Automation of Distribution Grid for Fault Detection, Isolation, Fault Location and Service Restoration

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***Abstract*—A new approach to power system automation for the distribution feeder is to locate and isolate the fault automatically. This paper presents automatic fault detection, isolation, fault location and service restoration using Zigbee communication. This system incorporates two systems: a power system which consists of a distribution feeder having number of load buses and a communication network of the distributed intelligent devices in the system.**

***Keywords*— Distribution System, Fault Location, Isolation Service Restoration (FLISR), Substation Protection, Feeder Protection, Self-healing.**

Introduction

In electric power system, power distribution system is an important part in order to supply reliable, efficient and continuous power to consumer.

This paper is based on the concept of self-healing, i.e. the ability of grid to detect the fault, find the location of fault then isolate that fault section and also restore the system. All this done automatically. Self-Healing is known as **Automated Fault Location, Isolation and Service Restoration(FLISR).** This is achieved by endowing Circuit breakers, Relays and Switches, multi-agent devices, etc.

Previous Related Work

The interfacing of communication network with power system is nowadays taking attention for reliable service. K. K. Agarwal presents an overview of principles for automatic fault location and isolation system to automatically isolate the faulted section in an overhead system [1]. The development of a fault management system for distribution automation system (DAS) for operating and controlling low voltage (LV) downstream of 415/240V [2]. Service restoration problem formulation and solution algorithm incorporated the load curtailment. A ranking based heuristic search algorithm is proposed which prioritizes the multi-objective service restoration problem and returns a new system configuration and load curtailment scheme to restore power to out-of-service customers following fault isolation[3].

Z. Wang and V. Donde present a deterministic algorithm that identifies a back-feed restoration strategy to restore the out-of-service load due to fault isolation while ensuring that the post-restoration network has a valid configuration. The algorithm is based on the concepts of network tracing and it supports both single-path and multi-path restoration[4]. According to Liu Jinsong, It's not practical to test and verify the feeder automation by producing short-circuit fault in real distribution network, and this prevents the practicality progress of feeder automation system[5].

The Fault Location, Isolation and Service Restoration (FLISR) application can improve reliability dramatically without compromising safety and asset protection. R. W. Uluski describes the FLISR function, provides information on the major trends of the day and issues that need to be resolved, and suggests where the industry should go[6].

An effective healer healing approach to accelerate the fault location function of the FLISR process is realized by optimal placement of fault indicators (FIs). A multiple objective function is formulated, and solved using multi-objective particle swarm optimization (MOPSO), to simultaneously minimize indispensable economic and technical objectives [7][11].

FLISR is one of the key automation application which reduces the outage time to the end customers and also reduces the financial penalties incurred due to outages. P. Parikh and M. Monadi proposed a fast FLISR algorithm using IEC 61850 based Generic Object Oriented Substation Event (GOOSE) technology [8][10]. The service reliability can be significantly affected if the communication system fails to operate successfully [9].

A multiagent-based distribution automation solution is proposed to be used in the distribution of self-healing grids to solve the service restoration part of the Fault Location, Isolation and Service Restoration (FLISR) task. FLISR algorithm based on the Multi-Agent System (MAS) concept is designed for active smart distribution grids by leveraging the DG-assisted service restoration functionality [12][13].

To communicate the status changes and the measurements with one another using IEC 61850 GOOSE messages, FLISR make use of Intelligent Electronic Devices (IED's)[14].

Nature of Faults

There is tremendous varieties and causes of faults in distribution grid. The most of the faults are occurred in distribution grid as it is nearer to the load.

1) Line to Line Faults:

These faults are occurred due to the contact between any two phases. The causes for these faults are falling of trees, birds, snakes on the line.

2) Line to ground faults:

These faults are mainly due to the contact between one phase and ground. The main cause for these faults is the falling of conductor on the ground.

3) Double line to ground faults:

These faults are occurred when any two phases comes in contact with the ground.

4) Three line to ground faults:

These faults are occurred when all the three phases come in contact with each other and the ground. The frequency of these faults is the least among the all faults.

5) Overload faults:

These faults are dependent on the nature of load. These are over current faults. The faults which are occurred in distribution grid are mainly of this type as the distribution grid is closest to the load.

6) Short circuit faults:

These faults are often considered as over current faults. When the current flowing through the line is 8 to 10 times more than normal line current, then this abnormal condition is considered as short circuit.

7) Unbalanced load faults:

The uneven loading of phases produces unbalanced currents to flow in the three phases. In this case, the neutral current is not zero.

Distribution Grid And Protection

We have considered radial distribution system of single distribution feeder for the automatic FLISR System. Depending upon whether the feeder is of primary or secondary distribution system, one feeder separates two buses.

