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Publication date:
2010

Document Version
Accepted author manuscript, peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Wei, M., & Chen, Z. (2010). Communication Systems and Study Method for Active Distribution Power systems. Paper presented at 9th Nordic Electricity Distribution and Asset Management Conference, Aalborg, Denmark.

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COMMUNICATION SYSTEMS AND STUDY METHOD FOR ACTIVE DISTRIBUTION POWER SYSTEMS

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ABSTRACT

Due to the involvement and evolvement of communication technologies in contemporary power systems, the applications of modern communication technologies in distribution power system are becoming increasingly important. In this paper, the International Organization for Standardization (ISO) reference seven-layer model of communication systems, and the main communication technologies and protocols on each corresponding layer are introduced. Some newly developed communication techniques, like Ethernet, are discussed with reference to the possible applications in distributed power system. The suitability of the communication technology to the distribution power system with active renewable energy based generation units is discussed. Subsequently the typical possible communication systems are studied by simulation. In this paper, a novel method of integrating communication system impact into power system simulation is presented to address the problem of lack of off-shelf research tools on the power system communication. The communication system is configured and studied by the OPNET, and the performance of an active distribution power system integrated with the communication system is simulated by EMTDC/ PSCAD.

1. INTRODUCTION

The environmental issues, such as Greenhouse Effects, have received great attention recently. The modern power system becomes more and more distributed, deregulated, and highly interconnected because of the increasingly involved renewable energy technologies. The distribution systems become more active and dynamic also because of the integration of small renewable energy based generation units, and the active load management. Nevertheless the communication technologies adopted in conventional power system may not suitable for the contemporary power system. Such like Power Line Carrier (PLC), as one of the most popular employed communication technique, does not meet the customers' demands any more, due to its rugged communication environment in the condition of plenty of Intelligent Electronic Devices (IED) in modern distributed power system need to exchange large amount of information for system monitoring, protection and control. Therefore the alternative communication techniques need to be investigated.

In addition, the power industry shows great interests in and is developing toward Smart Grid, which means an electricity network that can intelligently integrate the actions of all users connected to it. All these specific attributes of the power system present challenges to communication technologies.

Applications of communication technologies cover a wide range, from Supervisory Control And Data Acquisition (SCADA) [1, 2] system, remote measurement [3, 4], to monitoring, control, and protection, which are critical to the proper operation of power system and to maintain system reliability and stability. Therefore the proper cooperation and combination of the communication system and the power system depend on many aspects, such as related protocols, access technologies, and transmission media, etc. IP-based communication network implemented in power system has been proposed recently. Computer networks and data communication play increasingly important roles in modern power systems [5]. In this paper an Ethernet- based distributed power system communication network, as an example, is investigated and simulated, to introduce a novel method of study active distribution power system. The contents of the paper are presented in different sections as follows.

Section II introduces the ISO reference seven-layer construction of the communication system for distributed power system, and communication technology development. Then the development of active distribution system with renewable energy technologies is discussed in Section III, where the communication system applied in distribution power system is also presented. In Section IV a novel method of studying the distribution power system communication is illustrated by developing a practical LAN example. Subsequently in Section V the conclusion is given and the future work is suggested.

2. COMMUNICATION SYSTEM FOR DISTRIBUTED POWER SYSTEM

1) ISO reference 7-layer model

The ISO reference model [6] provides a framework for the coordination of standards development and to allow existing and evolving standards activities to be set within a common framework. The logical structure of the ISO reference model is made up of seven protocol layers, as shown in Fig.1. The AP function in the figure represents Application Process. The function of each layer is specified formally as a protocol that defines the set of rules and conventions used by the layer to communicate with a similar peer layer in another system.

