IEC 61850-7-420 based Communication Configuration to Integrate DER to Distribution System

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***Abstract*— With the increasing deployment of Distributed Energy Resources (DERs) in the distribution system, DERs presents many challenges for smooth and stable operation of the grid. For the effective management of DERs extensive communication between different components of DER and distribution system is required. In an effort to standardize the communication methods and modeling of logical nodes required for Intelligent Electronic Devices (IEDs) of DERs is issued in IEC 61850-7-420 standard. This paper presents the modeling of Distributed Energy Resources system as per IEC 61850-7-420 standard and simulation of the communication configuration, using network simulation tool i.e. OPNET modeler, needed to integrate DERs and Distribution system. Finally the performance evaluation of the designed communication configuration architecture for different communication technologies is presented.**

Keywords—component; formatting; style; styling; insert (key words)

I. Introduction

THE distribution systems were traditionally designed for unidirectional power flow from generators to loads. Increased penetration of Distributed Energy Resources (DERs) in the distribution system has posed many challenges in the operation of distribution system.

The communication architecture plays an important role in smooth functioning of DER integrated distribution system. Robust, deterministic and interoperable communication architecture is essential in order to ensure that all DER components exchange information, control commands and real time measurements effectively without any delay or loss. But DER manufacturers provide their own propriety protocols; these multivendor protocols present major technical difficulties, such as interoperability issues for implementation of communication architectures. With the publishing of IEC 61850-7-420 [1] as an extension to IEC 61850 [2], a widely accepted standard, the communications between DERs and other equipment became standardized.

In literature IEC 61850 based communication architectures for automation, protection and monitoring of substations has largely been reported [3-5]. IEC 61850 based communication aided distribution system protection schemes have been proposed in references [6, 7]. Taha *et al.* [8] and Apostolov [9] presented the object modeling of DERs with IEC 61850-7-420 and its extensions from the control and communication point of view. Kanabar *et al.* [10] presented the study of different communication systems between DERs and IEC 61850 based distribution system.

This paper presents the modeling of DER IEDs according to IEC 61850-7-420 and its extensions. Performance evaluation of the communication architecture for integrating DER in distribution system with different wired and wireless communication technologies using Optimized Network Engineering Tool (OPNET) [11] modeler is presented.

The organization of paper is as follows: Section II summarizes IEC 61850 communication standards, Section III explains the modeling of different distributed energy resources system according to IEC 61850-7-420, and Section IV presents the simulation study of communication between different DERs and distribution system using different communication technologies. Finally, Section V presents future work and conclusion.

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II. IEC 61850 Communication Standard

IEC 61850 provides a comprehensive model for power system devices to organize data, configure objects and map them on to protocols, so that they are consistent and interoperable.

The IEC 61850 standard consists of many parts. Part 3, 4 and 5 describes the general and specific functional requirements for communication in substation. The part 7-2 and 7-4 describe the abstract services and the abstraction of data objects. The data objects consists of building blocks Common Data Classes (CDC) elements which are defined in part 7-3. The mapping of these abstract services and data objects on to manufacturing Messaging Specification (MMS)

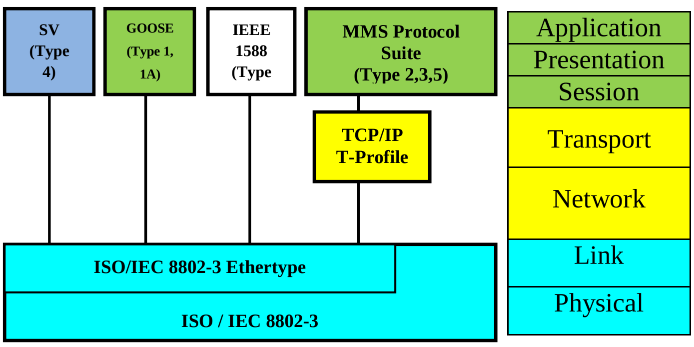

Fig. 1. OSI 7-layer stack of IEC 61850

protocols is defined in part 8-1. The mapping of sample values on to Ethernet data frames is separately defined in part 9-2. The part 10 of the standard defines a testing methodology to determine the conformance of equipment to be used.