Protective relays are used for the detection of any abnormal conditions in system and take appropriate action as soon as possible to regain the power system to its normal operation mode.

The feeder protection consists of a protection system on the substation side of the feeder, as well as one at every bus connected to the distribution side.

A. Substation Side Protection (SSP):

The substation side protection consists of the instantaneous over current relay (OCR) and Circuit Breaker (CB). When a fault current is persistent for a predetermined set of cycles, the OCR trips CB on all three phases. Depending on the measurement of current transformer (CT) on all three phases, the OCR operates. To handle the temporary faults like false alarms or transients a Reclosing Relay (RECR) is used. RECR automatically recloses the CB after a set delay after occurring of faults. If the fault persists still, OCR will trip the CB. After a few attempts of reclosing, the CB goes into LOCKOUT state, and a message is delivered to the substation control room reporting a fault. LOCKOUT is the state of a Circuit Breaker which shows the permanent open state.

B. Feeder Protection System (FP):

The feeder protection System (FP) consists of an over current relay (OCR) and Circuit Breaker (CB). When a fault current is persistent for a predetermined set of cycles, the OCR trips CB on all three phases. Also the CB can be operated by an external control signal.

An Isolator Switch (ISW) is used to isolate the incoming bus of the feeder section from the outgoing bus of the feeder section. By the external control signal, the IS disconnects fully both the end of faulty feeder segment. If this is not done, the one end of faulty feeder segment will be live when service is restored. As shown in Fig. 1, CB_{ij} provides protection for this scheme. Where i=1. . . . .N, which denotes the feeder segment. And j=1 for the CB equipped upstream of the feeder segment, j= 2 for CB equipped downstream of feeder segment.

The communication transceivers are also equipped on the SSP's and FP's to achieve communication between them. A Zigbee Protocol is used for the communication.

FLISR System

The FLISR system provides the Self Healing scheme for distribution grid. The Self Healing Grid is a system endowing sensors, automated controls, and advanced software that uses real-time distribution data to detect and isolate faults and to restore the distribution network to minimize the customers which are impacted. The fault location and isolation process has to be done before the service restoration takes place.

A. Feeder Model:

Consider an N-bus feeder as shown in Fig. 1. SSP denotes the substation side protection and FP_i denotes the i^{th} bus feeder protection system, where i=1,….., N. If the current flowing through the feeder section is greater than the threshold current for a time t_s, then the OCR of SSP trips the Circuit Breaker. The OCR in feeder protection system from FP_1 to FP_N are operated such that the CB closest to faulted feeder trips first. The adjacent upstream CB would trip if the first one is failed.

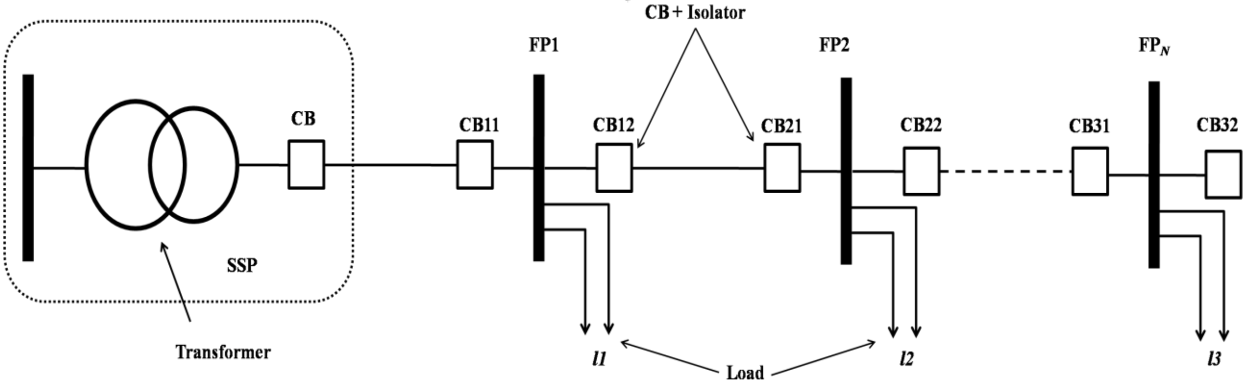


Fig. 1. Single Line Diagram of a Distribution system showing protective elements

$$t_N < t_{N-1} < t_{N-2} < \cdots\cdots < t_1$$

When the fault is detected, a message containing information about Type of Fault, Location of fault between any two feeder segments sent to the substation control room.

By using a remotely controlled tie switch as many as healthy lines are restored back into service. For the service restoration each feeder should be having at least one back up source.

COMMUNICATION NETWORK

The FLISR proposed in this paper uses ZigBee protocol for communication between the field and substation control room. Each FP is equipped with a ZigBee module. They are configured in star network. A serial communication technique is used for the data transmission and reception. The data string containing messages like LOCKOUT is exchanged with the distribution substation.

