Fault Location, Isolation, and Service Restoration (FLISR) Technique using IEC 61850 GOOSE

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Abstract: Electric distribution utilities are paying maximum attention towards the end-user supply reliability and increase in the quality of electricity.

Distribution network's "self-healing" nature is getting interested in the industry. With the deployment of distribution automation applications, they can not only achieve these performance goals but can also improve the situation awareness, and reduce the financial penalties caused by the system population. Defect Location, Isolation and Service Restoration (FLISR) are one of the major distribution automation applications, which can significantly reduce the outage time in the end customers.

Also, the standardized automation system based on IEC 61850 is increasing in the market. This letter proposes a fast FLISR algorithm using IEC 61850 based Generic Object Oriented Substation Event (GOOSE) technology. When deploying such smart applications commercially, challenges and potential solutions are discussed in more detail.

Keywords: Distribution Automation System, Fault Location, Isolation and Service Restoration (FLISR), IEC 61850, GOOSE.

I. INTRODUCTION

System is an important part of the electrical energy system to provide reliable, efficient and safe power to consumers. Implementation of performance rules in the high penetration and distribution system of distributed energy resources has forced the utility to improve the reliability of its network, and reduces financial penalties due to system population . For this, the implementation of various smart strategic distribution automation applications in the distribution network is required. The fault location, isolation and service reinstatement (FLISR) application (also known as fault detection, isolation and restoration, FDR) is an important building block for any utility's smart distribution grid solution . The FLISR enables utility to significantly improve their distribution network reliability and gain economic benefits . IEC 61850 specifies the communication system for power utility automation

Section-II of the paper discusses advantages of FLISR deployment with an example and compares various FLISR approaches. Further, D-FLISR solution using peer -to-peer IEC 61850 GOOSE communication is proposed in Section-III. Various challenges and possible solutions are proposed in Section-IV. Finally, Section-V concludes the work.

II. FLISR FOR SMART DISTRIBUTION NETWORKS

A. How FLISR Can Reduce Outage Time?

In case of fault on distribution network, the substation feeder safety normally has shutdown power on the normal feeder, which causes many end user customers to disrupt service, including industrial, hospitals, advertisements and residential. Figure 1 shows a common fault scenario and outage time comparison with and without the FLISR implementation. It can be seen from the figure that with the rapid FLISR action (within one minute), the total outage time can be reduced almost. 3-4 hours per outage. In this way, FLISR or circuit restructuring schemes can increase the distribution grid credibility significantly by restoring power to as many customers as possible.

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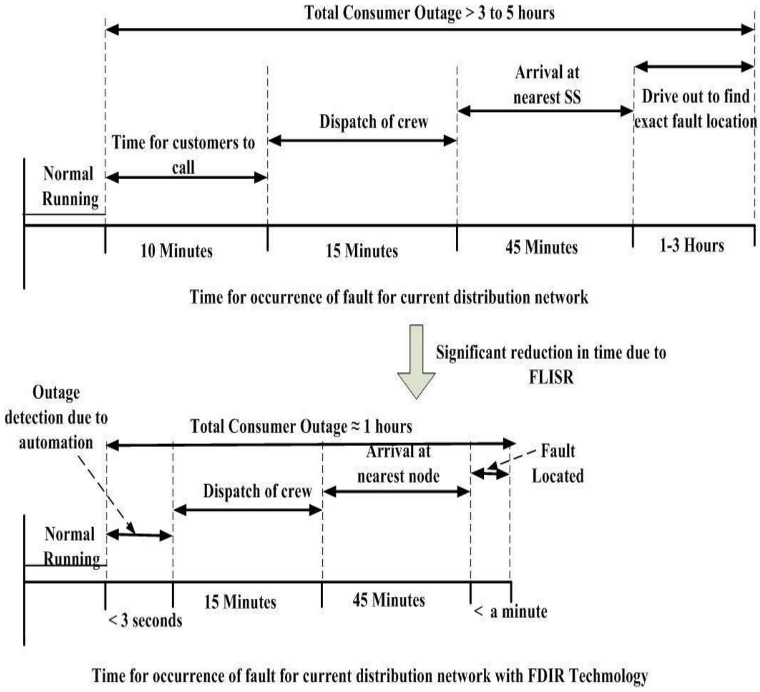

Fig. 1 Example on outage time reduction using FLISR deployment

As per the regulatory standard guidelines, many distribution utilities are measured based on power supply reliability indices to quantify qualitatively how well they are serving their customers, and may be subjected to regulatory.

