IMPLEMENTATION TECHNIQUES OF MULTISTATION LINE TRANSFER FUNCTION WITH FAULT TOLERANCE IN MEA'S DISTRIBUTION SYSTEM

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ABSTRACT

In power distribution system, the transmission line is one of the most important parts. The transmission line has to have a well maintenance and switching plan for reaching the highest reliability. However, failures of the transmission line especially overhead line cannot be set to zero and may result in a wide area outage impacting to various customers. Moreover, in a downtown area, routing of the transmission line is very difficult and very costly including be impossible to providing two direct terminal-station transmission lines to each substation making some substation have to receive electric power from a nearby substation making substations called inline substations which have low reliability due to they have only one power source and cannot perform substation line transfer functions. In addition, typically MEA's customer substations also have one incoming-line which is tapped on an open-loop transmission line according to well environment at that time. Nowadays, an environment of MEA's distribution area has changed very much such as severe traffic jams, a high number of high constructions, and a high number of high advertising boards resulting in higher chance of overhead-transmission-line faults than the past. For switching operations, MEA also has installed three remote-controlled switches/gas-insulated CBs at any tap point for quickly switching in some urgent situations such as a faulty preferred line has a location-known fault. So MEA is able to remotely transfer customer's load to another emergency line within a short time by a dispatching center. However, some faults happen with an indistinct location, MEA has to take time to find and clear them before switching causing long outage duration especially during severe traffic jams. A lot of solutions to detect a fault's location from a line-tap point of view are tried out but they are not long-term solutions due to several constraints such as FCI (Faulted Circuit Indicator) or DOC (Directional Overcurrent Relay) often are malfunction in high temperature. Consequently, MEA has created a project to build a switching-unit substation for any large customer who has a substation with one incoming line from MEA for increasing customer's reliability and also MEA's reliability. The large customers need electric reliability due to their lifeline depends on their productions whether are on schedule or not. Several large customers joining the project also support building area and some budget for building a switching-unit substation due to them realize benefits of a switching-unit substation. The switching-unit substation actually is a small-unmanned switching substation which has two incoming lines and one/two/three outgoing lines for customer substations. For fastest switching operation, the switching-unit substation have to has proper protective relays and a high-speed multistation line transfer function. The multistation line transfer function is comprised of several IEDs, communication switches and outdoor communication media, so MEA has seen a higher chance of an offline node and operational failure comparing to stand-alone substation line transfer function. The paper presents several useful techniques to implement multistation line transfer function (MLTF) with tolerance of function's component faults resulting in the highest availability. Additional points that we have to handle are extension and maintenance issues due to changeable number of in-line substations and difficulty of wide shutdown for maintaining. This paper will present an fault tolerance , extensible and maintainable implementation of MLTF to improve reliability of inline substations (typical substation and switching-unit substation). Finally, MLTF is able to reduce an outage time from 5-10 minutes to 0.2-0.3 seconds in case of one transmission-line failure.

INTRODUCTION

In several countries, electric utilities have to be assessed their performance of power system by reliability indices often according to the government policies. Moreover, a free trade policy also makes electrical utilities have to increase their performances and services for increasing a competition capability with other utilities including abroad competitors. So reliability is a key factor which is needed by the utilities for enhancing their power system. There are many ways to increase reliability of the power system such as renovating equipments, improving the power network, enhancing maintenance plan. However, the utilities still have to consider the return of investment if it does not impact their financial conditions. One of reasonable solutions to increase reliability is to improve a power system without changing primary equipments. So MLTF by compact PLCs as control units and existing IEC61850 IEDs as remote I/O units have been reconsidered.

MEA'S DISTRIBUTION SYSTEM

Metropolitan Electricity Authority (MEA) is a power distribution utility in Thailand responsible for distribution of electric power to the customers in Bangkok and two neighbouring provinces (Nonthaburi and Samutprakarn).

