Effects of Upgrading Primary Feeders from Radial to Loop: A Distribution Network Case Study

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Abstract: This paper provides a comparative examination of the effects of using superconducting fault current limiters (SFCLs) in upgrading radial and loop distribution schemes in power networks. Radial and loop distribution systems are often employed as topologies for the dissemination of electrical power to end customers. The integration of SFCL into power distribution systems has attracted growing interest because of its capacity to improve system dependability, minimize failure consequences, and facilitate the integration of renewable energy sources. This paper uses ETAP to simulate a coordination scheme on the Tarlac power distribution network using different SFCL resistances at different locations. The model shows the relevance of selecting the amount of resistance and the location of the SFCL in designing the protection coordination.

***Keywords*— radial distribution system, loop distribution system, superconducting fault current limiters, power networks**

I. INTRODUCTION

The conventional approach to the design and functioning of crucial electrical infrastructure has historically been guided by the fundamental concepts of reliability, specifically security and sufficiency. These measures enable the management of recognized and reliable risks in order to ensure a consistently high-quality power supply to end users with minimal disruptions over a prolonged duration. Undoubtedly, this has resulted in the creation of a very dependable infrastructure throughout the past century. This study presents a comparative analysis of radial and loop distribution systems, offering useful insights into the characteristics, advantages, and limitations of these two topologies. The objective is to assist power system planners and engineers in making well- informed choices on the selection of distribution system topologies, taking into account specific requirements and limitations. This eventually enhances the reliability, efficiency, and cost-effectiveness of power networks.

Normally, fuses can limit short circuit current, but they require a service call to get replaced after they blow up. Series reactors are also useful to limit short-circuit currents. However, they cause permanent reactive losses and deteriorate voltage regulation. Superconducting fault current limiters (SFCLs) can overcome these issues. They are capable of controlling fault currents to acceptable levels.

Electromechanical circuit breakers, which usually require more than one current cycle to open the circuit, are traditionally used for overcurrent protection in power systems. This technology can interrupt the circuit after a fault; however, it cannot avoid damage when the fault current is above the substation limits [1]. A current-limiting device is necessary to limit the DC fault current to a reasonably low level. Most of the research that has been done on superconducting fault current limiters (SFCLs) for use in DC power systems has focused on designs with a saturated iron core that are resistive or inductive [2] [3] [4] [5].

Internationally, the development of SFCL has experienced the prototype research phases of experimental, distribution, and transmission levels [6] [7]. In a short-circuit DC system, the short- circuit fault current is composed of an initial transient impulse current and a steady-state fault current [8].

II. A BRIEF BACKGROUND ABOUT SHORT CIRCUIT ANALYSIS

Prior to exploring the application of superconducting fault current limiters, a concise overview of short circuits is provided. The short-circuit current can be expressed using a general formula [9]:

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$$I = I_p sin(\omega t + \alpha - \varphi) + [I_m sin(\alpha - \varphi') - I_p sin(\alpha - \varphi) e^{-(\omega R/X)t} \quad (1)$$

I_p represents the maximum value of the symmetrical current, which is defined by the magnitude of the system voltage and the equivalent short-circuit impedance. I_m represents the maximum value of the current during regular operation. The voltage at the beginning is represented by α, while α' denotes the angle of impedance before the occurrence of a short circuit. The value of φ is determined by the arctangent of X/R, where X/R represents the equivalent short circuit ratio. Based on (1), the short circuit current consists of both the symmetrical short circuit component and the dc offset. The dc component exhibits exponential decay. The amalgamation of these two factors results in an imbalanced short circuit current, which is contingent upon the system's X/R ratio and the voltage angle during a fault event. The largest asymmetrical current occurs during the first half cycle when a fault happens at the zero-voltage crossing point. In order to restrict the maximum fault currents within a very short time frame, it is imperative to have the capability of promptly initiating SFCL.

III. Analysis Of Improving The Power System Transient Stability Using SFCL

The reliable functioning of the power system network relies on the equilibrium between mechanical and electromechanical forces that maintain the generators in synchronization. In a power system operating under normal conditions, there is a state of balance between the power used and the power produced inside the system. Depending on the circumstances, a significant disruption, such as a short circuit or line tripping, can temporarily suppress oscillation or permanently disrupt the state of synchronous equilibrium. The power system transient stability challenge involves determining if the power angle of the generator will remain unchanged or reach a new acceptable steady-state operating position once a failure occurs [10].

