Sympathetic Trip Protection Scenario in IEC 61850

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Abstract **-** IEC 61850 is a international standard for the communication networks and systems in substation. Implementation of high-speed peer-to-peer communication based applications help to promote smart methods in power system protection. This paper presents an approach of using IEC GOOSE for improvement in the performance of the distributed protection scheme, which would reduce overall fault clearing time. Sympathetic tripping logic for a fault on a Feeder has been chosen as the case for implementation. Detection of operation of a relay on a adjacent feeder can be used to adjust the sensitive settings of healthy feeders relays for the duration of an inrush. The paper aims in addressing appropriate Logical Nodes (LNs) with a logic equation in realising the sympathetic tripping logic.

Keywords- IEC 61850, GOOSE Messaging, Distributed Bus Protection, Sympathetic Tripping logic.

I. INTRODUCTION

There has been an increasing requirement for quality of power supplied by the utility. During a short circuit fault in the distribution system causing voltage sags, swells or unbalanced condition lead to interruption of manufacturing and other processes.

The electric power industry is in the process of intensive integration of Intelligent Electronic Devices (IEDs) in substations and power systems. The success of this effort is to a great extent a function of the development of a universal platform that will allow microprocessor based protection and control devices to interoperate over the substation local area network or the utility wide area network [1].

Microprocessor based multifunctional protective relays are the preferred IEDs in today's substation integration or substation automation systems. However, the process of relay integration is slowed down by the fact, that each relay manufacturer typically uses proprietary communications protocol and user interface software [2]. The industry is currently in the process of developing a universal platform that will allow a "plug-and-play" technology to replace today's proprietary devices [3].

The standard IEC 61850 for "Communication networks and systems in substations" [4] is accepted very fast. Substation Automation (SA) Systems have three logical hierarchical levels. The process level refers to the power system equipment in the substation represented by the process interface. The bay level consists of bay protection and control IEDs hosting the related functions [5,6]. The station level refers to tasks for the complete substation and consists substation computer with central functions and Human Machine Interface (HMI) and a gateway to the network control center. Station and bay level are connected by the station bus. Bay and process level is connected by a process bus.

IEC 61850 is a universal communication standard for Substation Automation System (SAS) which has the ability to offer interoperability amongst IEDs from different vendors [7,8]. The functions which are needed to be performed by the IEDs and functional elements are the smallest parts of a function that can exchange data. These functional elements in IEC 61850 are called Logical Nodes LNs. When a function is executed based on the exchange of communications messages between two or more devices, it is called "distributed function". Each LN has a list of Data objects with attributes [8].

The data objects and their attributes together represent the information which is needed to be exchange amongst LNs by the communication service offered by IEC 61850 [9]. Peer-to-peer communications are used to perform protection, control, monitoring and recording functions [10]. Any function can be divided into sub-functions and functional elements this communication service's interface is called Abstract Communication Service Interface (ACSI). One of the communication services models in the ACSI models is the Generic Substation Event (GSE) model service [9]. The GSE contains the generic Object Oriented Substation Event (GOOSE) [11].

IEC GOOSE messaging can be used in development and implementation of distribution protection schemes for improving the performance and reduction of overall fault clearing time. It is based upon the asynchronous reporting of an IEDs digital outputs status to other peer devices enrolled to receive it during the configuration stages of the substation integration process [3].

Communications based distributed functions utilize the IEC 61850 GSSE or GOOSE messages replacing the hard-wired connections as shown in Figure 1. All devices with communications interface have to be connected to the substation network switch to exchange data [12]. It is used to replace the hard wired control signal exchange between IEDs for interlocking and protection purposes and, consequently, is mission sensitive, time critical and must be highly reliable [13,14]. The expected communications based performance should be similar to the conventional hard wired interface.