A. *Message structure:*

The IEC 61850 has proposed two different types of communication stacks, and there are seven types of messages based on time requirements. Fig. 1 shows the IEC 61850 based communication stack. IEC 61850 specifies the communication of time critical GOOSE and sampled value messages directly on data link layer to avoid any overhead delays.

The type 2, 3, 5, 6 and 7 messages are mapped over complete OSI-7 layer stack as a client /server application. According to IEEE 802.1Q, priority tagging and Virtual Local Area Network (VLAN) tagging are defined in the link layer of the stack. This ensures the segregation of the IEDs according to their functions and also provides higher priority for the most time critical data.

B. *Time requirements for different messages*

IEC 61850 differentiates the different messages according to their transfer time requirements. The transfer time counts from movement the transmitting node puts data content on top of the transmission stack up to the moment the receiving node extracts the data from the transmission stack. The IEC 61850 standard specifies the time requirements of different messages for substations, but the time requirements for DERs connected to distribution system are not specified. IEEE 1646 standard [12] gives the time requirements to different types of information messages for external or remote or DER IEDs to the substation. Table I gives the time requirements of different messages of distribution substation and DERs.

TABLE I
MAXIMUM MESSAGE DELIVARY TIME

Information Type	**Internal in substation (msec)**	**External (DER) to substation (msec)**
Protection information	0-4	8-12
Monitoring and control information	16	1 s

IEC 61850 was initially proposed for substation automation systems later it was extended to utility automation. The new extensions of the standard such as part 7-420 defines the logical nodes for DERs, part 90-1 describes the communication between two substations, part 90-5 describes the Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118, part 90-7 describes the Object Models for DER inverters, etc.

III. MODELLING OF DER SYSTEM AS PER IEC 61850-7-420

The physical electrical devices of the DER system have corresponding communication devices connected to them. These physical communication devices are Intelligent Electronic Devices (IEDs). In each physical device i.e. IED there may be one or more logical devices. Composition of relevant logical nodes for providing information needed for a particular device is defined as logical device. The groups of data objects that serve specific functions are defined as logical nodes. IEC 61850-7-420 defines the logical nodes for DER systems except for wind power plant which are defined in a