MEA typically receives electrical power from Electricity Generating Authority of Thailand (EGAT) at 230 kV, 115 kV, and 69 kV buses of 17 terminal stations. The voltages are reduced to 24 kV or 12 kV at distribution substations and distributed to medium-voltage customers and distribution transformers. The low-voltage customers receive power from distribution transformers at 400/230 V. In 2017, the electric energy of 52,645.96 GWh was supplied by 155 distribution substations through 1,850.03 circuit-kilometres high-voltage sub-transmission lines and 18,515.44 circuit-kilometres medium-voltage feeders.

CUSTOMER SUBSTATIONS

In MEA's distribution system, high voltage customer's substation typically has one incoming-line which is tapped on an open-loop transmission line according to a beginning condition as shown in Figure 1.

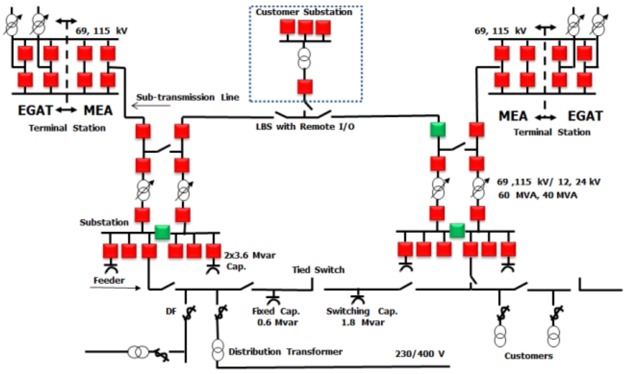

Figure 1. Typical Customer Substation's Connection on MEA's Distribution System

But the increasing of high rise buildings and others infrastructure also increase the risk of overhead-transmission-line faults, For switching operations, MEA installs three remote-controlled switches at tap point for quickly switching in some urgent situations such as fault on preferred line. So MEA is able to remotely transfer customer's load to another emergency line within a short time from dispatching center. However, some faults occurred with an unknown location, MEA has to spend time to find and clear them before switching causing long outage duration especially during severe traffic jam. A lot of solutions to detect a fault's location from a line-tap point of view are tried out but they are not long-term solutions due to several constraints.

SWITCHING-UNIT SUBSTATION

Metropolitan Electricity Authority (MEA) has redesigned transmission line for customer tapped point by installing a switching-unit substation to increasing customer's reliability and also MEA's reliability. For high voltage customers, who are mostly industrial or business complex, reliability of supply is crucial to their daily operation. Some of these customers participate in the project by providing land / space for switching unit substation installation. Moreover, MEA also lays underground cable to customer substations for maximizing reliability of an outgoing line of the switching-unit substation.

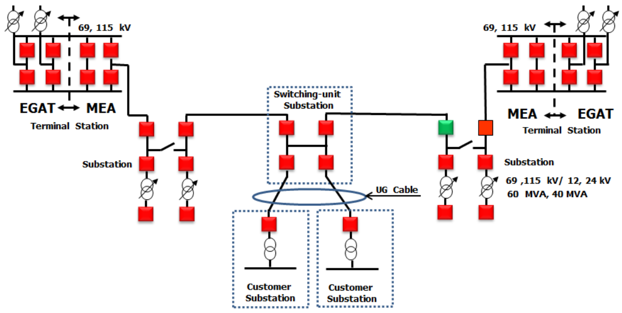

Figure 2. Connections of Switching-unit Substation and Customer Substations

The switching-unit substation actually is a small-unmanned switching substation which has two incoming lines and one/two/three outgoing line for customer substations shown in Figure 2. For faster switching operation, the switching-unit substation have to has proper protective relays and a substation control system allowing MEA's SCADA to control and monitor especially in an abnormal situation. In addition, each transmission line between terminal substation will have maximum 8 substations (switching-unit substation and typical substation included) based on cable capacity for limiting functional complexity.