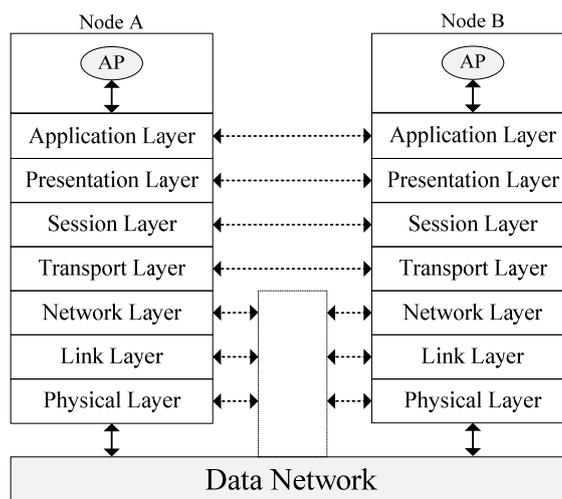


Fig. 1. ISO reference 7 layers model.

The upper layers are application oriented and are concerned with the protocols associated that allow two end user application processes to interact with each other, normally through a range of services offered by the local operating system.

The three lowest layers are network dependant and are concerned with the protocols associated with the data communication network being used to link the two communicating nodes. Particularly, the link layer builds on the physical connection provided by the particular network to provide the network layer with a reliable information transfer facility.

2) Development of communication technologies according to the ISO reference model

Introducing the development of communication technologies is prerequisite to be based on the ISO reference 7-layer model, otherwise it is confused and senseless with the comparison among difference layers. Consequently some of the significant communication technologies referenced to the corresponding layers are listed in Table I [8]. Especially, in Table II the different media on the physical layer are listed, whose advantages and disadvantages are referred to [7]. To practically fulfill the communication technologies, the corresponding protocols [6] [8] applied are also presented in Table III.

Table 1 Communication technologies on seven layer of ISO reference model

ISO reference model	Technologies
Application Layer	Semantic conversion
Presentation Layer	Encryption, Compression
Session Layer	Authentication, Permissions, Session restoration
Transport Layer	Statistical multiplexing, Virtual circuit, Flow control, Error recovery
Network Layer	Connection model, Host addressing, Message forwarding
Data Link Layer	Flow control, Error notification, Frame synchronization, Physical addressing, Collision detection, Physical addressing, LAN switching, Data packet queuing, Quality of service, Virtual LAN
Physical Layer	Bit-by-bit or symbol-by-symbol delivery, Modulation Line coding, Multiplexing, Bit synchronization, Circuit switching, Equalization filtering, Forward error correction, Channel coding

Table 2 Communication media on physical layer

Media	Service
Twisted Pair Metallic cable	Leased Service
Coaxial Metallic Cable	Satellite
Fiber Optic Cable	UHF radio
Distribution Line Carrier	VHF Radio
Power Line Carrier	Microwave Radio

Table 3 Communication protocols on seven layer of ISO reference model

ISO reference model	Protocols
Application Layer	NNTP, SIP, SSI, DNS, FTP, GOPHER, HTTP, NFS, NTP, SMPP, SMTP, SNMP, TELNET, (MORE)
Presentation Layer	MIME, XDR
Session Layer	NAMED PIPES, NETBIOS, SAP
Transport Layer	TCP, UDP, SCTP, SSL, TLS
Network Layer	IP, ICMP, IPSEC, IGMP, IPX, APPLE TALK
Link Layer	ARP, CSLIP, SLIP, ETHERNET, FRAME RELAY, ITU-T G.HN DLL, L2TP, PPP, PPTP
Physical Layer	RS-232, RS-485, V.35, V.34, I.430, I.431, T1, E1, POTS, SONET/SDH, OTN, DSL, 802.11A/B/G/N PHY, ITU-T G.HN PHY, ETHERNET, USB, BLUETOOTH

Because TCP/IP is in widespread use with an existing internet, many of the TCP/IP protocols have been used as the basis for ISO standards. Moreover, since all of the protocol specifications associated with TCP/IP are in the public domain, and hence no license fees are payable, they have been used extensively by commercial and public authorities for creating open system networking environments [6]. The TCP/IP related protocols for each layer are specified in Fig.2.