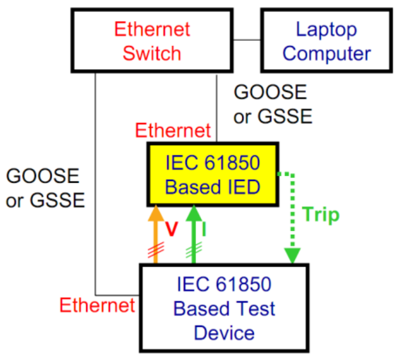

Figure 1 IEC 61850 GSSE or GOOSE based IED functional testing

The associated IEDs receiving the message use the contained information to determine what the appropriate protection response is for the given state. The decision of the appropriate action to GOOSE messages and the action to take should a message time out due to a communication failure is determined by local intelligence in the IED receiving the GOOSE message. The GOOSE message has the potential for being used in protective relays to send tripping signals [15]. In substation protection and control is distributed. All the substation equipment such as transmission and distribution lines, transformers etc., have dedicated protective relay. Configuration of advanced multifunctional protection relays based on XML IEC 61850 Substation Configuration Language is discussed in [14].

Sympathetic trips are undesirable relay operations for unbalanced or highload conditions which occur during or immediately following out-of-section faults. The root cause of the sympathetic trip problem is the type and connection of loads served by distribution feeders. There are two classifications of sympathetic trips, those which occur due to delayed voltage recovery conditions, and those which occur due to the load unbalance during an out-of-section fault.

Delayed voltage recovery conditions is extended duration voltage sags which are commonly initiated by a fault on adjacent lines of the same voltage level or on higher voltage source lines. Delayed voltage recovery can cause outages when protective relays respond to prolonged excessive currents [16, 17 and 18].

The delayed voltage recovery problem is a result of the type of connected load. The culprit loads are large blocks of low-inertia induction motors that lose speed rapidly during a fault-caused voltage sag [19]. Single-phase residential air conditioners are a common application for these motors. Compounding their already easy-to-stall characteristics [20,21]. These same motors must also work against a high refrigerant gas pressure held in the compressor itself.

As these motors stall, they draw more current as the effective motor impedance decreases. Given that there could be many air conditioners served by a single feeder, the increase in feeder load current for the affected phase(s) can be appreciable. when a feeder is restored after an extended outage, the load can exceed the normal feeder load until normal load cycling is re-established.

Whenever the voltage is recovered the stalled motors on adjacent feeders draw large amount of currents. This inrush current will trigger the operation of distribution feeder protective overcurrent relay located on individual feeders. leading to the troublesome sympathetic tripping, This is undesired. Typical fault currents and voltage sag profile on faulted feeder during a fault during delayed voltage recovery condition is discussed in detail in [22].

The following factors increase the probability of a sympathetic tripping: Time delayed fault clearing because it increases the time of the suppressed voltage condition, High feeder loading, Feeder load that is comprised of a high percentage of motor load, Relatively low relay settings - ground and phase, Voltage dips low enough to stall motors but not low enough to drop-out the motor contactors, Fast trip times on the feeder relaying because the feeder breaker will be susceptible to tripping prior to the distributed load’s thermal unit tripping, Low-set instantaneous relays used in fuse savings schemes being applied on the feeder[23]. Similar Overcurrent Protection Issues is also observed in Distribution Feeders with Distributed Generation [24].

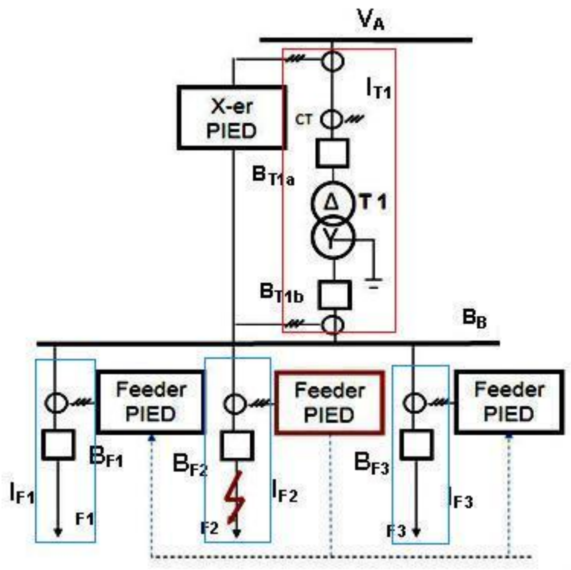

Figure 2: Sympathetic trip protection

Papers [16,17and18] discuss solutions to avoid sympathetic tripping of radial feeders, One common sympathetic trip solution offered in these papers is to permanently raise phase and ground overcurrent element pickup thresholds. This solution unnecessarily penalizes fault detection sensitivity. Relay-based solutions are provided in [22]. Time-integrated Threshold Restraint a Secure Sectionalizer control logic solution in [25].