Fig. 1 represents the quenching and recovery characteristics of SFCL when a reclosing scheme is 2 Fast 1 Delay (2F1D). When a fault occurs, the resistance of SFCL increases. If a re-closer is tripped, SFCL recovers.

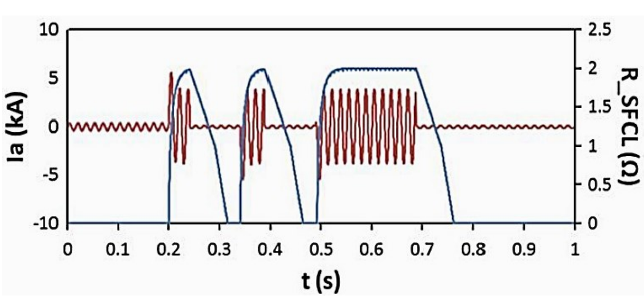

Fig. 1. Quenching and recovery characteristics of SFCL

IV. Effects of Upgrading Primary Feeders from Radial to Loop Distribution Network

A. *Positive Effects*

- Voltage Stability: Loop systems can help maintain more stable voltage levels across the network, especially during periods of high demand or in the presence of variable generation sources.
- Enhanced Fault Isolation: Loop configurations make it easier to isolate and locate faults, as the system allows for sectionalizing without affecting the entire network.
- Reduced Outage Duration: If a fault occurs, power can be rerouted through alternative paths, minimizing the impact and reducing downtime for affected customers.
- Improved Reliability: Loop distribution enhances system reliability by providing multiple paths for power flow. This redundancy reduces the impact of faults and outages.
- Increased Load Capacity: Loop distribution can better accommodate load growth without significant infrastructure changes, as power can be supplied from different directions.

B. *Negative Effects*

- Increased Maintenance Requirements: The added complexity may result in increased maintenance demands, as more equipment and devices need to be monitored and maintained.
- Potential for Overloading: In some cases, there might be a risk of overloading certain segments of the loop, especially if load patterns change unexpectedly.
- Training Needs: The transition may require additional training for personnel to operate and maintain the new loop distribution system effectively.
- Increased Maintenance Requirements: The added complexity may result in increased maintenance demands, as more equipment and devices need to be monitored and maintained.
- Complexity and Cost: Implementing a loop distribution system can be more complex and costly than a radial system. It may require additional equipment, such as sectionalizing switches and automation systems.

C. *Overall Considerations*

- System Design: The success of the upgrade depends on careful system design, including the placement of switches, protection devices, and overall network configuration.
- Customer Impact: Minimizing disruptions to customers during the transition is crucial. Proper planning and communication are essential.

  Regulatory Approval: Depending on the jurisdiction, regulatory approval may be required for major changes to the distribution system.

V. Digital Simulation

To investigate the effect of the SFCL on the operational characteristics of the overcurrent relay and the protection coordination between the relays, the short circuit tests at two feeders in a power distribution system in Tarlac simulated with the SFCL are shown in Fig. 2. In the short-circuit tests, the SFCL resistance was connected in series with the line impedance.

There will be four cases of faults occurring on the radial and loop distribution systems with SFCL of different impedances and locations. For Case 1, there will be no resistance for the YBCO thin film SFCL; for Cases 2 to 4, there will be 2.3, 4.6, and 11.5 Ω, respectively.

Fig. 2 shows the power distribution system with SFCL and interconnecting switch in the tie-line.