APPROACH OF MULTISTATION TRANSFER LINE FUNCTION

A multistation line transfer function (MLTF) is one of automatic line transfer function that is designed for increasing reliability of inline substations (substation have only one power source) including switching-unit substations. The MLTF works on data from several concerned substations so a data communication system is needed for implementing the function.

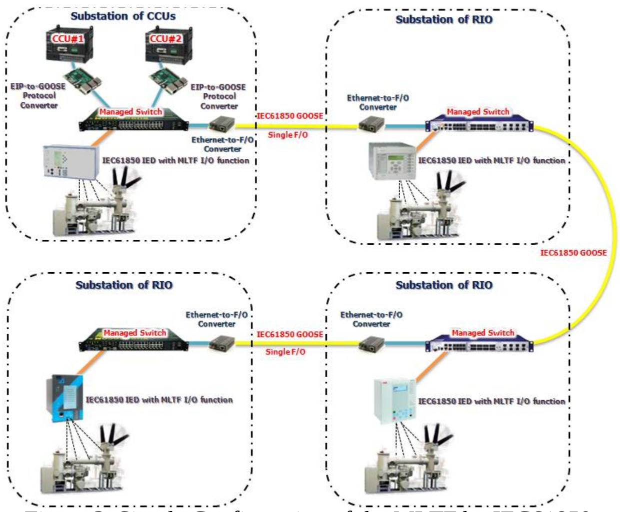

Figure 3. Simple Configuration of the MLTF by IEC61850

Substation automation using IEC61850 (IEC61850 SA) now is more widely implemented in many power utilities around the world due to its opening and sharing abilities.

Currently, communication architecture of IEC61850 SA is based on Ethernet and TCP/IP technology. Thus, any existing IEC61850 IED of any substation can communicate to dedicated central control units (CCU by programmable logic controller) to perform the MLTF function. We use the dedicated CCUs by PLCs for avoiding a logic-gates-capacity problem of non-dedicates IEDs. However, typical PLCs do not support IEC61850 but support Ethernet/IP (EIP) and Ethercat, so we have to use EIP-to-GOOSE protocol converters for making them work in IEC61850 network. Due to the MLTF requirement of fast response time, a GOOSE (Generic Object Oriented Substation Event) messaging is needed [1]. The GOOSE messaging works in a data-link level of the OSI model, so it needs to make a wide-area-ethernet network of several substations by single-mode F/O (Fiber Optic) to Ethernet modems / Single-mode plug-in module for supporting the GOOSE messaging shown as Figure 3. The wide-area-ethernet network by F/O to Ethernet modems is an easy and secure approach but it needs dedicated F/O. Another point, the wide-area-ethernet network has weak points from several network effects such as a traffic flooding, so a network administrator has to configure managed switches for reducing the effects as less as possible. Furthermore, the MLTF by IEC61850 SA also needs an IED that has a big logic-gate capacity and unique IP. For avoiding IP conflict, NAT (Network Address Translation) device/function is required [2]. Thus, the MLTF by IEC61850 has to be designed carefully for reducing any effect on other systems.

Operation of the MLTF

For the first example of MLTF operation shown as Figure 4, once an undervoltage relay (21) detects that undervoltage is occurring on an inline substation 1 for 0.2 seconds and no any pickup of any distance relay that ensures there is fault between the terminal station 1 and the inline substation 1. After that the MLTF will open the faulty incoming-line CB that receives an electric power from the terminal station 1 then the MLTF will close an opened CB of the open-loop substation 2 for delivering a electric power from the terminal station 2 to all inline substations.

