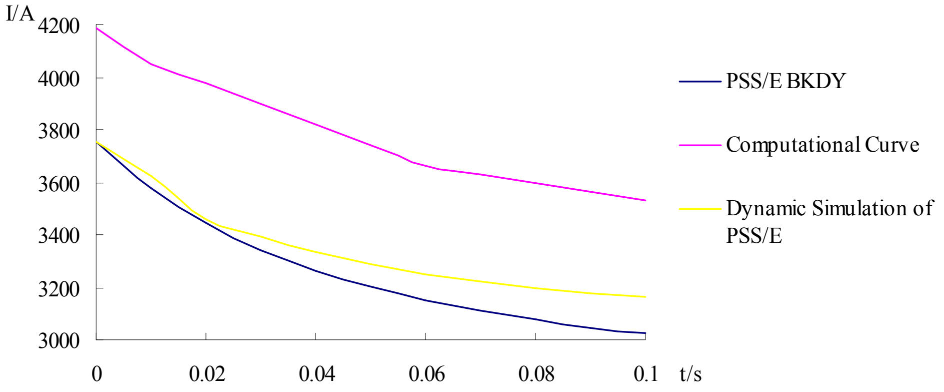

Fig. 3 Diagram of the periodic component of fault current decaying when Bus1 is three-phase short-circuited.

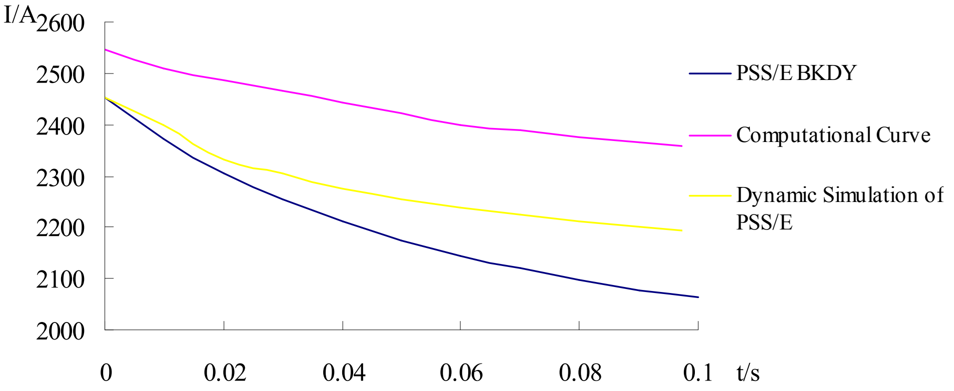

Fig. 4 Diagram of the periodic component of fault current decaying when BusA is three-phase short-circuited.

A comparison between the calculation results by PSS/E BKDY and dynamic simulation shows that they are fairly close in general, with quite good accuracy, which is consistent with the conclusion in reference [4]. In contrast, the results by computational curve are more conservative, and the rate of tolerance varies with short-circuit location. If the fault is applied to Bus1, all the rates of tolerance are greater than 10% and the minimum one is 11.52% (at 0.1s); if the fault is applied to BusA, all the rates of tolerance are less than 10% and the minimum one is 3.81% (at the instant of fault application). So there is still a safety margin when the results by computational curve are used for checking the values of circuit breaker interrupting current, but it is too conservative to make full use of circuit breaker interrupting duty in some cases (Bus1 in this case for example).

In fact, it can be concluded that, for BusA the branch power flow on both sides of BusA is flowing into it, while for Bus1 the branch power flow is flowing out of it except for the generator branch. So the network structure of BusA in fault is closer to the typical connection used for formulating computational curve shown in Fig. 1, which makes smaller tolerance of calculation results. Therefore, the calculation accuracy of computational curve for short-circuit current decrement is related with the network structure with respect to short-circuit location. But the steady-state power flow, network structure data and generator dynamic parameters are directly used for calculation with PSS/E BKDY, so the problem above no longer exists.

In addition to the errors caused by network structure, the actual generator parameters and operating conditions on each source branch used for calculation with computational curve are quite different from the ones used for formulating it. So it is just an approximate calculation method, and the greater the difference is, the larger the error is [3]. With the development of computer technology, PSS/E BKDY, a simple method of calculating short-circuit decrement quickly, will hopefully replace computational curve in time to play a greater role in practical engineering.

Conclusions

In this paper, the calculation results of short-circuit decrement in IEEE9 system by PSS/E BKDY and computational curve are compared and summarized as follows:

As two methods of calculating short-circuit decrement, the accuracy of the result by PSS/E BKDY is quite good while the one by computational curve is so conservative that it makes larger errors.

The reason causing errors lies in that, the power flow, network structure data and generator dynamic parameters are directly used for calculation with PSS/E BKDY, which leads to quite good accuracy; while the method of computational curve is based on the typical power flow, system connection and parameters quite different from actuality, which inevitably makes large errors.

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