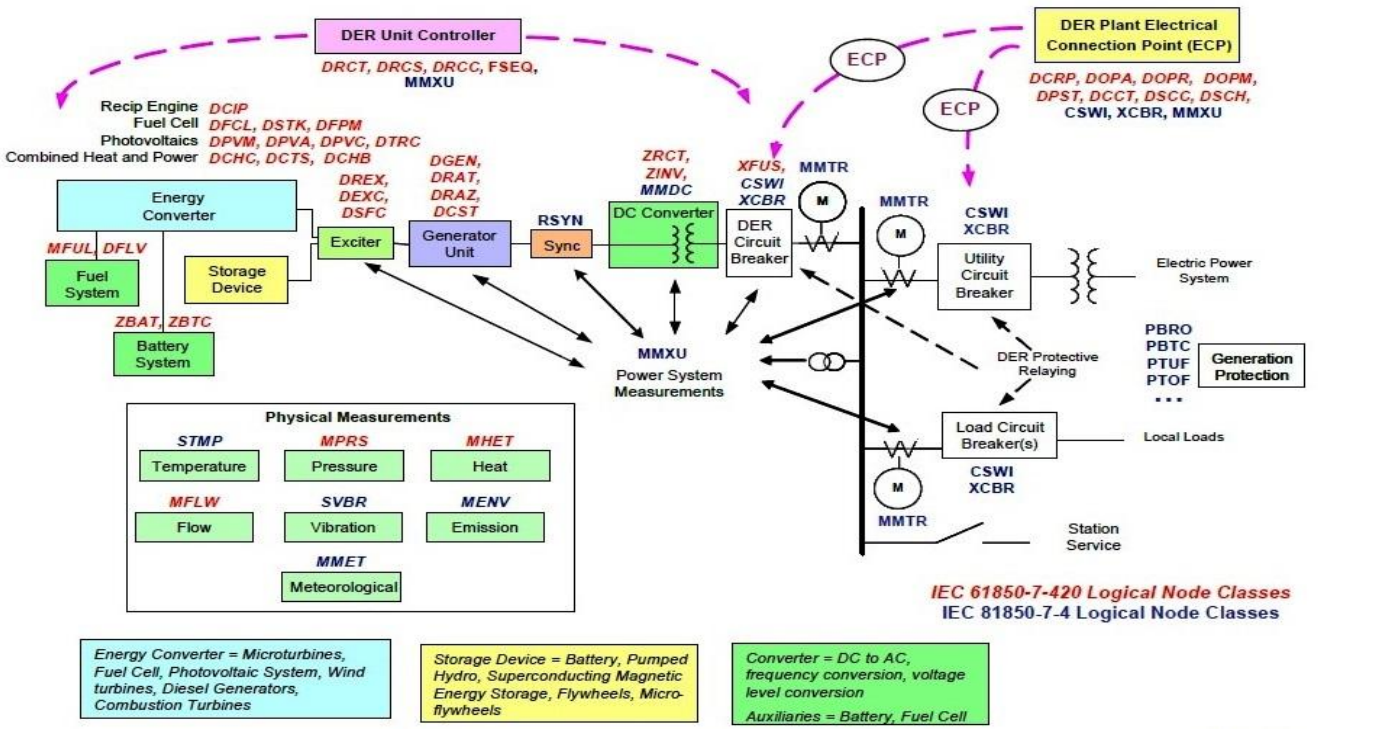

Fig. 2. Organization of DER logical nodes and Logical devices at ECP [1]

separate standard IEC 61400-25-2 [13]. These logical nodes and data classes are in accordance or compatible with the nodes defined part 7-4.

The DER system communication IEDs are modeled with relevant logical nodes defined in the IEC 61850 standards. In this paper modeling of following types of DER systems is presented:

1. Photo Voltaic (PV) system
2. Diesel Generator system
3. Wind plant system

Each DER plant is connected to the distribution substation via electrical connection point (ECP). At this point of connection a circuit breaker and metering devices are present. Fig. 2 shows different logical nodes associated with the DER system components.

Every DER plant is modeled to have 4 IEDs – ECP control IED, DER control IED, Breaker IED and Measuring Unit (MU) IED. ECP control IED receives the settings, commands or modes from the control center and sets the implement the same at DER. DER control IED corresponds to the controller of each DER which sets or controls the different parameters of the DER plant. Breaker IED corresponds to the circuit breaker connecting DER to the substation and Merging Unit IED corresponds to the CT and PT at the ECP.

A. *Photo Voltaic system:*

PV system directly converts solar energy into electricity and it is modular in nature.

The IED corresponding to PV system i.e. DER control IED contains logical nodes DPVC, DTRC, PTOC, PHIZ, MMXU and CSWI. DPVC and DTRC nodes contain the information required for maximizing the power out of array and tracking controller to follow sun movement respectively. PTOC and PHIZ logical nodes detects AC over-current flow and DC ground fault to threshold and sends the detection signal to CSWI node in case of any fault. CSWI node sends the opening or closing signal to XCBR node in breaker IED. STMP and MMET logical nodes contain the information and settings for temperature measurements and meteorological conditions respectively. The ZINV logical node defines settings and status information of inverter, which converts DC to AC.

The ECP control IED contains logical nodes DOPA, DPST, DCCT, DSCH, DRCS and DRCC logical nodes. DOPA logical node associated with settings related to authorize control of DER units such as start or stop of DER unit, change operating mode of DER plant etc. while the DPST logical node provides the real-time connection status and measurements at ECP. The DCCT and DSCH nodes define the settings for DER economic dispatch parameters and energy services schedule. The nodes DRCT, DRCS and DRCC define the settings for control characteristics and capabilities of DER unit, status of DER and control actions of DER units.

B. *Diesel Generator system:*

The ECP control IED of diesel generator system is similar to that in PV system. And the DER control IED corresponds to the exciter and controller of the diesel plant. The DER control IED contains the logical nodes DRAT, DGEN, DCST, DEXC, DSFC and DCIP. DRAT, DGEN and DCST nodes contain the status information and controls of DER generator operations, ratings and costs respectively associated with its operations. DEXC and DSFC nodes comprise the functions related to DER excitation ratings and speed or frequency controller to set the energy output. DCIP node contains the diesel engine characteristics, measured values and controls.