Fines If the regulator feels its performance then it should not be as good as it should be. There are many different measurement indices that are used to measure utility reliability effectiveness, such as: SIID (System Average Interruption Period Index) to measure the average number of obstacles experienced by the customer; Safi (System Average Interrupt Frequency Index) shows the average number of hurdles experienced by a customer; CAIDI - (Customer Average Interruption Period Index) calculates the average outage period, which will experience a given customer; CML - Customer lost minutes by average 100 customers; CI - Average customer per customer interruption; e.t.c.

B. FLISR Process Steps

Following are the various steps of a typical FLISR system:

1) Fault location (followed by fault detection): Fault location algorithm is the first step for the FLISR, which is triggered by the substation protection devices (Intelligent Electronic Device, IED or reclosed controller). After faulty feeder tripping, the faulty section on the tripped feeder needs to be located. A faulty section of the feeder is referred as a portion of feeder between two switches/recloses.
2) Fault isolation: After identifying the faulty feeder section, both sides of the fault need to be isolated using switches/recloses.
3) Capability Estimation: After isolation and before restoration, a capability estimation need to be carried out to determine if service restoration from a healthy feeder is possible.
4) Service Restoration: From capability estimation, it is determined whether complete or partial load of the faulty feeder can be transfer to healthy feeder .Accordingly, the service restoration process closes tie-switch and corresponding feeder switches.

C. FLISR Architectures

Tis subsection discusses the various architectures of
FLISR deployment:

1) Centralized FLISR (C-FLISR)
2) De-Centralized FLISR (DC-FLISR)
3) Distributed FLISR (D-FLISR)

Centralized approach may be implemented as one of the applications of the Distribution Management System (DMS) or Distribution-SCADA. Feeder optimization can be achieved at the highest possible level, with more complex switching logics, and effective load distribution. However, each switch controller needs to communicate with the control center directly, and this may require high bandwidth communication network, as well as accurate load model information. The response time of the complete automation system may be comparatively high.

On the other hand, DC-FLISR system is deployed at the substation level using a single or a redundant automation device installed in each substation. The remote I/O modules installed at each switch/recloser locations need to be connected to the distribution substation automation device over communication network. As compared to the C-FLISR, the DC-FLISR system is faster with lower bandwidth requirements. The achieved solution may not be the best optimized one, but it is easy and less expensive to deploy.

The distributed approach (D-FLISR) uses controlled devices at each switch/recloser locations, and these devices communicate among each other to determine where the fault has occurred and to determine the appropriate switching actions necessary for the restoration. The IEC 61850 GOOSE based peer-to-peer communication technology is a good fit for such applications. As the intelligent devices (controllers) are distributed, reliability of the scheme higher, however, this requires controller (instead of remote I/O units) at each switch location.

This paper focuses on the D-FLISR scheme based on the IEC 61850 GOOSE, as proposed in the following section.

III. PROPOSED D-FLISR ALGORITHM USING IEC 61850 GOOSE MESSAGES

A. Typical Distribution System Loop and Control Structure

Fig. 2 shows a typical distribution system with a loop configuration where feeders from two substations can be connected through a normally open tie switch. Each substation contains a breaker/reclosed which is controlled by the substation protection Intelligent Electrical Device (IED) (operates substation breaker/reclosed in case of fault on the feeder).

