

Line to Ground Faults Protection and Control method in Active Distribution Network using IEC 61850

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Abstract— Protection and control automation messages transfer between devices and the control center (CC) over IEC 61850 standard protocols in active distribution network (ADN) using Ethernet. Wireless communication network provides real-time monitoring and control of ADN. The proposed novel approach framework presents line to ground (LG) faults protection and control method utilizing IEC 61850 standards at bay level between intelligent protection devices for fast and reliable protection. Moreover, this bay level peer to peer communication utilizes IEEE 802.11 wireless local area network (WLAN) to reduce the fault protection time and other messages transferring time instead of Ethernet communication by GOOSE multicast communication services. End to end time delay and throughput of data transmission between the coordination nodes are illustrated using NS2 simulation.

Keywords— line to ground faults, IEC 61850, active distribution network, IEEE 802.11.

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1. INTRODUCTION

IEC 61850 standard communication protocol accomplishes the automation function in interconnected networks in active distribution networks (ADN). The smartness of ADN relies on the reliability of the protection, control, and communication operations (PCC) between the interconnected intelligent electronic devices (IED) and the control center.

When LG faults occur the overcurrent relay (OCR) detects the fault from its settings and trips the protection devices. Distribution generators (DG) detect islanding from the isolated feeder and apply anti-islanding. Fault currents are varying in ADN due to DGs impedance parallel to Thevenin's equivalent. DGs capacity and location also determine the fault current calculation.

Different methods utilize LG faults protection and control at distribution system. A novel protection method based on relay agent improves the protection performance in single phase earth fault protection for the radial distribution system with DGs [1]. The voltage comparison method operates when in zone faults occurs and unable to operate when out of zone fault occurs [2].

ADN encompasses the interconnected IEC 61850 enabled field devices of relays, circuit breakers, sensors, actuators, and DGs. As the DG levels increase the fault current varying from precalculated settings when overcurrent ground faults occurred. The proposed adaptive over current system which automatically amends all the OCRs protection settings and interfaces between layers using IEC 61850 protocols [3]. Protection coordination system utilizes the dual settings in directional overcurrent relays (DOCR) which specifies two inverse time-current characteristics depends on both forward/reverse fault direction in the meshed distribution system with DG [4] and the time-current-voltage characteristics for each DOCR can achieve a significant reduction in the total relay operating time in ADN [5]. IEEE 1547 interconnection status describes DGs monitoring protection, control functions and information exchange [6].

The sophisticated smart grid system overview the end to end architecture by the integrating information and communication technologies [7]. Multi-tier overlay communication infrastructure utilizes in decentralized ADN for power control and communication operation [8]. Standard-compliant automation approach utilizing IEC 61850 interoperability concept proposed [9], and the cost-effective real-time low voltage monitoring system also utilizing IEC 61850 open standards [10].

IEC 61850 provides the smartness in PCC functions in substation automation [11]. Integrated smart substation design and implementation utilize IEC 61850 standard for digital information sharing in the three layer device to improve reliability, reduce complication and maintenance [12]. The proposed framework describes a new smarter interface device solution to distribution generation (DG) for power grid protection and also implements a new islanding detection algorithm for field measurement and communication between DGs and distribution system operators [13]. IEC 61850 real-time communication requirement employs IED open architecture at ADN [14].

Wireless networks are the crucial part of ADN in smart grid for transmission time sensitive sensor data through the transmission line networks. Wireless sensor network utilizing framework uses for transmission line monitoring [15].

The proposed multihop wireless networks with a cellular frequency-reuse structure exploit IEEE 802.11a standard communication infrastructure for active monitoring and control of distribution networks [16]. The survey investigates the challenges, protocols, and architecture of cellular technology to support neighborhood area networks (NAN) applications [17].

IEC 61850 standards utilize Ethernet technology for automation services in ADN. The researcher scrutinizes that the IEC 61850 protocols utilize wireless technologies for

distribution automation. Several smart PCC applications of WLAN in IEC 61850 based smart distribution substations are discussed in this paper [18]. The paper investigates IEEE 802.11ac deployment between IEC 61850 enabled IEDs [19].