C. *Wind plant system:*

The wind plant is modeled similar to other DER plants and the ECP control IED is similar to that of PV system. The DER controller IED corresponds to wind turbine and back to back converter. The WCNV logical node contains data names focused on a back-to-back converter (AC-DC-AC) for variable speed operation of a induction generator or a synchronous generator. WTUR, WGEN, WYAW, WNAC, WROT contains the information of wind turbine generator, nacelle, yaw and rotor respectively. The data classes for active power control of wind power plant are in WAPC logical node and WMET contains the wind power plant meteorological conditions.

IV. Simulation Study

In order to simulate the communication network required for DER integration to distribution system, a test system with a substation and 3 DER system, as shown in Fig. 3, is considered. The communication network has been simulated using OPNET Modeler software tool. The OPNET Modeler software tool facilitates the design and study of communication networks, devices, protocols and applications [10]. Fig. 4 shows the communication network of the test system considered.

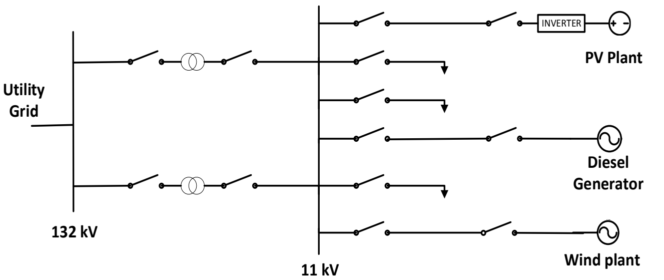

Fig. 3 Test System

A. *Modeling of IEDs in OPNET*

The IEDs of the DER system are modeled in OPNET based on the type of the traffic generated or received by them. In the OPNET modeler software, the object palette under ethernet_advanced type library contains two types of node models. The 'ethernet_station_adv' node corresponds to two layer node, which sends the data directly mapped on the MAC layer. In 'ethernet_workstation_adv' node data is mapped on MAC layer through TCP/IP layers. From Fig. 2 it quite clear that the breaker IED, DER Control IED and ECP control IEDs

