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Planning scheduling strategies to suppress the magnitudes of fault currents

Ming-Tse Kuo [a], Hao-Ting Wei [a,b,*]

[a] Department of Electrical Engineering, National Taiwan University of Science and Technology, 43, Sec. 3, Keelung Road, Taipei 106, Taiwan, ROC
[b] Department of System Operation, Taiwan Power Company, No. 242, Sec. 3, Roosevelt Rd., Taipei City 100, Taiwan, ROC

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ABSTRACT

With traditional circuit breakers, the interrupter capacity margin is insufficient. To increase interrupting capacity, the circuit breaker can be upgraded or a device can be installed to suppress the fault current, thereby correcting the small fault current margin. In this paper, the power dispatch method is used to suppress the fault current. Simulations are performed and summarized to show the best scheduling policy for increasing the breaker capacity margin to allow for safe operation of the system. Scheduling policies take advantage of existing equipment, so there is no need for any additional purchases for the system. The proposed method will be able to significantly reduce the fault current directly and effectively compared to traditional practices.

Introduction

The origin of this study is that you need to install additional FCL or replace CB with higher breaking capacity when the system planners found the fault current of a substation is too high. Because of the procurement of equipment and installation of equipment, you will be needed for buffer period about several months. This substation will bear the risk of CB which cannot interrupt the fault current when a ground fault occurs during buffer period. Therefore, the most effective method is to use planning scheduling strategies to suppress the magnitudes of fault currents in order to solve the risk of the high fault currents during this buffer period. Power load demands are rising as the worldwide population increases. Consequently, the demand for generators, the source of fault currents, is also increasing. The continuous expansion of the grid infrastructure contributes to increased system reliability, leading to a lower impedance of the overall system. Consequently, in some areas, the value of the fault current has surpassed the interrupting capacity of the circuit breakers (CB). In the event of a fault, a circuit breaker is needed to separate the fault. Therefore, sufficient interrupting capacity of the circuit breaker is necessary for safe system operation. When reviewing the system shock, the fault current should be reviewed first. Subsequent power flow analyses and a stability review should then be carried out.

The following are common solutions to excessive fault current issues:

(1) Upgrade the system by replacing circuit breakers with insufficient interrupting capacity. This is a straightforward monetary solution.
(2) Use superconductor circuit breakers to suppress the fault current. With the advancement of power electronics technology in recent years, more electric utilities are employing this approach. The advantage of this solution is that it the power branch does not need to be cut off to isolate the fault current. However, the disadvantage is that there will be extra losses from the added equipment costs and construction time [1–9].
(3) Use power electronic switching components to suppress the current [10,11].
(4) Use a cascading impedance or high impedance transformer to suppress the fault current. The drawback of this approach is additional cost and increased power loss [12–14].
(5) Use a non-superconductor fault current limiter [15].

The commonality among the described methods is the additional costs to purchase equipment for fault current suppression. As purchasing and equipment replacement both take time, it is

* Corresponding author at: Department of System Operation, Taiwan Power Company, No. 242, Sec. 3, Roosevelt Rd., Taipei City 100, Taiwan, ROC. Tel.: +886 223666630.
E-mail addresses: mkuo@mail.ntust.edu.tw (M.-T. Kuo), u160895@taipower.com.tw (H.-T. Wei).

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Nomenclature

API	Application program interface	PSS/E	Power System Simulator for Engineering
AG	Asynchronous generator	SC	Short circuit
CB	Circuit breaker	SG	Synchronous generator
CHP	Combined heat and power	SCIG	squirrel cage induction generator
FCL	Fault current limiter	Taipower	Taiwan Power Company
IEC	International Electrotechnical Commission	WRIG	wound rotor induction generator

unlikely to scheduling strategies to suppress the fault current immediately. This study uses breaking power branches, or scheduling-based generator allocation, to isolate fault currents. It can even work in coordination with a main breaking transformer to increase the system impedance, thereby inhibiting the fault current. This method does not cause device overloads and increases the interruption margin of the breaker circuit at the expense of grid reliability. This paper simulates the optimal breaking branches and scheduling generator sets using the Power System Simulator for Engineering (PSS/E) [16] with Python application program interface (API). Currently, this approach is applied in the planning of operation for Taiwan's next-month grid.