Detailed analysis of GOOSE message structure and its simulation using software and real protection devices are provided [20], and the proposed fast fault location, isolation, service restoration (FLISR) algorithm utilizes IEC 61850 based GOOSE message for reduction of the service outage time [21].

This paper proposes a novel approach based framework for LG faults protection and control method in ADN over IEC 61850 standards of SMV, GOOSE, MMS to utilize IEEE 802.11 WLAN standard. The objective describes the PCC functions between peer to peer IEC 61850 enabled IEDs using GOOSE multicast service when LG fault protection and coordination for both primary and backup protection at bay level.

Section II briefly introduces the overview of LG fault protection, IEC 61850 protocols standard, and IEEE 802.11 wireless LAN. Section III presents the proposed framework. Section IV illustrates the end to end delay, throughput of wired and wireless nodes using NS2 simulation. Section V describes the conclusion.

2. OVERVIEW OF THE REQUIREMENTS

A. Line to Ground Faults protection

Line to ground (LG) faults classified as the single line to ground (SLG) fault and double line to ground (LLG) fault under unsymmetrical faults, and three lines to ground (LLLG) fault under symmetrical fault. SLG and LLLG fault calculation is considered for minimum and maximum fault settings respectively. However, SLG fault calculation is considered for the process settings. The calculation of the fault current and voltage determine the process settings of the relay, circuit breaker, fuses, other protective devices ratings and the system stability.

Thevenin's equivalent circuit utilizes for finding the fault current. The calculation uses per unit quantities with or without fault impedance and certain assumptions. Per unit quantities of the sequence components of the positive (Z_1), negative (Z_2) and zero (Z_0) calculation obtained from the balanced symmetrical system with the various transformer connections ($\Delta/Y/Y$ grounded).

$$\text{Fault current, } I_f = \frac{3 E_f}{Z_1 + Z_2 + Z_0 + 3Z_f} \quad (1)$$

where, $E_f = 1$ p.u., Z_f – fault impedance, for bolted fault $Z_f = 0$

Fault current in a phase = fault current in p.u. (I_f) \times base current at fault point.

The current is flowing from the source and returning the same balanced feeders. When LG faults occur in a feeder the imbalanced or residual current is flowing through the earth. Earth fault relay (EFR) which detects this zero sequence difference of overcurrent, exceeds the predetermined value and will operate with the determined operating time.

$$\text{Operating time, } t = \frac{TMS \times \alpha}{(I_f/I_p)^{\beta-1}} \quad (2)$$

where,

TMS – Time Multiplier Setting

I_f – Fault current (A)

I_p – Pickup current (A)

α, β – constants for different type characteristics

If OCR fails to function at primary LG fault protection, the downstream located OCR will operate as backup protection with the coordination time interval (CTI). The dual settings DOOCR utilizes for both primary and backup protection from its forward and reverse settings.

B. IEC 61850 Protocols Standard

Substation SCADA automation abutments IEC 61850 protocol standards for real time monitoring, recording, processing and controlling between PCC devices and CC. The set of protocols in which the types are the generic object oriented substation event (GOOSE), sample measured values (SMV) and manufacturing message specification (MMS). GOOSE exchanges the logical binary data from logical nodes between IEDs and to CC using multicast services. SMV transmits the analogue sample data at sources nodes. GOOSE, SMV are the publisher-subscriber architecture. MMS transfers data collection utilizing TCP/IP while monitoring. MMS is the client-server architecture. IEC 61850 protocols are functioning between the process, bay and station levels of ADN. Table. I. shows IEC 61850 standards for ADN automation.

