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Safeguarding Protection Hardware in Modern Power Systems

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Abstract: *Load growth and the attendant need for interconnection for reliability of supply systems results increase in system fault levels. There is a compelling need to devise solutions to prevent the ratings of equipment such as circuit breakers being exceeded. An attractive solution would be an introduction of fault current limiting devices in the power grids. Fault Current Limiters (FCL) seems to be cost-effective and reliable fault current limiter technology across a broad spectrum of utility systems. Traditional approaches to managing fault currents are complex and expensive. By adding FCLs, utilities can lengthen the service life of equipment and cost-effectively expand generation while improving the resiliency of the overall network.*

I. Introduction

The modern power systems are facing fault current problems when expanding existing buses. Larger transformers result in higher fault duty levels, forcing the replacement of existing bus work and switchgear not rated for the new fault duty. Alternatively, the existing bus can be broken and served by two or more smaller transformers. Another alternative is use of a single, large, high-impedance transformer, resulting in degraded voltage regulation for all the customers on the bus. The classic trade-off between fault control, bus capacity, and system stiffness has persisted for decades. Other common system changes can result in a fault control problem:

- In some areas, such as the United States, additional generation from co generators and independent power producers (IPPs) raises the fault duty throughout a system
- Older but still operational equipment gradually becomes underrated through system growth; some equipment, such as transformers in underground vaults or cables, can be very expensive to replace
- Customers request parallel services that enhance the reliability of their supply but raise the fault duty

Fault-current limiters (FCL) offer a solution to controlling fault current levels on utility distribution and transmission networks. These fault current limiters, unlike reactors or high-impedance transformers, will limit fault currents without adding impedance to the circuit during normal operation. Development of superconducting fault-current limiters is being pursued by several utilities and electrical manufacturers around the world, and commercial equipment is expected to be available in near future.

II. FCL - The Requirement Of The Modern Power System

Almost in every field of modern civilization there is the requirement of electrical energy which has resulted in a considerable increase of electrical power consumption. To meet the demand of large electrical energy, the size of the power generating stations has become large. In many cases, now a days, generating stations are connected among themselves by interconnected networks (power grids), making the utility systems extremely large. Modern power grids also have put forward to go for increased use of distributed generation (DG) which involves placing smaller local generation sources closer to the loads.

Usually the consumption area of electrical power is very wide, the chances of any kind of unforeseen accident, fault or abnormal condition is very common. Somewhere in a power utility network, an unforeseen accident creates a short circuit. The sudden reduction of the impedance of the power utility network during short circuit lead to an increase in current, termed a fault current. It is a large current surging through the various parts of power grids, causing a voltage reduction too.

The increase of electric power consumption has necessitated an increase in the system fault current levels which has led to larger mechanical and thermal stresses and endanger the mechanical integrity of power system hardware viz. circuit breakers, transformers and other equipments. The increase in load, generation, interconnection and penetration of DG into power network escalated the short circuit fault current level to or exceeds the capacity of protective switchgear such as circuit breaker. The short circuit fault current level in some places becomes so high that the breaking capacity of the circuit breaker reached to its maximum possible rating which is limited by the physics of the applied dielectric medium. Hence, the circuit breaker must either be upgraded or replaced in the near future. Neither up gradation nor replacement is economical and feasible from utilities perspective as the levels of fault currents would continue to grow with the increase in power demand. Because of these reasons the importance of limiting the fault current has been increased considerably. With the limited fault current, a breaker with a low rating or existing rating can be used and is cost effective compared to the breaker replacement.

Earlier, most of the researches were not focused on limiting the fault current but basically on breaking the circuit to isolate the fault and thus prevent damage to costly equipment. Many approaches to limiting fault currents have been proposed in the past which include the use of circuit breakers with ultra-high fault current rating, high impedance transformers, current limiting fuses, air-core reactors, reconfiguration of the system such as splitting of power buses. None has proved to be efficient or economical. Usually circuit breakers are expensive, cannot interrupt fault currents until the first current comes to zero and have limited life times. The high impedance transformer with their high losses makes the system inefficient. The fuses have a very low withstandable fault current and it has to be replaced manually. The air-core reactors are subject to large voltage drops, incur substantial power loss during normal operation and require installation of capacitors for volt-ampere reactive (VAR) compensation. The system reconfiguration using bus-splitting besides adding cost reduces the system reliability and its operational flexibility.