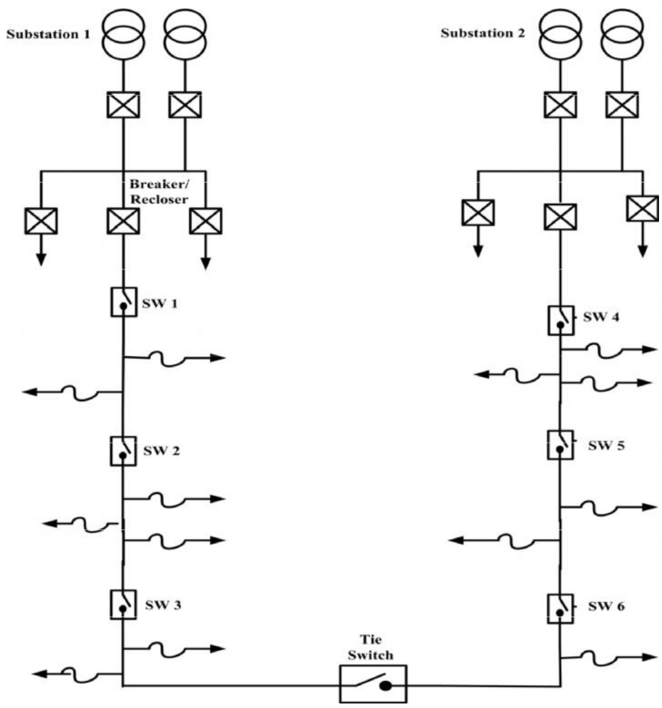

Fig. 2 Different architectures of FLISR

Multiple switches/reclosers are installed over each feeder. These switches/reclosers are also equipped with a local control
Which has a communication capability. Message / information exchange high speed, peer-to-peer IEC 61850 will be through good communication between reclosure controllers in D-FDIR. D-FLISR is done in each switch / reclamation controller, and not a controller, takes the entire FLISR sequence as a master

B. IEC 61850 GOOSE Messages for the Proposed FLISR

Following is the list of GOOSE message types required for the proposed D-FLISR:

Table - I GOOSE message types

GOOSE message types	Description
LO	Lock Out message
FD	Fault Detection message
TT	Transfer Trip message
FIA	Fault Isolation Acknowledgement
FIC	Fault Isolation Complete confirmation
FNC	Fault Not Isolated
SM	Sufficient Margin available
NSM	No Sufficient Margin
RC	Restoration Complete
RT	Restoration Terminated

In addition, each controller needs to load the maximum load through the respective switch / controller for the settable (short and long) timing. There are two quantities in this load for this algorithm: 1) power and 2) current. Power is also required for load capacity calculation, and current requirement for segment loading capacity and capacity building and carrying capacity of switch / reclosures. Therefore, the following items will need analog GOOSE:

1) Pre-fault load current and power
2) Transformer power capacity
3) Feeder section current capacity
4) Recloser current load margin
5) Recloser load current at the end of D-FLISR process

C. Algorithm Requirements / Estimates

I Reclacer controllers have battery backup power, which is enough to meet the D-FLISR algorithm.
ii. Transformers and feeder capacity margins are programmed in the reclosure controllers before the algorithm operation.

D. Fault Location And Isolation Algorithm

Figure 3 shows fault space and algorithm algorithms. The location space process starts after an upstream substation breaker or reclosure (by accidentally by digital relay or controller), and later a LO conveys message to GOOSE.

If the lock-out reclosure / breaker is not immediately near the fault, the downstream switch will switch which understands the mistake and loses power after locking. These switch controllers will multicast FD GOOSE messages at LO GOOSE messages and power loss reception. If the Substation Breaker / Reclosor does not get any FD good message (but still heartbeat / healthy communication receives a good message), in this case the fault is located immediately after the substation breaker and before the downstream Hence, substation relay also sends TT message to immediate Downstream Isolation Switch (DIS) (which identifies immediate downstream switch from faulty section), and opens the switch, upon reception of acknowledgement (FIA) message from downstream switch, the FIC message is sent by upstream intelligent device (which can also be a substation feeder relay or a controller).

The switch controller that is immediately upstream and adjacent to the fault is the Upstream Isolation Switch (UIS); this is determined by looking at all the recloser/switch IDs that were broadcast along with the FD messages. The UIS also sends TT message to DIS. In case an upstream and/or downstream switch is stuck (due to mechanical failure), FNC message is sent by UIS and/or DIS, and other upstream and/or downstream will be re-assigned as UIS and/or DIS respectively.