IEC 61850 associated with the three layers of the physical, data link and application layer. The device model starts with a physical device which defines the network address and connects to the network. Physical devices are connected with logical devices, and the logical device includes logical nodes. Common Data Class (CDC) describes the type and the structure of data within the logical nodes. The interoperability of the IEC 61850 utilizes fast and reliable Ethernet communication. High speed function services, easy configuration, and the devices are self-describing are the features. Lower installation cost, extension, and integration are the advantages.

C. IEEE 802.11 – WLAN Standard

IEEE 802.11 standard defines the two type network architectures of infrastructure network and ad hoc (peer to peer) network. It covers physical layer and media access control (MAC) layer. This client-server architecture has no licensed bands between 2.4 to 5.8 GHz and allowed data rate 1 to 54 Mbps. WLAN functions used in industrial, medical and scientific applications. This simplified configurable network accesses real-time, location independent and ensures mobility, reliability, and compatibility of the network. The management, control, and data frames utilize starting communication, channel access, data transfer, and control information. Higher frequency range, efficient coding, ease of installation and lower cost are the properties of WLAN. It also has some limitations to traffic disruption, maintenance, and network security. The feature of power management is to turn off when inactive. Table. II. shows different IEEE 802.11 network standards.

3. PROPOSED FRAMEWORK

The proposed framework represents the overcurrent protection of LG faults in ADN using IEC 61850 protocols. Fig. 1, illustrates the proposed framework.

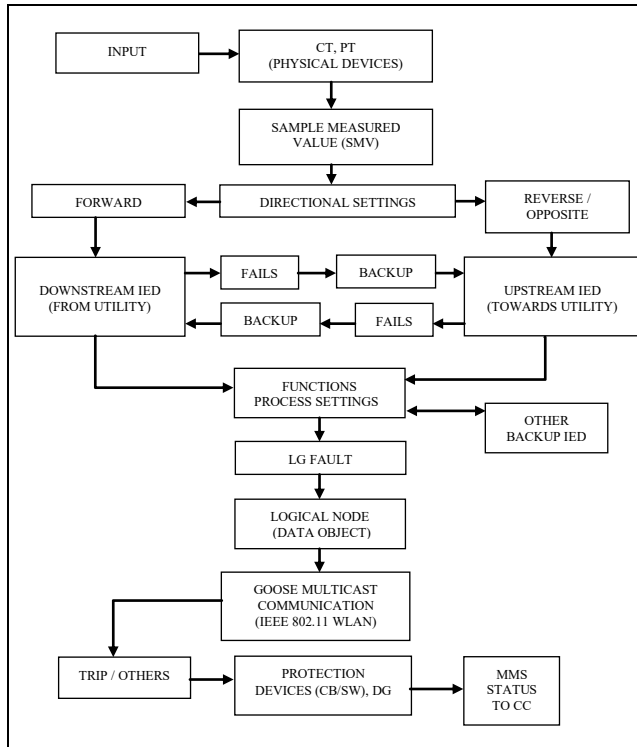


Fig. 1. Proposed Framework for LG fault protection using IEC 61850.

The feeder connected physical devices (CT,PT) acquire the input values of current and voltage from the feeders at process level. Overcurrent IED get current values of $i(t)$ from phases (i_1, i_2, i_3) and earth (g), and the voltage values of $v(t)$ of v_1, v_2, v_3 . OCR IEDs are monitoring and recording SMV data of the current and voltage at prescribed time intervals. When LG faults occurred at t sec the values exceed the predetermined settings ($i_{\min} \leq t \leq i_{\max}$) and the output changed from the following equations,

$$i(t) \rightarrow i_1(t)+g(t) / i_2(t)+g(t) / i_3(t)+g(t) \text{ (for SLG fault)} \quad (3)$$

$$i(t) \rightarrow i_1(t)+i_2(t)+g(t) / i_2(t)+i_3(t)+g(t) / i_1(t)+i_3(t)+g(t) \text{ (for LLG fault)} \quad (4)$$

$$i(t) \rightarrow i_1(t)+i_2(t)+i_3(t)+g(t) \text{ (for LLLG fault)} \quad (5)$$

then data attributes changed the quality and behaviour at the time event.