Thus, it is required to find a more effective way to limit fault currents in power systems which fulfills the following criteria: the normal impedance of the system should not be increased, availability of the power supply should not be affected and the fault current should be limited to an acceptable value. Fault Current Limiters (FCLs) are expected to provide the required protection for power systems from excessive short-circuit currents. A Fault Current Limiter can be defined as: "a device which imposes negligible impedance in the line during normal operation of power system, but limits fault current to a predetermined level in case of a fault". Figure 1 shows typical waveforms of fault current with and without FCL.

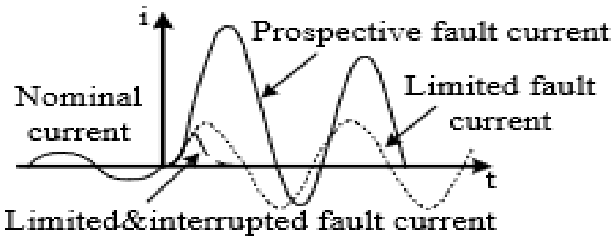

Figure 1: Typical waveform of a fault current with and without an FCL.

FCL capability can provide the following specific benefits:

1) Lower fault currents make working in the live substation environment safer by decreasing fault current levels below ground mat ratings and lowering the chance of arc ignition, plasma injury and system catastrophic failure
2) Offer a more cost-effective and operationally timely solution than rebuilding or adding infrastructure
3) Ease the constraints on system planning and allow for more cost-effective system growth
4) Enable higher reliability in the grid by reducing/eliminating the need to split the bus to reduce fault conditions
5) Improves voltage-dip performance at different bus levels of the grid by reduction of fault levels
6) Enable the ability to increase power capacity in a substation beyond existing levels
7) Allow for the reduction of existing fault current areas of the grid without impacting current system performance
8) Allow for the implementation of higher power delivery and improved voltage stability as the grid is upgraded
9) Improve asset utilization and firm capacity by decreasing the fault levels and reducing the levels of component usage required to support N-1 redundancy
10) Reduce or eliminate issues associated with transient voltage recovery'

III. Characteristics Of An Ideal FCL

Ideally, an FCL should fulfill the following requirements before its operation is considered acceptable:

1) Low impedance during normal operation of the power system - an FCL should not cause a significant voltage drop,
2) Rapid, fail-safe and adequate current limiting performance - the FCL should react fast to limit the first fault current peak,

3) Automatic recovery within a short recovery time - after the fault is cleared the FCL should return to a low-impedance state,
4) No deterioration of the limiting behavior during the FCL's useful life,
5) High reliability,
6) Low initial cost and low losses (low operational cost),
7) Small size and low weight,
8) No risk for operational personnel,
9) Environmentally friendly - it should not use substances that can have a detrimental influence on the environment, such as greenhouse gasses,
10) Integration into existing protective schemes,
11) Low maintenance requirements.

IV. Classification Of FCL

The FCL must be able to limit the first peak of the fault current and must become 'invisible' for the power system as fast as possible after the fault is cleared. The fault reaction delay and post-fault-recovery delay are among the most important functional characteristics of the FCL. Figure 2 shows the classification of the FCL types in three groups based on the used technology. From the aspect of fault-reaction delay, FCLs can be classified into two groups (see Figure 2): FCLs with inherent reaction and FCLs with a fault-reaction delay.