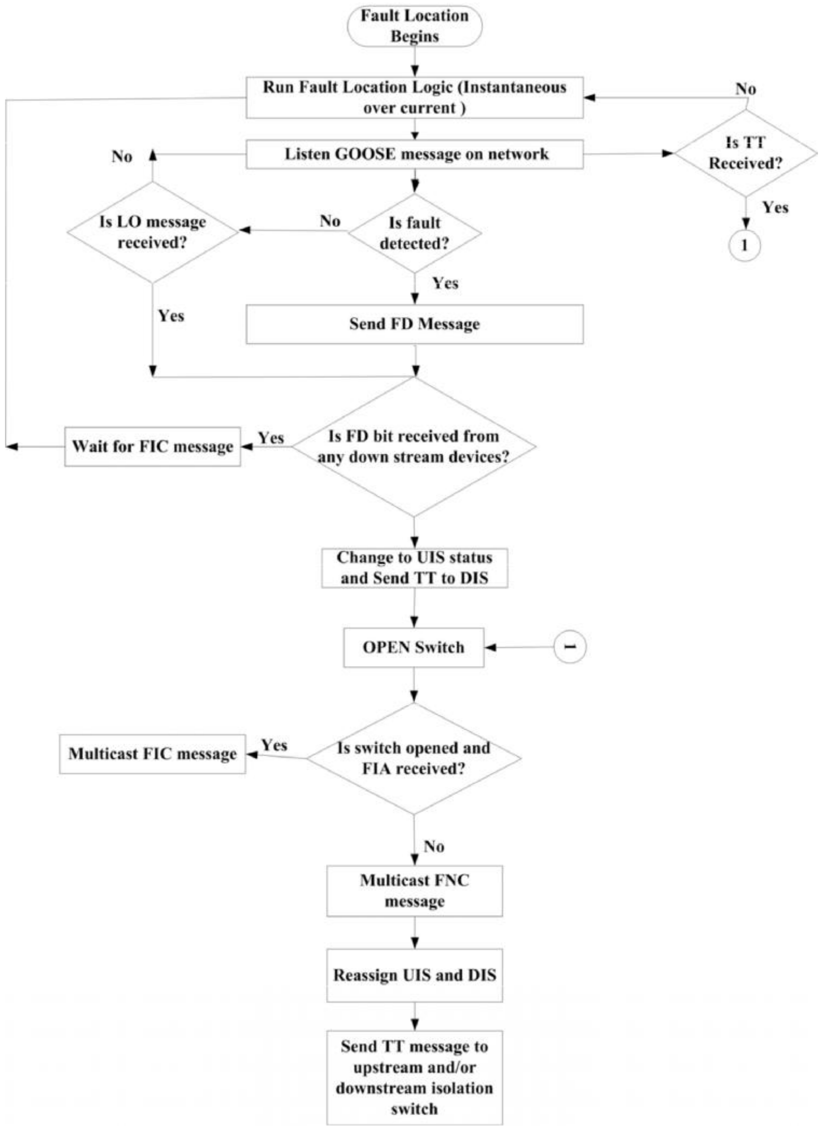

Fig. 3 Fault location and isolation algorithm

E. System Restoration Algorithm

In order to restore the system, two conditions must be completed:

1. Optional substation should have sufficient electricity capacity.

2. In the healthy section and the D-energyed section both "switch and layer" capacity and feeder conductor capacity should be sufficient switches.

Controllers need to communicate with the Healthy Feeder Substation Controller to determine the faulty feeder whether the substation can support additional amounts. It is also important to check that each segment of the loop (with the exception of the dead segment) can handle the additional load and there may be sufficient make up and capacity in the tie.

Figure 4 shows system restoration algorithms, which started on reception of FIC message. Each switch controller on the healthy feeder uses the calculation (1) of the current capacity margin (CCM), and transmits the CCM messages with the relevant luggage ID for all downstream switches on the defective feeder.