The structure of data model defines as,

Logical device / logical node / data object / attributes (mode, behaviour, health, etc.)

GOOSE transfers information route to IEDs which the data objects represented from the logical node.

For example, overcurrent earth fault protection defined as

Relay IED / OCP / EF / Pos / Val, general, q, t .

GOOSE transfers the data object OCP.EP message from the publisher IED to subscriber IED by multicast communication service.

Protective devices and DGs received the GOOSE trip message and operated. The IEDs send their status through MMS over TCP/IP to CC whether the circuit breaker opened, and either DG has applied anti-islanding or connected to the backup storage device. DG protection system also enhanced as IEC 61850 enabled system. DGs anti-islanding operation functions as remote access control from IEC 61850 enabled IED. If the downstream forward IED (R_f) fails to operate, it sends the Fails message to upstream reverse IED (R_r), then upstream IED operates as a backup protection, and the same when upstream IED fails then it will coordinate with the downstream IED for backup protection.

The wireless network represents a model as $M = (R, L)$ associated with the protection system. Where, $R = (R_f \cup R_r) \cup R_b$. R_f represents the primary forward IED and R_r represents the reverse IED. R_b is the backup IED. L is the set of logical connectivity links from the source node to multicast nodes. The end to end delay of the trip data / other is the output transfers between the publisher IED to the subscriber IED.

Time delay between IEDs,

$T_d =$ Receiving end time of subscriber IED (E_t) – Starting transmitting time of publisher IED (S_t).

$$T_d = E_t - S_t \quad (6)$$

Average end to end delay = T_d / total packets received

The following algorithm is used to operate for this proposed function.

Algorithm: IEC 61850 enabled overcurrent IEDs to utilize IEEE 802.11 WLAN.

Input: LG fault SMV data

Output: GOOSE multicast communication of LG fault data object for tripping / others

Step 1: SMV analogue data form physical devices output settings

Step 2: IEDs process from the prescribed directional settings

Step 3: Logical data output generated from the triggered event by the change of IED data attributes

Step 4: GOOSE exchanges this logical output from publisher to subscribers

Step 5: Time delay $T_d = E_t - S_t$

Step 6: CB/ SW tripped, DGs applied anti-islanding / connect to backup storage

Step 7: MMS transfers IED status over TCP/IP to CC

Step 8: If primary forward / reverse IED fails, then operates with coordinated reverse / forward IED or other backup IED

Step 9: Go to Step 1 to Step 8

4. SIMULATION AND DISCUSSION

The following simulation shows the end to end delay and throughput of sensor nodes using wired Ethernet data and wireless IEEE 802.11 data using NS2 simulation.

Fig.2.(a, b) shows the end to end delay and throughput of 50 bytes (GOOSE data size) in Ethernet 10 Mbps data rate between wired nodes.

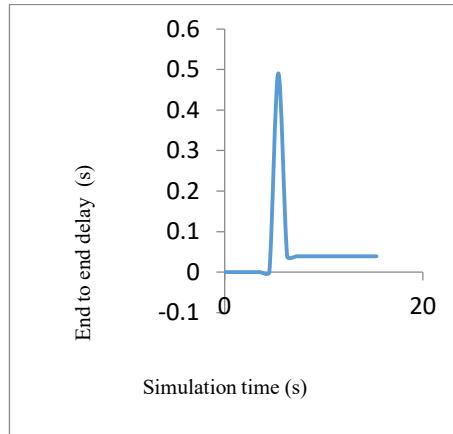
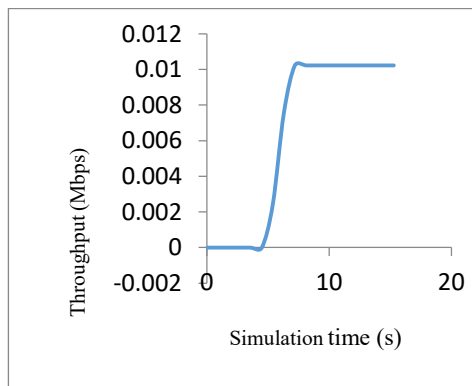


Fig. 2. (a) Wired End to end delay (s).