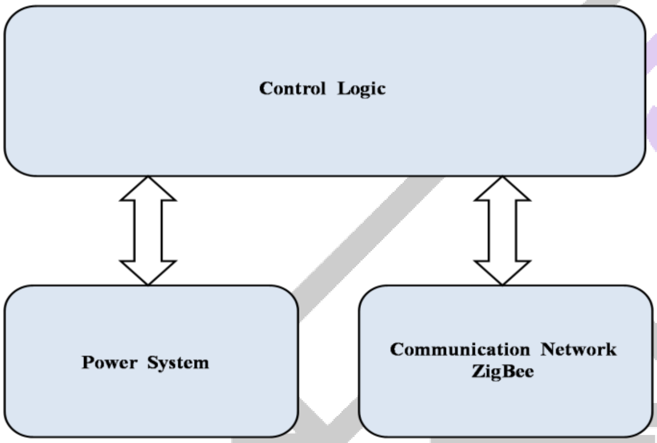
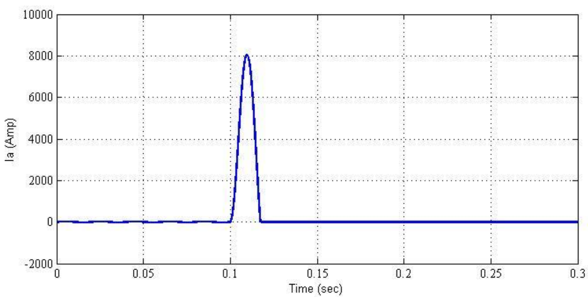


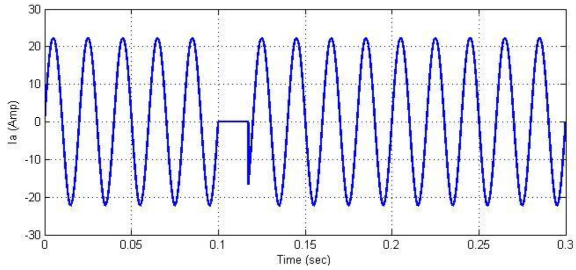
Fig. 2. Block diagram for Interfacing of Power System and, ZigBee module with Control Circuit.

SIMULATION

As shown in Fig. 1. there is a power system of 11kV, $50H_Z$ distribution system which is simulated using simpower system blockset. The distribution feeder is having a 33/11 kV transformer whose secondary is connected to the distribution feeder. The primary of the transformer is connected to the 33kV transmission line at distribution substation. In order to model this, a three phase source block is connected to the primary of three phase transformer. The modeling of load is done by using a three phase series RLC block which provide the active power demand of 10kW and the VAR demand of 100 var.



(a)



(b)

Fig. 3. Current waveform of Phase- A at (a) faulted load section (b) healthy load section.

The modeling of overcurrent relay (OCR), is done by using a level detector which generates signals 1 or 0 according to whether line current exceeds the threshold value or not respectively. In this simulation we have set the threshold value current of 1 kA. The output signal of V-I measurement block is given to the OCR block.

The combination of Isolator switch and CB is modeled by using a single ***Three phase Circuit Breaker Block*** with the enabled external control.

We have modeled a ***Balanced three phase to ground fault*** by using a three phase fault block.

The *Powergui* function block is used for load flow analysis to calculate the branch current and node voltages. These calculation are made at specific time steps of 1 ms.

SIMULATION RESULT

Fig. 3(a) and Fig. 3(b) shows the waveform for faulted load section and healthy load respectively. At the event of a three phase balanced fault on load ***l1*** (see Fig. 1.), a fault current of 8000 A flows through the load. As this value of fault current exceeds threshold value i.e. 1 kA, the CB equipped on FP_1, trips the supply for load ***l1***.

Whereas at the healthy load section, there will be a **Zero Current Period** during the occurrence of fault a**t** ***l1***. This happens, because the fault draws all the current from feeder supply.

LIMTAION OF FLISR

a). Switch Failure:

It is already proposed that if one switch is failed, the immediate upstream switch is going to be operated.

b). Failure of communication link:

Dual communication path or technology per device can further enhance the communication link reliability, with additional cost of redundant communication network.

c). Immediate Second fault:

If an immediate second fault occurs on a faulty section, then FLSIR process should be terminated. If the second fault occurs on healthy section, it will be put in queuing process.

CONCLUSION

The FLISR system along with the self healing scheme helps to increase reliability of the system. This reduces the outage time and related financial penalties.

This paper presents study of FLISR system. The details of fault location, fault isolation and service restoration are discussed. For achieving reliable operation wireless communication technology is discussed. Various limitations for the FLISR system are also discussed.

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