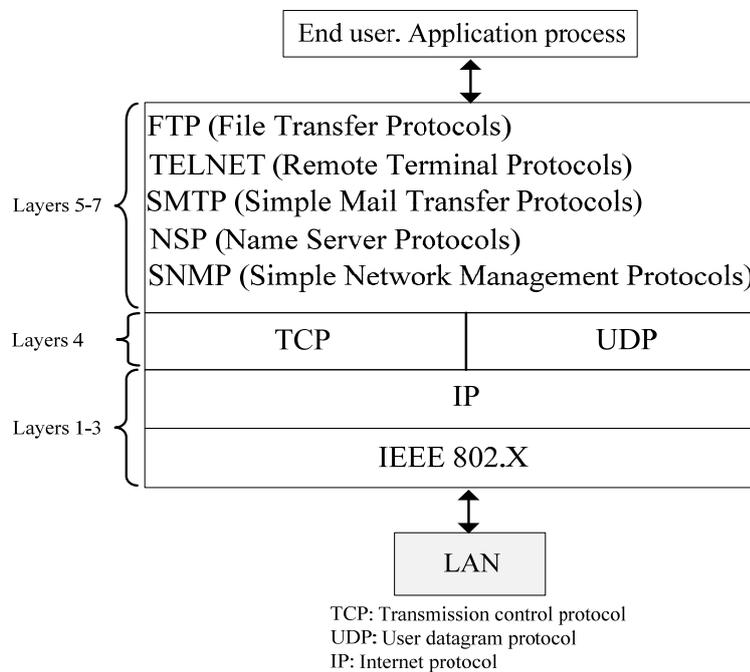


Fig. 2. TCP/IP protocol suite

In terms of the power industry application, the IEC family standards, such as IEC61850 series, IEC61400 series, etc. belong to the Application Layer protocols, which are described in the following part.

3) Logical node model

Regarding the communication in power system, IEC 61850 standards [9] defines not only the concepts of logical devices, logical nodes and data contained in the logical device and nodes, which are all crucial for the description and information exchange for power systems, but also the communications among different logical nodes and logical devices. The logical nodes are the smallest entities decomposed from the application functions. Several logical nodes build a logical device. A logical device is always implemented in one IED (Intelligent Electronic Device). [9]. Take a protection scenario as an example, Figure 3 depicts the relationships among the application function: among protection, logical device, IED, and LN XCBR (the Logical Node XCBR represents the common information of a real circuit breaker). In this paper the communication network: Ethernet LAN is configured based on the concept of LN model.

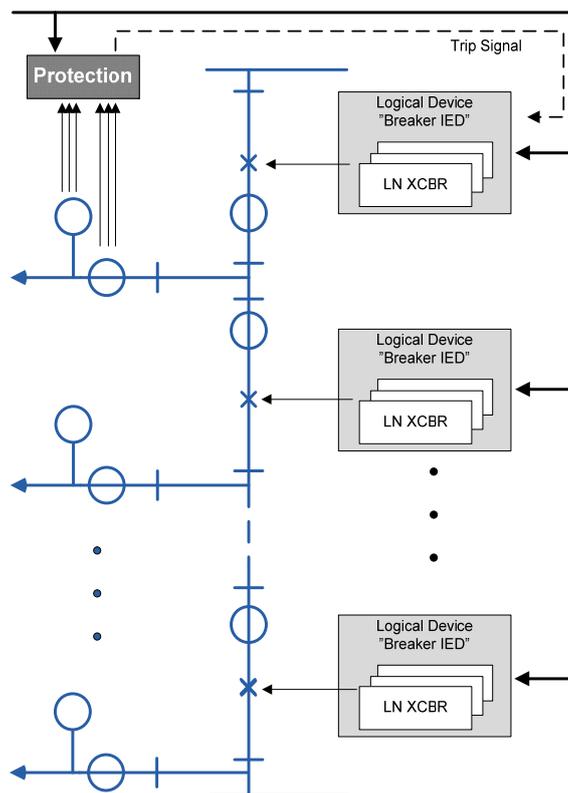


Fig.3. The relationship between protection and Logical Node

3. DEVELOPMENT OF ACTIVE DISTRIBUTION POWER SYSTEM WITH RENEWABLE ENERGY TECHNOLOGIES

Traditional electrical power system architectures reflect historical strategic policy drivers for building large-scale, centralized, thermal- (hydrocarbon- and nuclear-) based power stations providing bulk energy supplies to load centers through integrated electricity transmission (HV-400kV, 275kV and 132kV) and distribution (MV, LV-33kV, 11kV, 3.3kV and 440V) 3-phase systems.