(b) Wired Throughput (Mbps)

Fig.3.(a, b) shows the end to end delay and throughput of 50 bytes (GOOSE data size) in IEEE 802.11 WLAN, 54 Mbps data rate between wireless nodes.

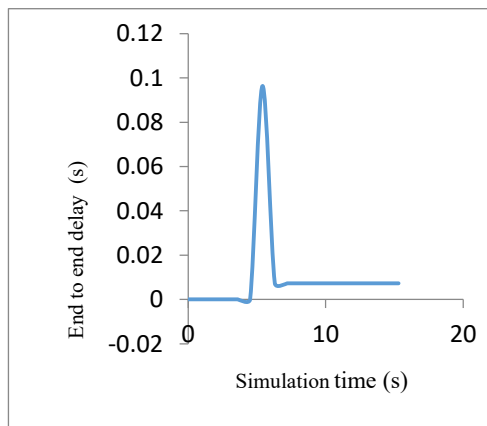
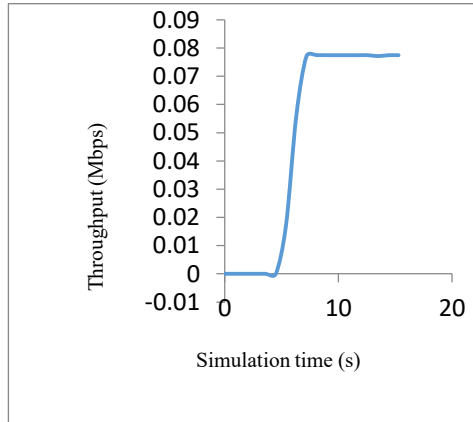


Fig. 3. (a) Wireless End to end delay (s)



(b) Wireless Throughput (Mbps)

The data transmission started at 5 sec in simulation for both wired and wireless data rates. When the simulation started the end to end delay of wireless nodes is very low (≈ 0.1 sec) compare with wired transmission (≈ 0.5 sec). The wireless throughput (≈ 0.08 Mbps) got high performance compared with wired throughput (≈ 0.01 Mbps). We decide that IEC 61850 standards will achieve high performance and low end to end delay when utilizing IEEE 802.11 WLAN from illustrated the simulation.

5. CONCLUSION

The proposed framework describes the protection method of LG faults using IEC 61850 protocols to utilize IEEE 802.11 WLAN multicast communication services in active distribution network. This implementation method operates only between IEC 61850 enabled IEDs and DGs. As the direct communication functions between peer to peer devices of IEC 61850 enabled devices, DGs do not require the separate overcurrent islanding detection method for anti-islanding and protection system does not require adaptive settings. IEEE 802.11 WLAN improves high throughput performance and reduces end to end time delays of transferring messages between logical nodes instead of Ethernet communication. This will help us to establish the protection system in ADN to interface with IEDs and DGs in real time implementation.

TABLE I. IEC 61850 STANDARDS FOR ADN AUTOMATION

IEC 61850 Standard Protocols	Delay Time (ms)	Automation application	Packet size (Bytes)	Sampling Frequency (Hz)
SMV (type 4)	10	Protection application	126	4800
GOOSE (type 1)	3-10	Logical state Trip, Block signal	50	
MMS (type 5)	1000-5000	Data to Control	300 KB	1
(type 2)	50-100	Centre Status	200	20

TABLE II. IEEE 802.11 NETWORK STANDARD

IEEE 802.11 Protocols	Data Rate (Mbps)	Frequency band (GHz)	Spectrum
802.11 a	54	5	OFDM
802.11 b	11	2.4	DSSS
802.11 g	54	2.4	OFDM, DSSS
802.11 n	600	2.4 / 5	OFDM

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