CCM = Feeder Capacity Limit – pre-fault load current (1)

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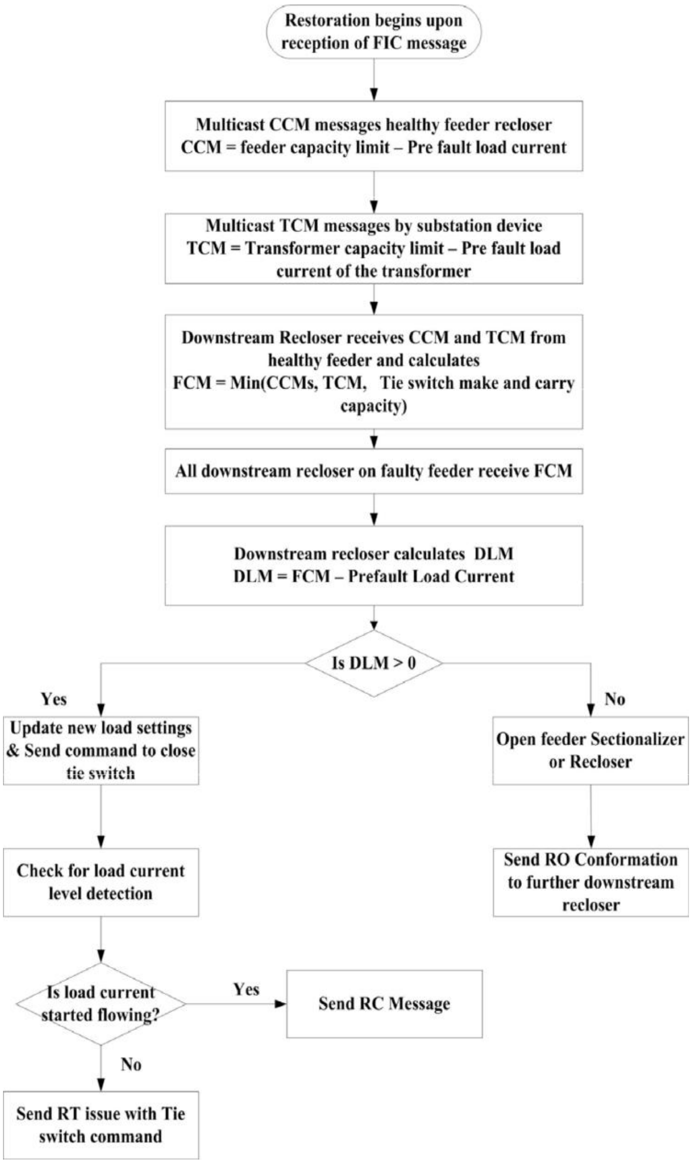

Fig. 4. System restoration algorithm

At the same time, substation relay/controller populates Transformer Capacity Margin (TCM), and transmits TCM message to all downstream switches:

TCM = Transformer Capacity Limit – pre-fault load current (2)

Upon reception of CCM messages and TCM message, each of the downstream switch controllers would calculate Feeder Capacity Margin (FCM) using (3), and Downstream Load Margin (DLM) using (4):

FCM = Min (CCMs, TCM, Tie-switch make & … carry capacity) (3)

DLM = FCM – pre-fault load current … on reverse direction (4)

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If the downstream vaccine controller on the faulty feeder check is DLM positive value (the load margin is sufficient for the related feeder section), the multicast opens the available adequate margin (SM) message, or the switch controller switch and then does not send any sufficient margins. Available (NSM) messages At the reception of SM and NSM messages, the tie-switch controller ties off the switch.

IV. CHALLENGES & POSSIBLE SOLUTIONS

A. Communication Technologies for D-FLISR

The success of the FLSIR depends on the reliable communication technology used for information / message exchange between intelligence devices located along the feeder. In addition, the Power Line Communication (PLC) may not be suitable for the FLISR application, because the feeder line section will be separated. In recent reports on the National Institute of Standards and Technology (NIST) framework and roadmap for smart grid interoperability standards [8], several wired and wireless communication technologies have been identified for various wire grid applications [9]. Potential wireless technologies for successful implementation of FLSIR are discussed briefly after Table II.