Nevertheless, as a result of industry restructuring and international policy driving towards low-carbon, renewable energy production, the traditional centralized power system with hierarchical control structures has been developed to involve active distribution power system with renewable energy. [10]

1) Renewable energy

Renewable energy is energy generated from natural resources such as sunlight, wind, water, tides, and geothermal heat, which are renewable (naturally replenished). In 2006, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, which is mainly used for heating, and 3% from hydroelectricity. New renewables (wind, small hydro, modern biomass, solar, geothermal, and biofuels) accounted for another 2.4% and are growing very rapidly. The share of renewables in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3.4% from new renewable. [11]

As one of the most significant renewable energy, wind power is growing at the rate of 30% annually, with a worldwide installed capacity of 157,900 megawatts (MW) in 2009, and is widely used and actively developed in Europe, Asia, and the United States. [11]

2) New demands on the communication technologies for distribution power system

After substation automation systems were introduced several years ago, the traditional vendor-specific communication protocol connections for the basic architecture were replaced with a communication bus. Due to the progress in technology, it is possible to provide a standardized digital data communication for automation systems. In the mid-1990s, standardization activities were started both in the United States and in Europe. Finally an agreement was reached to use the Ethernet as a communication base for the substation bus. The high-speed properties of current Ethernet technology, together with its dominant position in the Local Area Network (LAN) field, make Ethernet an interesting communication technology for distribution power system automation usage. Indeed some research has investigated whether Ethernet has sufficient performance characteristics to meet the real-time demands of substation automation. However there has been very little work on the active distribution power system automation using Ethernet technique [12]. Therefore this paper provides a novel study method to examine the performance of switched Ethernet for distribution power system communication and automation.

3) LANs access technologies: Ethernet

In this paper the second layer (Data Link Layer) is focused to investigate the effects of LANs protocols on the distribution power system. Therefore the Data Link Layer-based LAN access techniques are discussed.

As one of the LAN access techniques, Ethernet has evolved significantly for decades. It has been already applied as high speed backbone applications in data communication for industries,

which can be one of the reasons power industry reached the agreement to employ Ethernet as the power communication standard. [12]

Ethernet defines a number of wiring and signaling standards for the Physical Layer of the ISO reference networking model, through the means of network access at the Media Access Control (MAC) /Data Link Layer, and a common addressing format. Ethernet is standardized as IEEE 802.3. The combination of the twisted pair versions of Ethernet for connecting end systems to the network, along with the fiber optic versions for site backbones, is the most widespread wired LAN technology. It supports all popular network and higher-level protocols. Traditional Ethernet supports data transfers at the rate of 10 Megabits per second (Mbps). As the performance needs of LANs have increased, the industry created additional Ethernet specifications for Fast Ethernet and Gigabit Ethernet. Fast Ethernet extends traditional Ethernet performance up to 100 Mbps and Gigabit Ethernet up to 1000 Mbps speeds. In this paper the switched Ethernet is selected due to the higher data transmission speed compared with the shared Ethernet. [6]