Through software simulations, it is not difficult to determine which cables to break to isolate the source of the fault current and increase the system impedance as seen from the fault location.

Introduction to fault current calculation

The primary purpose of fault current inspection is to determine whether the circuit breakers are powerful enough to break the fault current, isolate faults and prevent further damage to the equipment.

Common failures in power systems include [17]:

Symmetric faults

(1) Three-phase short-circuit fault (positive sequence network)

Asymmetric faults

(2) Single-phase ground fault (positive, negative, and zero sequence network in series)
(3) Phase fault (positive and negative sequence network in parallel)
(4) Two-phase short-circuit ground fault (positive, negative, and zero sequence network in parallel)

Although the current of a single-phase ground fault may be greater than that of a three-phase short circuit fault [18,19], there is a higher probability of three-phase short-circuit faults because, after maintenance, the restoration of the isolated ground switches is often forgotten due to human error. Therefore, the primary objective is to address three-phase short-circuit faults.

Calculation of three-phase short-circuit fault current

In the event of a short-circuit (sc) fault in the power system, according to Thevenin's theorem, the system can be simplified to an AC power supply in series with a resistor (R) and an inductor (L), as shown in Fig. 1.

This network after fault occurrence at $t = 0$ can be described with the following differential equation:

$$L\frac{di}{dt} + R \cdot i = E_{\max}\sin(\omega t + \phi) \tag{1}$$

The solution of the differential equation is:

$$i = e^{-\frac{R}{L}t}\left(\frac{-E_{\max}}{\sqrt{R^2+\omega^2L^2}}\sin\left(\phi - \tan^{-1}\left(\frac{\omega L}{R}\right)\right)\right) + \frac{E_{\max}}{\sqrt{R^2+\omega^2L^2}} \times \sin\left(\omega t + \phi - \tan^{-1}\left(\frac{\omega t}{R}\right)\right) \tag{2}$$

The first term of the expression represents the decaying DC-component and the second term is the stationary current. The DC-component is dependent on the moment the fault occurs with respect to the voltage. The DC component appears when the value of the voltage is not 0 at the moment of the sc. In a case of a 3ph sc, there will always be a DC component, in at least two phases. The damping of the DC-component is determined by the R/L ratio.

The effective value of total (asymmetric) fault current consists of two components: a symmetrical AC component and a DC component that causes asymmetric phenomena, as shown in Fig. 2. The effective value of the total fault current equals the square root of the sum of the squares of the effective value of the AC component and the square of the effective value of the DC component, as shown in formula (3):

$$I_{asy} = \sqrt{(I_{ac})^2 + (I_{dc})^2} = \sqrt{(I_{sy})^2 + \left(\sqrt{2}I_{sy}e^{\frac{-t}{\tau}}\right)^2} = I_{sy}\sqrt{1 + \left(\sqrt{2}e^{\frac{-t}{\tau}}\right)^2} \triangleq DI_{sy} \tag{3}$$

where $D = \sqrt{1 + \left(\sqrt{2}e^{-t/\tau}\right)^2}$ is called a DC effect multiplier.

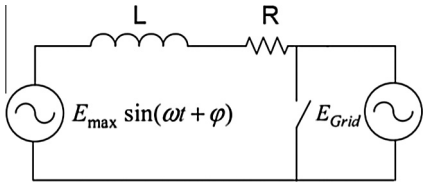

Fig. 1. A Thevenin equivalent circuit in a short-circuit fault.

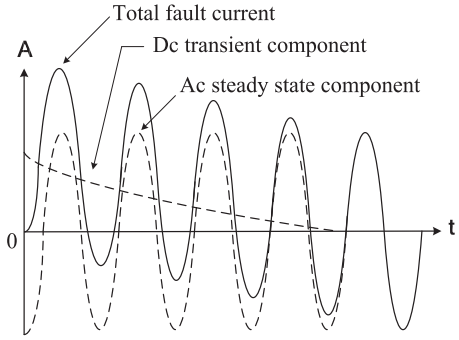

Fig. 2. Waveform of a short-circuit fault.