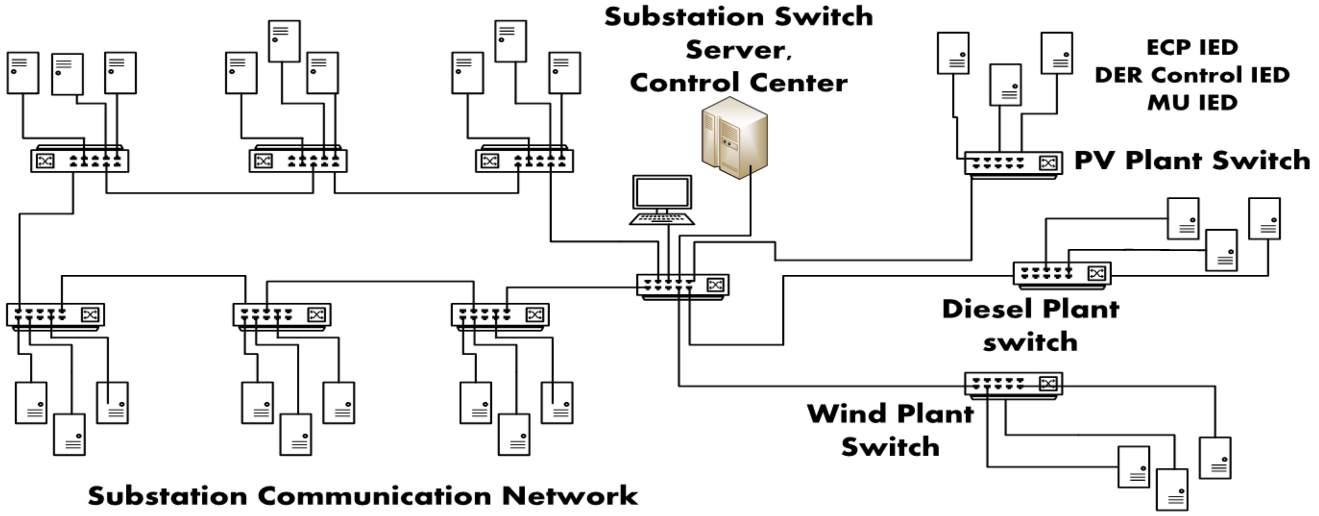

Fig. 4. Communication Network Architecture of the Test system

receive or send the GOOSE, Sample Values and MMS type messages. Hence in order to simulate these IEDs a custom node model is designed, based on the object oriented modeling approach, in OPNET Modeler using node model and process model editor. Fig. 5 (a) and (b) shows the customized node models for wired and wireless respectively developed in OPNET node model editor, which supports GOOSE, Sample Values and MMS type of traffic. The Merging Unit IED only sends Sample values to other IEDs, in which data is directly mapped on to the MAC layer, is modeled as 'ethernet_station_adv' node.

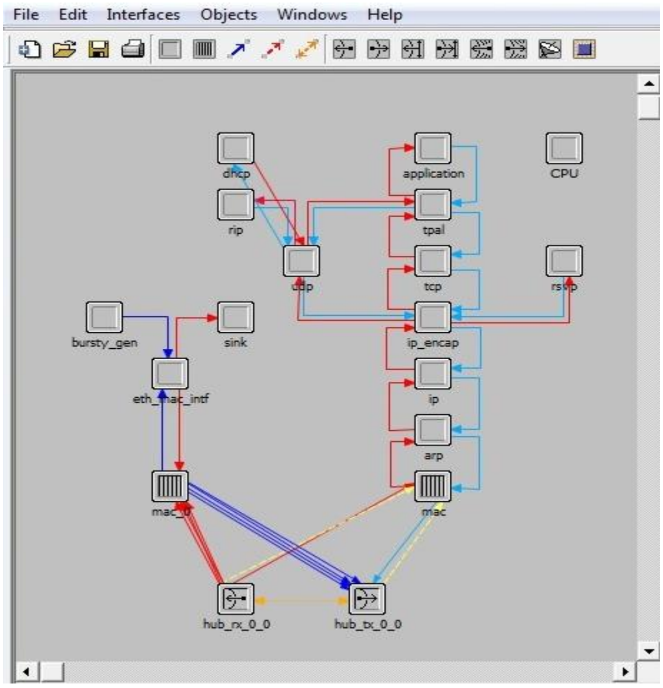

Fig. 5 (a). Customized Node model for wired Breaker and control IEDs

The 'ethernet16_switch_adv' node selected from the object palette library of OPNET, is a switch node model with 16 port interfaces which supports full duplex communication at the rate of 100 Mbps. In wireless communication network simulation 'wlan_bridge' node is selected as switch, as it provides a wireless accesses point and Ethernet port interface. The '100BaseT_adv' node model that supports full duplex fiber optic communication at the data rate of 100 Mbps is selected as communication links in the modeled network. The standard 'ethernet_server_adv' and 'ethernet_wkstn_adv' node models are modeled as server and station PC respectively.

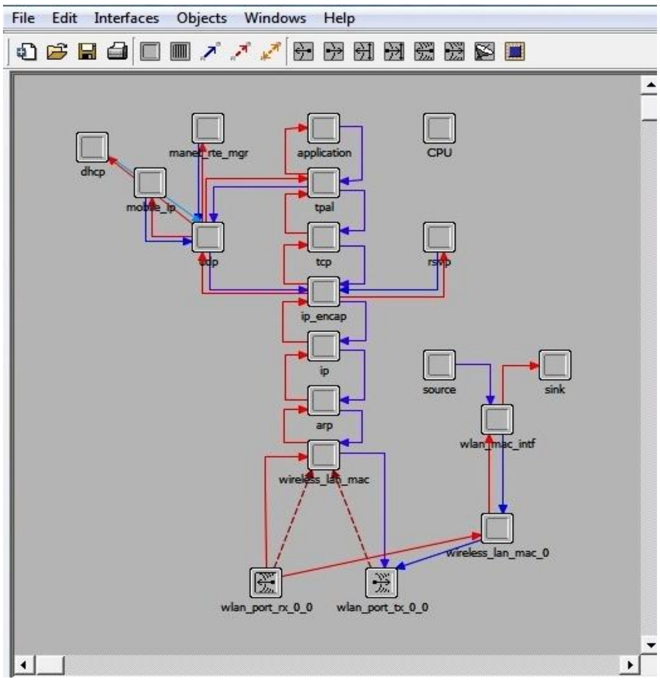

Fig. 5 (b). Customized Node model for wireless Breaker and control IEDs

The communication network of the test system, shown in Fig. 3 is simulated in OPNET modeler. The test system includes a substation with 2 transformers, 6 feeders and 3