Table- II Potential wireless technologies

Wireless Technology	Data Rate	Approx. Coverage
Wireless LAN	1-54Mbps	100m (repeater may increase the coverage)
WiMAX	70Mbps	48Km
Cellular	60-240Kbps	10-50km
Spread spectrum radio (900 MHz)	106Kbps	Up to 50km with repeater

The implementation of wireless technology provides many advantages over wired, for example low installation costs, mobility, remote location coverage, fast installation, etc. However, there are some challenges / limitations in each technique. Some common concerns for wireless technologies are: 1) Wireless technologies running in the licensed frequency spectrum are more sensitive to interference / noise effects; 2) Wireless technologies with less licensed spectrum have less interference, but they are comparatively expensive solutions; 3) Wireless media security is naturally low. Further discussions on these technologies can be obtained from .

B. Contingency Considerations

1) Communication Link Failure: Distribution automation applications are acquired primarily by using intact communication links between intelligent devices. However, an effective algorithm has to consider the discrepancy in the communication link. The proposed FLISR IEC 61850 depends on the multicasting of good messages. To check communication cooperation with other techniques, good technique provides heartbeat / re-transmission mechanism. If a particular controller does not receive good messages after waiting time ends, then other switch controller will assume link or device failure. In this case, the algorithm will eliminate that switch from the FLISR sequence. This would mean that no control action will be taken to the switch. Also, it is proposed to notify the failure of communication of this substation Human Machine Interface (HMI). If a good message is not received from multiple controllers, then the controller should be connected to the substation HMI, and declare the FLISR termination. With the additional cost of dual communication path or technology unnecessary communication network per device, communication links can be further enhanced.
2) Distributed - Switch Controller Failure: Most digital controllers have self-detection facility. When identified as a component failure, the controller will communicate to other coworkers about its failure. As a result, the switch will end with the FLISR sequence (with the failure controller).
3) Mechanical failure of switch or tie-switch: If the UIS fails, the proposed algorithm for taking actions carried out by the UIS upstream switch controller, already reassign the UIS and / or DIS, provide the solution for this contingency DIS, and if downstream DIS fails

C. Limitations of the Proposed Algorithm – Future Scope

1) *Complicated distribution network Configuration, and Voltage Regulation Barriers:* The proposed algorithm applies to the loop distribution network. There may be more complex distribution network configurations, e.g. Multi-loop distribution network. The proposed algorithm does not cover multi-loop at once. In order to solve this problem, multi-loop networks should be split into multiple single loop logic or centralized FDIR (C-FDR), which is discussed before the proposed algorithm, deployed to cover the entire distribution network is done Restoration voltage regulation can be restraint from obstacles. These restrictions are not considered in the current algorithm, and will be addressed in the future.
2) *Immediate second mistake:* It is possible that FLISR made another mistake before completing its sequence. Currently, algorithms can not address this issue. It has been proposed here that, if the faulty feeder (FD) message is detected before the faulty process, before the complete confirmation (RC), the process of restoration should end, and it should be informed to the submission HMI needed. In the case of a second mistake on healthy feeder during a FLISR process, secondary FLISR will trigger only after running the current FLISR; It has to be implemented in the queuing process.
3) *Fault* Persist after Restoration: It is possible that even after a mistake rehabilitation process a mistake persists. This could possibly happen when two defects occur together on two different sections of the same feeder. In this case it is possible to start the FLISR algorithm for the second time or to eliminate FLISR and to travel the entire feeder on the basis of utility exercises.
4) *Blind Spots:* The initial version of the algorithm can not detect dark spots, which are defects located between a reclugger controller and its current transformer. For this feature, the fault detection device must be installed on either side of the switch / reclosure or directionality will be required. This option can be expensive. Therefore, it can happen that the fault location can not accurately provide the feeder feeder section, and therefore the mistake persists after the restoration. The last item discusses the proposed solution in this situation.

V. CONCLUSION

This paper proposes a fast D-FLISR algorithm based on IEC 61850 GOOSE messaging to reduce service outage time. The complete details of fault location, isolation, and service restoration process are discussed with identified different types of IEC 61850 GOOSE messages. The proposed restoration algorithm also considers various capability limits of the feeder, switch and transformer. Furthermore, the wireless based communication technologies are discussed to achieve the proposed algorithm with low cost. Various contingency scenarios and limitations of the algorithm are discussed, and solutions to each of these identified challenges are proposed in further detail.

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