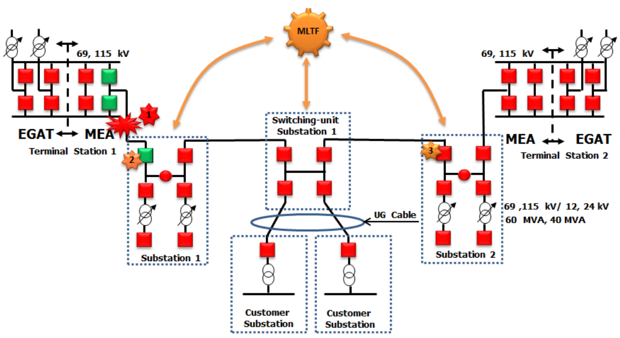

Figure 4. Operation of the MLTF when Faulty Line of the Terminal Station-1 Occurs

For another example of the MLTF operation shown as Figure 5, once an undervoltage relay (27) of a receiving substation has found that voltages are below a setting point and there also is a line-differential tripping (87L) of a line of a inline substation 1 that supply an electric to the nearby receiving substation (switching-unit substation 1). These show that there is a fault on a transmission line between the two substations. So the MLTF will open two end CBs of the faulty transmission line for surely isolating the fault. After that then the MLTF will close an opened CB of the open-loop substation 2 for delivering an electric power from the terminal station 2 to outage load.

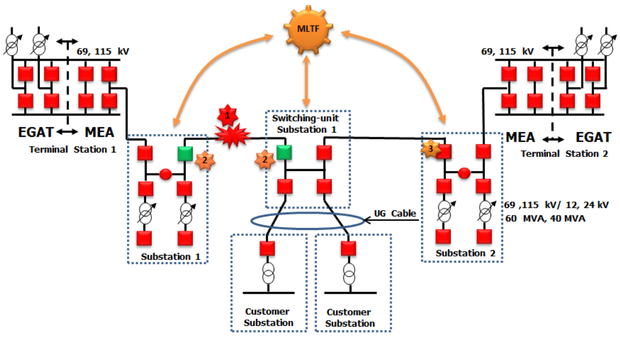

Figure 5. Operation of the MLTF when Fault Occurs between the Substation 1 and Switching-unit Substation 1

Fault Tolerance of the MLTF

The MLTF is comprised of several IEDs, communication switches and outdoor communication media, so MEA will meet a higher chance of any offline node and operational failure comparing to stand-alone substation line transfer function. For dealing with above problems, we have to apply a hot-standby concept on the MLTF CCUs due to they are a brain of the MLTF. For MEA, the CCU that we use actually is a programmable logic controller (PLC) with a EIP-to-GOOSE protocol converter. The protocol converter also does a job of CCU switch-over by ICMP (Internet Control Message Protocol) checking and EIP forcing. The good points of PLC usage are a virtually none-used-up logic capacity and a LADDER programming of PLC that is very similar to wiring control circuits resulting in an easy maintenance by any level of maintenance guys. However, a number of IEC61850 IED as remote I/O of the MLTF at any substation is only one and also some part of communication path have no any backup path making a single point of failure on retrieval of substation information of some substations. For increasing the MLTF availability and the power distribution reliability, we have to design the function to deal with any offline IED or mal-operation of any substation. The principle for dealing with them is a full-effort jobs transfer shown as Figure 6. The full-effort jobs transfer is a scheme that the CCU will transfer jobs of offline IEDs or undone jobs of any IED to the nearest healthy IED for reducing the outage load as less as possible.