DERs connected to feeders 1, 4 and 6. The detail modeling and simulation of the substation can be obtained from [3]. The Substation Communication Network (SCN) contains two transformer bays; six feeder bays and one bus section bay which are modeled as subnet. Each subnet contains its corresponding bay IEDs and a bay switch. The SCN also consists sever and station PC which are connected to station switch, also all bay switches are connected to the station switch. The DERs are also modeled as a subnet, which contains the DER IEDs and a switch. The DER Subnet is connected to station switch of the SCN. Fig. 4 shows the communication network of the test system.

B. Types of messages and traffic

The IEDs of DER bascially exchange three type of messages. First are the trip/open commands which are exchanged between DER control and Breaker IEDs. Sometimes these commands are also issued from substation control PC to DER breaker IED. Second type of messages are the sample values of current and voltage values at the ECP of DERs. The Merging Unit IEDs send these messages to their corrosponding DER control IED. Third type of messages are status update in which the DER control IEDs and breaker IEDs constantly update their status to the substation server. The size of messages is given in Table II.

TABLE II
SIZE OF DIFFERENT MESSAGES EXCHANGED BY DER IEDS

Type of message	**Source IED**	**Destination IED**	**Size (bytes)**
Trip commands	DER Control IED	DER Breaker IED	98
	P&C IEDs (substation)		
	Station PC		
Sample Values	MU IED	DER Control IED	102
Status Update	DER control IED	Server	200
	DER Breaker IED	DER Control IED	150
		Server	

C. OPNET Simulation for different scenarios

The performance of the communication network is studied for wired and wireless configurations. Two scenarios with wired and wireless configurations are studied.

Wired:

1. 100 Mbps wired communication links between DER IEDs and DER switch; and between DER subnet and substation switch.
2. 1000 Mbps wired communication links between DER IEDs and DER switch; and between DER subnet and substation switch.

Wireless:

3. IEEE 802.11g 54Mbps wireless communication between DER IEDs and DER switch; and 100 Mbps wire communication between DER subnet and substation switch.
4. IEEE 802.11a OFDM 24Mbps wireless communication between DER IEDs and DER switch; and 100 Mbps wire communication between DER subnet and substation switch.

In Fig. 8, the simulation of communication network using wired technology in OPNET Modeler software is presented. Here two different technologies of wired links, 100BaseT duplex link with 100 Mbps data rate and 1000BaseX duplex link with 1000 Mbps data rate, are considered. The distance between the substation and DER for the simulation is considered to be 5 km. The different types of messages are configured in the OPNET using "Application Config" node. The different types of messages exchanged in substation and from DER IEDs and substation controller IEDs configured in OPNET is shown in Fig. 6. Different types of applications defined in "Application Config" node are used in "Profile Config" node to configure different profiles for simulating the proposed network. Different profiles set up in the proposed network are shown in Fig. 7.

Network configuration involves the set up of traffic and other network parameters. For example, the raw data sampling rate, packet size, start time, and stop time need to be selected for each MU IED before the simulation. Moreover, the source address, destination address, multicast group address, and transmission method is specified for each IED to ensure that the messages are transmitted to the correct receivers. The traffic in ECP and DER control IEDs is set by specifying the application name of specific type of traffic it generates and destination address for the traffic to be sent, in each node. When the network is configured, the statistics to be collected are decided. In this paper, for the performance evaluation of the proposed communication architecture, the end-to-end (ETE) delay for time-critical messages and throughput are selected as a key statistics. The results are tabulated in Table III.

