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Fault current limiter using a series impedance combined with bus sectionalizing circuit breaker

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ABSTRACT

The necessity and procedure for application of series fault current limiter (FCL) composed to bus sectionalizing in power network of IRAN have been discussed. In this regard, all of the high voltage substations in the power network of IRAN were evaluated in point of view of the fault current amplitude. The short circuit analysis of the power network was done based on the actual and future network specifications which have been designed and published by Iran Generation Transmission & Distribution Company in 2005. The overall results of this analysis and the detail data of using FCL together bus sectionalizing for two of the most important high voltage substations of Iran are presented. This method allows decreasing of 27% in fault current amplitude. The economical observation shows this method can be profitable if high voltage substation contains more than four feeders.

1. Introduction

At the beginning, generating units were separated from each other. But by increasing the electrical demand and in order to increase the system stability and reliability, they gradually became interconnected and more generating units, substations, parallel transmission lines, series and parallel capacitors were installed. One of the problems related to the growth of the transmission and distribution of electrical energy system is the fast increase in the short circuit level that may cause the following effects:

1. Overheating the series devices in the fault route.
2. Increase transient and recovery voltages produced by cutting off the increased current which can damage insulations of power system.
3. Producing very high mechanical forces in the transformers, generators, and reactors.
4. Power system stability can be lost depending on the fault current amplitude as well as its clearing time.
5. Because of the growth in the fault current amplitude it is possible that the circuit breakers installed in the past cannot interrupt the fault current and it is needed to replace that an extra investment in time and money will be needed. To avoid these extra costs we may have restriction in paralleling the power transformers to reduce system interconnectivity and this also reduce transmission capacity and system reliability.
6. Decreasing in reliability of electrical network.

There are generally three solutions to remove those effects:

1. To design power network in a way that probability of occurring a fault be low enough.
2. Using applicable strategies in order to minimize the network damage when a fault occurs.
3. Using fault current limiter depending short circuit current level of each desired bus of power system.

Nowadays a combination of above solutions can be used to design optimum and reliable network. But since the consumption of electrical energy is increasing (especially in advancing countries) and every day our life are becoming more dependent to this kind of energy, the electrical networks develop and it is impossible to remove completely short circuit faults. Also design power apparatuses based on increasing short circuit currents is not commercially reasonable. In this regard from the beginning of the 1970, fault current reduction became an important researching aspect in the world. A commonly used technique for reduction fault current is based on insertion of high impedance in the power system just after fault occurrence. There are different techniques for preparing and inserting this high impedance in system. These techniques can be classified as follows:

– FCL with a fuses and fast mechanical switch (multi-short or multi-divided commutating elements) [1–3].
– FCL with super-conducting coils [4–6].

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– FCL with LC resonant circuit (using solid state switch, ZnO varistors) [7–10].
– FCL with inter-phase power controller [11,12].
– FCL with Polymer PTC Resistor [13].

During a fault the voltage of system will become disturbed and decreased largely but it can be developed using fault current limiters. All the proposed FCL strategies are generally based on inserting of an high impedance in series of fault current, but the procedure of impedance insertion are different [14–18,24]. The desired specifications of an ideal FCL will be as follows:

1. Having very low impedance in the normal condition of power system.
2. Inserting high impedance when a fault occurs.
3. Fast operation to restrict the DC component of fault current.
4. Having capability to operate shortly more than one time and to be self recovery.
5. Not to insert harmonics in power system.
6. To prevent the increasing in transient over voltages.
7. Having a high reliability.

2. Limitation of short circuit current

The necessity of fault current reduction to an acceptable level seems indispensable and one of the best alternatives for this aim is using Fault Currents Limiter [19–22]. Without FCL, the circuit breakers must be used with very high interruption capability and this is a very expensive solution to protect power system against increasing short circuit current. In addition of this economical aspect, technical problem does not yet allow to make very high capacity circuit breakers at extra high voltage. As it is known the protection system has a delay in fault detection dependent to the relay specification, also the operation of the circuit breaker and extinguishing the arc is not instantaneous and it causes another delay to remove faults. Because of these delays, fault current can't usually be interrupted before 2–8 cycles of the power frequency after the fault. In this duration a very high current is flowing through the power system devices which it can be destructive even in this short duration (especially since the fault current is extremely high in the first cycles because of the presence of the DC component of the fault current) [23–29]. Hence using high capacity circuit breakers doesn't solve the problem completely and all effects produced due to increasing of short circuit current may even be intensified and threaten the insulation system of the devices. So it leads the manager of power system to limit the high short circuit current as it is possible.

3. Specification of power network of iran

Total installed capacity of power network of Iran will be reached to 31,000 MW if considering the addition of 1745 MW to the generation system in 2004. This shows an increasing rate equal to 6.6% per year. The total produced energy by the generation system of Iran was more than 124,000 GWh and in comparison with the electric power generation in 2003 has had 7.4% growth. Power and electrical energy per person were respectively 530 W and 2015 kW and have shown 3.5% and 5.7% growth in comparing with ones of 2003. In 2004 the growth in generated energy was about 10% and in the first half of 2005 was about 12% [28].

This growth in generation and demand has a great effect on the short circuit level of the high voltage substations which make the utilities to analyze the transmission network from the short circuit level viewpoint to find a suitable way to restrict of fault current increasing at substations. The overall specification of the generation and transmission system of Iran has been shown in Tables 1 and 2.

4. Results of short circuit calculation

Based on the network configuration and data of the high voltage transmission lines and power generation systems, the required data files were precisely prepared for the power network of Iran considered respectively for years 2004 and 2011. These files used in the software developed in PWUT and TAVANIR to determine and monitor the short circuit current in 230 kV and 400 kV buses of whole network not modifying impedance matrix of network [31] or resizing the network using Thevenin's theorem. Table 3 shows the results for the substations having highest short circuit levels.

As can be seen in Table 3, in the actual network of Iran only a few numbers of the substations have large fault current. It has been found out that in some of the 230 kV and 400 kV substations the fault current levels are close to the short circuit capacity of the installed circuit breakers (especially those substations which are close to generating units or those that have many incoming lines). So however at the present time they are capable to interrupt successfully the short circuit current but with respect to the network expansion in future years, the short circuit level in those substations should become more than the breakers capability as the results shown in column related to year 2011 in Table 3. So the fault current limitation study was seemed necessary to carry out in extended Iran's power network [28].

5. Fault current limitation using a combined method

In those substations that the fault current is more than 40 kA, the preventive actions should be planned to restrict fault current level. In this regard, bus sectionalizing can be one possible solution [30]. Using this method, the network connectivity will be reduced but the equivalent short circuit impedance of substation will increase and as well as it restricts fault current. But it is clear that this will affect power flow through the network and can cause operational problems and decrease network reliability. So using this solution needs a very vast network study and causes a configuration of power system different from that one exists. This method has been completely explained in [9]. In this paper, using series fault current limiters to restrict fault current is focused. As an

Table 1
Overall specification of the generation power system in Iran.

Type of power plants	Installed capacity (MW) Inside the global network	Out of the global network	Total
Steam	16,402		16,402
Gas	7938	100	8038
Combined cycle	4060		4060
Hydro	1998		1998
Diesel	458	75	533

Table 2
Overall specification of the power transmission lines length of Iran's network.

Voltage level (kV)	Inside the global network	Out of the global network	Total
400	10,079		10,079
230	20,444		20,444
132	13,210		13,210
63 and 66	30,264		30,264
20 and 33	244,960	179	245,139