Figure 2 is a general scheme of Distribution Feeder with a Fault on feeder F2. A Phase time-over current element - Feeder Protection Intelligent Electronic Device (PIED) is on each feeder. The following sections in the paper discuss a sympathetic trip logic using IEC 61850 architecture with GOOSE messaging. The Logical Nodes in implementing the Sympathetic trip logic are detailed. Finally a logical equation for the scheme.

II. SYMPATHETIC TRIP LOGIC

Multiple protective IEDs with IEC 61850 GOOSE can be connected to the substation LAN and used in distributed bus protection applications for distribution systems. In case of a fault on any of the protected feeders (F1 in Figure 2), the Feeder protection IED will see a fault. The same fault current will be seen by the transformer protection IED. As soon as the overcurrent protection element of the feeder relay starts, the IED will send a GOOSE message indicating the detection of a fault on the feeder.

Each of the relays on the healthy feeders subscribes to GOOSE messages from all adjacent feeder protection IEDs and when it receives a message suggesting a fault and its operation of realy. The healthy feeder PIED can adapts its settings for the period of time that the expected inrush condition is going to last. Two options which are usually available is to block the sensitive overcurrent setting or reduce the sensitivity by increasing the pickup setting for the duration of the inrush [26].

The benefit of using GOOSE messages in such a scheme is instead of large number of required wires between the binary inputs and relay outputs of all distribution feeder protection IEDs, it just need to publish and subscribe to GOOSE messages from the adjacent Feeder PIEDs. The following section tries to realize this logic using few realevent logical nodes.

III. LOGICAL NODES FOR THE FEEDERS

These logical nodes are located in the Physical device (PD) Relay on each Feeder. From Figure 3 we can see that the logical nodes involved with each feeder to realize the sympathetic tripping scheme are Current transformer TCTR, Voltage transformer TVTR, a time overcurrent relay here we have chosen voltage controlled/dependent time overcurrent protection PVOC [8]. The relays PIED send GOOSE Message to other relays PIED available on each feeder. The LNs are described in detail with data attributes in [11].

A. Current transformer

Instrument transformer LN-TCTR performs the function of measuring the current secondary side flowing through the feeder and gives instantaneous current value to the PVOC relay The LN-TCTR together with LN-LLN0 and LN-LPHD are all located in the a logical Device-LD [9] as shown in Figure 3.

B. Voltage transfomer

LN-TVTR performs the function of measuring the voltage from secondary side flowing through the feeder and gives instantaneous voltage value to the PVOC relay The LN-TVTR together with LN-LLN0 and LN-LPHD are all located in the LD [9] shown in Figure 2.

C. voltage controlled/dependent time overcurrent protection

The relay LN-PVOC[11] on each feeder is a AC time over current relay. When the AC input current exceeds a predetermined value, and in which the input current and operating time are inversely related through a substantial portion of the performance range

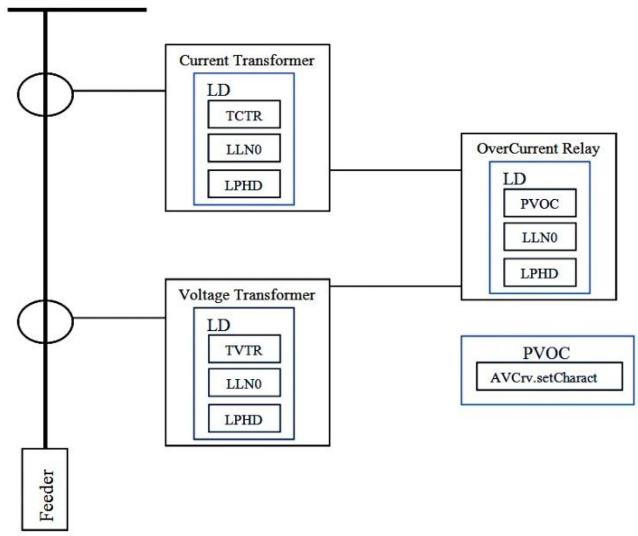

Figure 3: Logical Nodes for the proposed sympathetic tripping logic

The optional settings under Data objects in PVOC class which are of interest here are