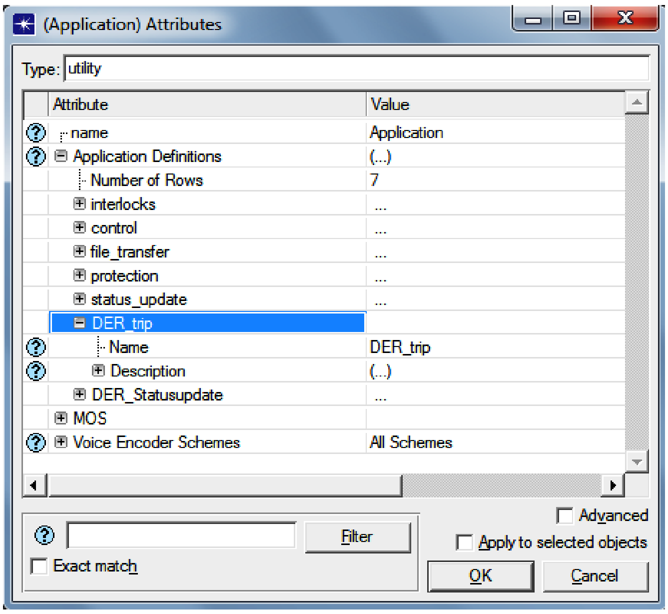

Fig. 6. Application Configuration

It can be observed from the Table III that as data rate of links increases from 100 Mbps to 1000 Mbps the message delay decreases significantly and throughput is increased slightly. It is also noted that the links between station switch and server has highest throughput. Further the time delay for GOOSE message is very less, which is within the range specified in the standard. The delays for other types of messages are also low and within limits, as specified in the standards shown in Table I.