FCL Technology	Non Semiconductor based FCLs	➢ FCL utilizing quench transition of SC materials (inherent reaction) ➢ FCL based on core saturation effect (inherent reaction) ➢ Transformer type parallel resonant circuit (inherent reaction)
	Solid State FCLs	➢ Bridge type FCLs (inherent reaction) ➢ FCLs with discharging capacitors (delay exist) ➢ FCLs with series compensation (delay exist) ➢ FCLs employing resonance effect (delay exist)
	Hybrid FCLs	➢ FCLs employing mechanical switches (delay exist)

Figure 2: FCLs classification based on used technology and fault-reaction delay

V. FCL Applications

Fault-current limiters can be applied in a number of distribution or transmission areas. Three main applications areas are shown in Figures 3,4 and 5

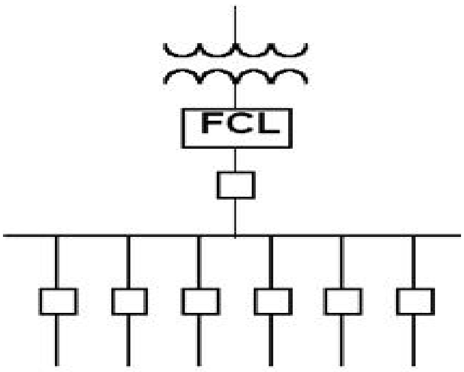

Figure 3: Fault current limiter in the main position. The fault current limiter FCL protects the entire bus

The most direct application of a fault current limiter is in the main position on a bus (Figure 3). Benefits of an FCL in this application include the following: a larger transformer can be used to meet increased demand on a bus without breaker upgrades a large, low impedance transformer can be used to maintain voltage regulation at the new power level, damage to transformer is limited, reduced fault current flows in high voltage circuit that the transformer, which minimizes the voltage dip on the upstream high voltage bus during a fault on the medium voltage bus. An FCL can also be used to protect individual loads on the bus (Figure 4). The selective application of small and less expensive limiters can be used to protect old or overstressed equipment that is difficult to replace, such as underground cables or transformers in vaults. An FCL can be used in the bus-tie position (Figure 5). Such a limiter would require only a small load current rating but would deliver the following benefits: separate buses can be tied together without a large increase in the fault duty on either bus during a fault, a large voltage drop across the limiter maintains voltage level on the unfaulted bus, the paralleled transformers result in low system impedance and good voltage regulation; tap- changing transformers can be avoided, excess capacity of each bus is available to both buses, thus making better use of the transformer rating.

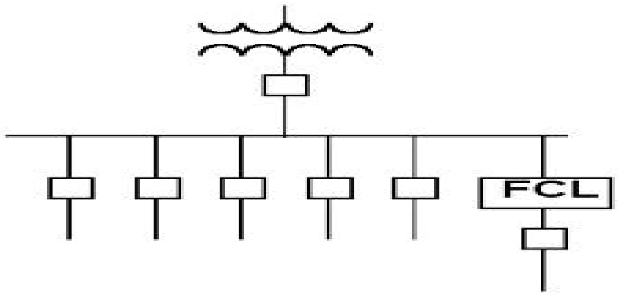

Figure 4: Fault current limiter in the feeder position. The fault current limiter FCL protects an individual circuit on the bus. Underrated equipment can be selectively protected as needed in this manner.

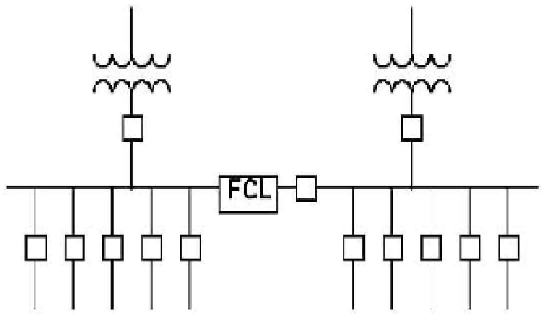

Figure 5: Fault current limiter in the bus tie position. The two buses are tied, yet a faulted bus receives the full fault current of only one transformer.

VI. Conclusion

The paper discussed the recent challenge before power engineer to cope up with the ever rising high fault current magnitude and suggested a solution in terms of incorporation of fault current technology into the existing grids. The research in the field of FCLs has been intensified in the last decade with the aim of overcoming the disadvantages of existing FCL technologies. Despite the numerous publications proving the ability of diff erent FCL technologies to protect power systems from over-currents, FCLs have still not been commercialized. Two problems remain viz. (1) Existing FCL technologies have to be improved, namely, the fault reaction and post fault recovery delays and power losses during nominal operation of the system have to be improved (2) The initial cost of FCLs should be lowered.

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