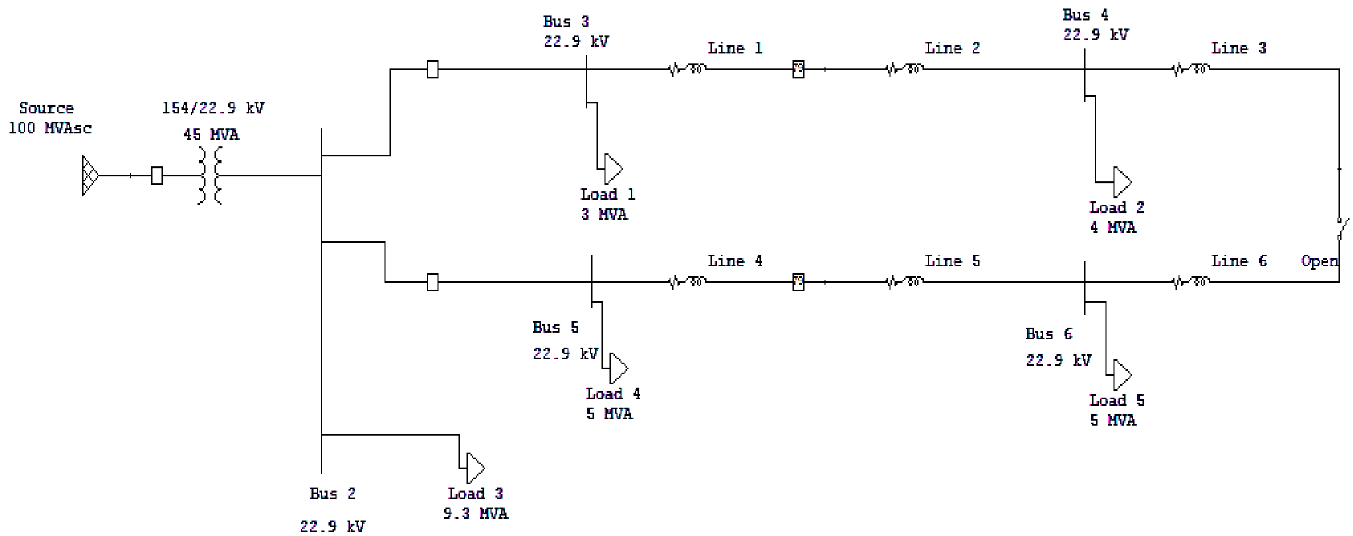

Fig. 2. Power distribution system with SFCL and interconnecting switch in the tie-line.

VI. Results and Discussion

Table 1 shows the magnitude of the three-phase fault according to fault location with different SFCL's resistances.

TABLE I

THREE-PHASE FAULT AT VARIOUS LOCATIONS AND DIFFERENT SFCL RESISTANCES

Cases		SFCL Ω (YBCO thin film)	3Φ-fault (A) at Bus 3	3Φ-fault (A) at Bus 4	3Φ-fault (A) at Bus 5	3Φ-fault (A) at Bus 6
Radial (SFCL located near the source)	Case 1-0	None	872.78	860.60	873.31	861.30
	Case 1-1	2.3	615.11	610.06	672.72	667.00
	Case 1-2	4.6	446.49	443.58	469.80	465.70
	Case 1-3	6.9	328.57	326.68	337.61	334.95
	Case 1-4	11.5	210.13	209.11	213.22	211.74
Loop (SFCL located near the source)	Case 2-0	None	875.51	871.13	875.75	871.27
	Case 2-1	2.3	874.00	876.05	875.27	876.58
	Case 2-2	4.6	781.93	785.66	784.24	786.63
	Case 2-3	6.9	605.34	608.66	607.40	609.53
	Case 2-4	11.5	402.73	405.12	404.22	405.74
Loop (SFCL located at the tie-line)	Case 3-0	None	875.51	871.13	875.75	871.27
	Case 3-1	2.3	872.80	860.70	873.36	861.46
	Case 3-2	4.6	872.79	860.63	873.33	861.36
	Case 3-3	6.9	872.78	860.62	873.32	861.33
	Case 3-4	11.5	872.78	860.62	873.32	861.31

According to the experiment, a three-phase fault of greater magnitude occurs when there is no or less resistance in the SFCL and the fault location is in close proximity to the power supply.

As the resistance of the SFCL increases, the fault current decreases. Similarly, the fault current decreases as the distance from the power source increases.

VII. Conclusion

Through the analysis of the experimental results, it was confirmed that the resistance of the SFCL should be selected to be within a limited range to maintain protection coordination.

Therefore, the analysis of the effect of the SFCL introduction on the existing protective devices as well as their protection coordination should be carried out first before the SFCL is installed in the field.

VIII. Future Considerations on the Interactions Between SFCLs and Power Systems

An SCFL can be effectively used to increase transient stability and power quality without upgrading the power grids. However, to employ an SFCL properly, other factors need to be considered:

- Coordination between SFCLs and the protective devices.
- Recovery characteristics and Open-Close-Open duty.
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- Operations with other flexible AC transmission system (FACTS) devices.

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