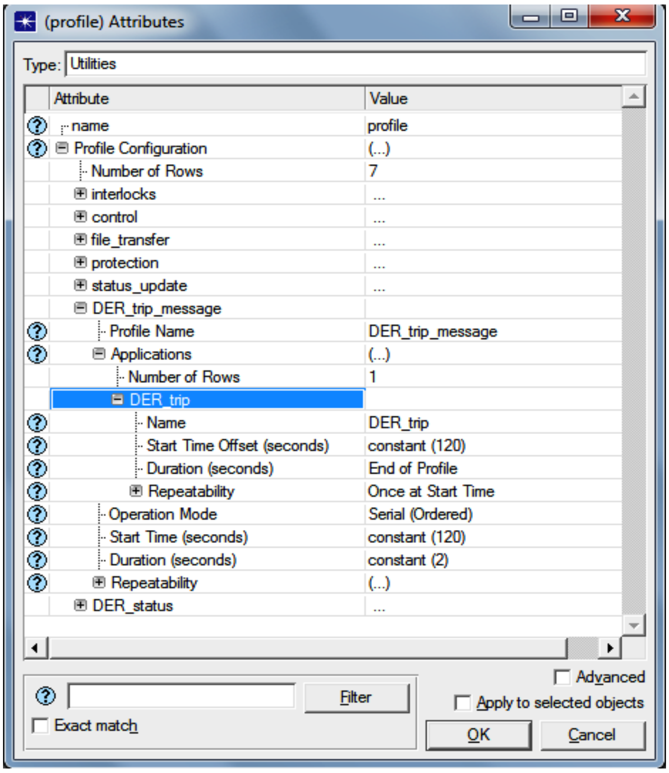

Fig. 7. Profile Configuration

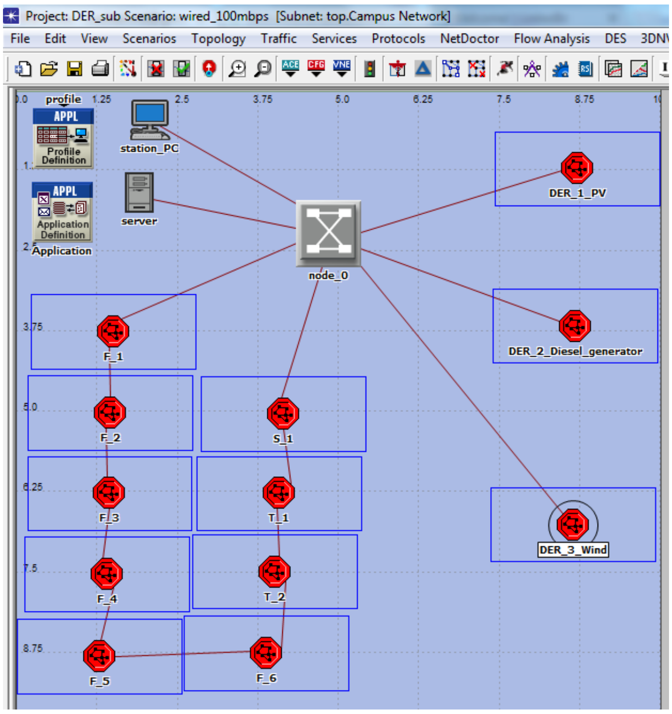

Fig. 8. OPNET Simulation of communication network architecture with wired technology.

As shown in Fig. 6, wireless LAN technology IEEE 802.11 with extended rate PHY (IEEE 802.11g) and OFDM (IEEE 802.11a) with data rates 54Mbps and 24Mbps respectively have been considered in simulation study.

The traffic in the simulation using wireless networks is similar to wired networks, where "Application Config", "Profile Config" nodes are used. Table IV shows, the maximum GOOSE message time delay for WLAN network is 0.84 msec. The time delay for sample values and MMS type messages in also within the range specified in standards shown in Table I.

TABLE III
PERFORMANCE EVALUATION OF 100 AND 1000 MBPS WIRED LAN

Type of Message	100 Mbps		1000 Mbps	
	Delay (ms)	**Throughput (kbps)**	**Delay (ms)**	**Throughput (kbps)**
GOOSE	0.11	80	0.08	80
Sampled Values	0.14	3500	0.106	3500
Other MMS type traffic	0.22	1000	0.203	1000

TABLE IV
PERFORMANCE EVALUATION OF 100 AND 1000 MBPS WIRED LAN

Type of Message	54Mbps		24 Mbps	
	Delay (ms)	**Throughput (kbps)**	**Delay (ms)**	**Throughput (kbps)**
GOOSE	0.84	80	0.88	80
Sampled Values	1.02	3500	1.03	3500
Other MMS type traffic	0.92	1000	0.92	1000

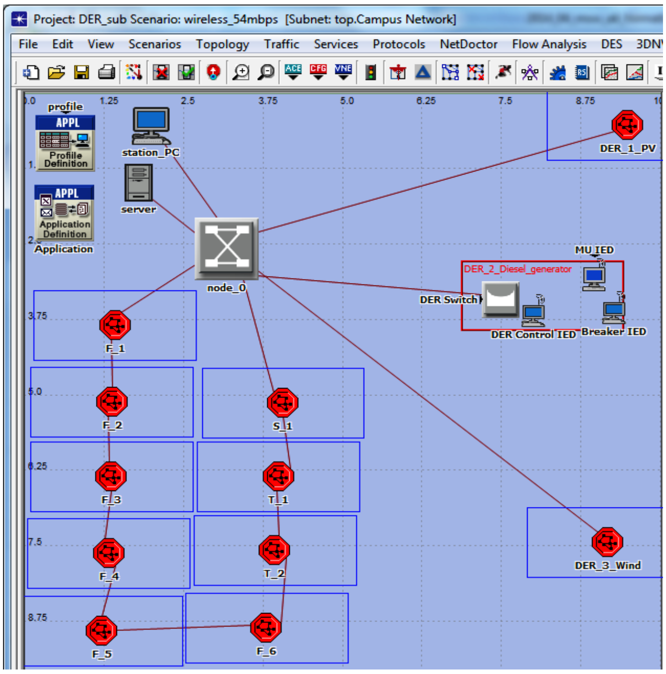

Fig. 9. OPNET Simulation of communication network architecture with wireless technologies.

V. Conclusion and Future work

This paper presented the communication configuration for integrating DER in distribution network. OPNET modeler software is used for modeling the DER IEDs and simulating the communication network with wired and wireless technologies. The performance evaluation of the proposed communication network for time delay and throughput in network is presented. In this study three DER systems were considered and were integrated with the distribution network at the distribution substation.

In future this work can be extended by evaluating different emerging communication technologies such as Wimax, Zigbee etc. Different communication network architectures with several DERs and multiple substations, for microgrids shall be studied.

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