AVCrv-CURVE-'operating curve type' (for voltage controlled current curve), setting curve-CURVE is a data class specification for analogue settings.

AVChr33-CSG-'Multiline curve characteristic' definition 'curve shape setting'-CSG-is also a data class specification for analogue settings, it refers to the attribute AVCrv.setCharact=33 for instance.

AVst-CSD-'active curve characteristic' and 'Curve shape description'–CSD is a data class specification for description information.

IV. OPERATION OF RELAYS AND FEEDER PIED SETTINGS DURING DELAYED VOLTAGE RECOVERY TIME.

Soon after the fault on a Feeder its Relay normal operation will begin, simultaneously it would send a GOOSE Message to healthy/neighbouring feeders other IEDs connected to the same Bus. Each of the relays on the healthy feeders subscribes to GOOSE messages from all adjacent feeder protection IEDs and when it receives a message indicating adjacent feeder fault.

The fault situation would satisfy the condition $V_F<V_{rms}$, Where V_F is the Feeder sample voltage send by TVTR. V_{rms} is the normal operating Bus voltage setting made in the relay PVOC and the condition $I_F>I_{NS}$. where I_F is the feeder current sampled from TCTR, I_{NS} is the normal relay pickup value set for the individual Feeders. The GOOSE message sent during above condition could prepare the adjacent Feeder relays (PIED) for the inrush current which would follow soon after the fault is cleared and voltage is restored.

There are several ways to prevent undesired operation of relay during this current inrush situation, as the inrush current is above the normal operating and pickup value. one option is to block the sensitive overcurrent setting. other is to reduce the sensitivity by increasing the pickup setting for the duration of the inrush. Blocking the sensitive overcurrent setting is undesired as it may permanently block the overcurrent element if the blocker malfunctions.

A preferred solution is to reduce the sensitivity by increasing the pickup settings for the period of time that the expected inrush condition is going to last. This can be achieved by a setting which would raise the operating curve to a higher value from a family of curves, only for a short duration of expected inrush.

A. *Realy settings for the duration of inrush*

As discussed earlier LN-PVOC from the available data objects the settings AVCrv-CURVE-operating curve type for voltage controlled current curve is assigned by AVChr22-CSG-Multiline curve characteristic definition it refers to the attribute AVCrv.setCharact=22. This setting is during inrush which can be 1.5times of normal setting. The operating curve could be raised to this setting if it satisfies the following logic equation.

($I_F > I_{NS}$) AND ($V_F < V_{rms}$)=*faulted feeder PIED operation* (sends GOOSE message)

(*Faulted feeder PIED operation*) AND ($V_m \cong V_{rms}$)

V_m is the measured voltage across the individual feeder by TVTR. If the above logic condition is met. AVCrv.setCharact=11 is modified to AVCrv.setCharact=22.

Where AVCrv.setCharact=11 is normal relay setting and AVCrv.setCharact=22 is the setting for inrush condition. This setting goes back to AVCrv.setCharact=11 after few operation cycles.

V. Conclusions

In this paper we disscused about the phenomenon of sympathetic tripping and how healthy feeders respond to a fault on a adjacent feeder. Peer-Peer communication is utilised for localised distributed protection. The paper addressed a solution to avoid sympathetic tripping using GOOSE messaging. This paper gives a solution how a setting of data object AVCrv-voltage controlled current curve of logical node LN-PVOC in a feeder PIED can be modified. Thus LN-PVOC operating curve is changed to a new operating curve, this setting for the duration of inrush current would avoid sympathetic tripping situation on a distribution feeders.

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