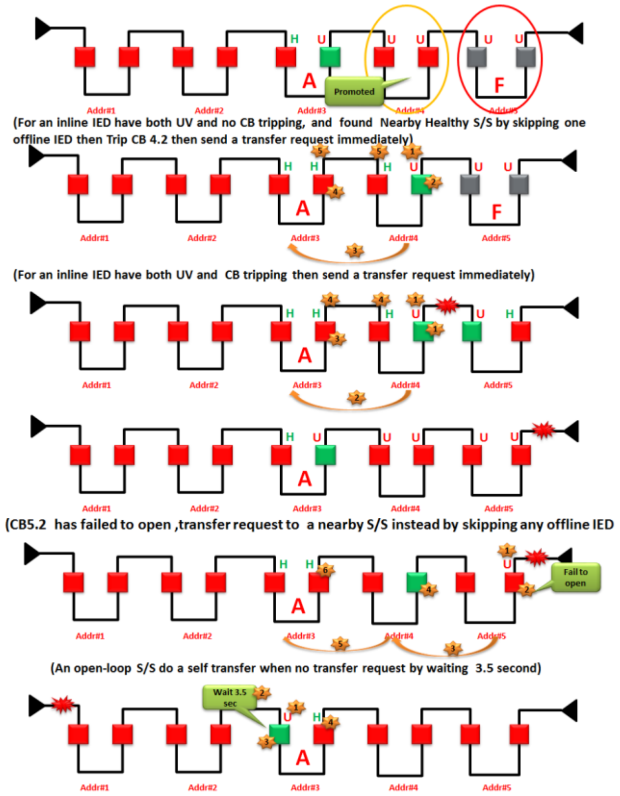

Figure 6. Examples of full-effort jobs transfer

Extension of the MLTF

Major points that we have to handle are extension and maintenance issues due to changeable number of in-line substations shown as Figure 7 and difficulty of wide shutdown for maintaining. Thus, we have to design to cope with maximum number of substations (Typically 8 substations for MEA's sub-transmission lines). Typically, we use a cable capacity for calculation the maximum number. The central controller has to prepare GOOSE signals (both subscribing and publishing) for adding substations in the future. The important GOOSE signals for adding substation is a connection address that shows each substation location. Normally, we use method of ascending order with some reserved number in the middle shown as Figure 8.

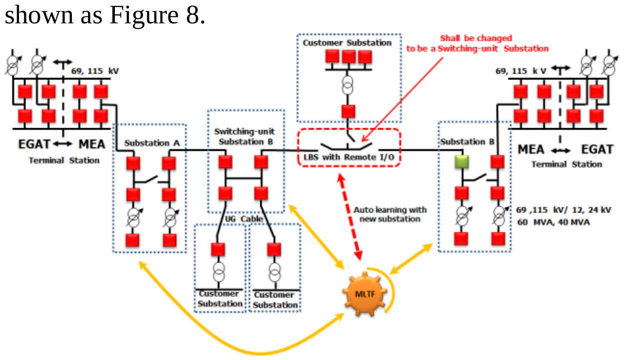

Figure 7. Extension of the MLTF

For maintenance test, we can use a GOOSE simulation method for some substations that cannot be shutdown. However, the GOOSE simulation method is not too easy to perform due to we use several people to manually change values. Nowadays, we have not found perfect software for simulating several GOOSE subscriber and publisher with softPLC.

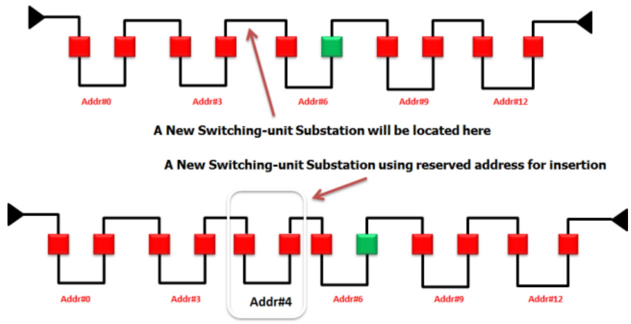

Figure 8. IED Insertion Technique of the MLTF

CONCLUSION

The paper presents several useful techniques with IEC61850 approach to implement a high-speed line transfer function among substations called multistation line transfer function (MLTF) resulting in the highest availability. Major points that we have to handle are fault tolerance, extension and maintenance issues due to several components of the MLTF, changeable number of in-line substations and difficulty of wide shutdown for maintaining. This paper will presents an fault tolerance , extensible and maintainable implementation of MLTF to improve reliability of inline substations (typical substation and switching-unit substation). Finally, MLTF is able to reduce an outage time from 5-10 minutes to 0.2-0.3 seconds in case of one transmission-line failure.

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