4) Structure of the communication network for distribution power system

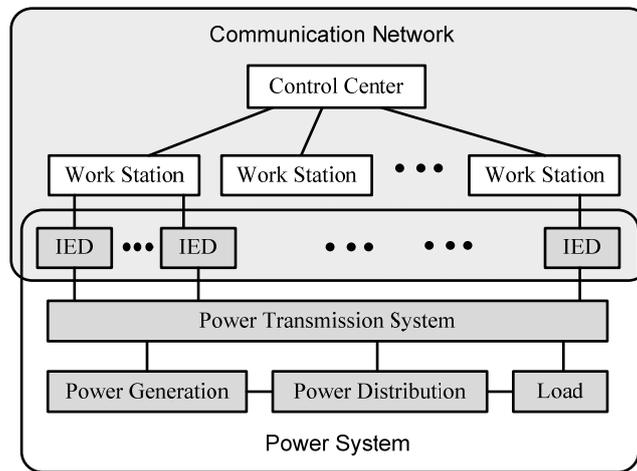


Fig. 4. Structure of combined communication network and power transmission system

The way how the communication network combined with the power transmission system is displayed in Fig. 4. The IED represents Intelligent Electronics Device, who are the main components collect data from the power system, and also deliver commands to the power system.

4. A NOVEL METHOD FOR DISTRIBUTION POWER SYSTEM COMMUNICATION STUDY

In order to investigate the performance of the distribution power system involved with communication techniques, a novel method of doing the study is introduced in this part.

1) Communication network development

A communication network with an Ethernet LAN is configured on the secondary side of the primary power system to simulate the communication scenarios. The communication nodes

represent the IEDs in distributed power system. This communication network is implemented with the OPNET Modeler [14].

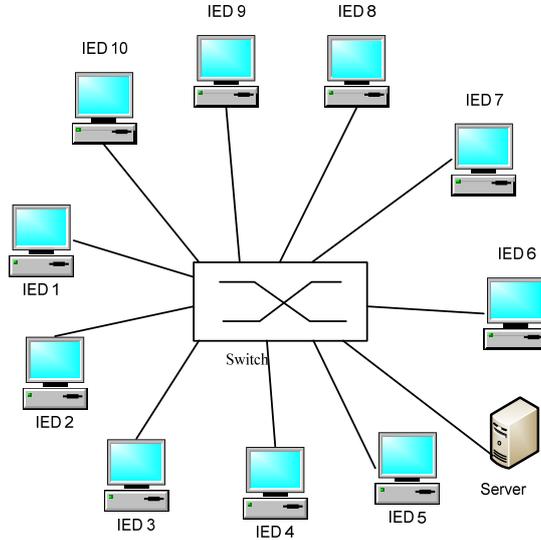


Fig.5. Star topology Ethernet LAN for distribution power system

The communication nodes of the Ethernet network studied in this paper may represent any of the following categories of IEDs. [8] [13]

- a) Merging Unit IEDs, which are mainly responsible for the processing and transmission of the digital voltage and current signals from the field CT and VT to the field Ethernet bus.
- b) Breaker IED, which not only controls the breaker's open/close, but also monitors the states and conditions of the circuit breaker, receives the trip/close command from the P&C IEDs and sends state change events to corresponding protection IEDs through the process bus.
- c) P&C IED, a universal device, integrates the protection & control functionalities for the bay unit in the substation.

In this paper an Ethernet LAN with 10 Merging Unit IEDs nodes in a star topology are taken as an example, as displayed in Figure 5. To specify the file size transferred for each communication node, some calculations need to be fulfilled. The sampling frequency of the voltage and current data transferring of each IED is assumed as 6400Hz for a 50 Hz power system, which means at least 128 data points are acquired in 20ms, and each sampling data is represented by 2 bytes. Then the file size becomes $128 \times 50 \times 2 = 12800$ bytes, considering the 3-phase voltage and current measurement, the data flow becomes $128 \times 6 = 76800$ bytes. [15]

2) The method for distribution power system communication

The Ethernet LAN ETE (End to end) delay is depicted in Fig.6. In this example, the average ETE delay is approximately 5.465×10^{-4} s.

The specific ETE delay data are partly listed in Table IV. The completed delay data was saved as a .txt file, i.e. IED_LAN_delay.txt in this example, which is also displayed in Fig.7. The novel approach to connect this ETE delay attribute with the response of distribution power system devices is to input the data to the power system simulation platform, which is selected as EMTDC/PSCAD.

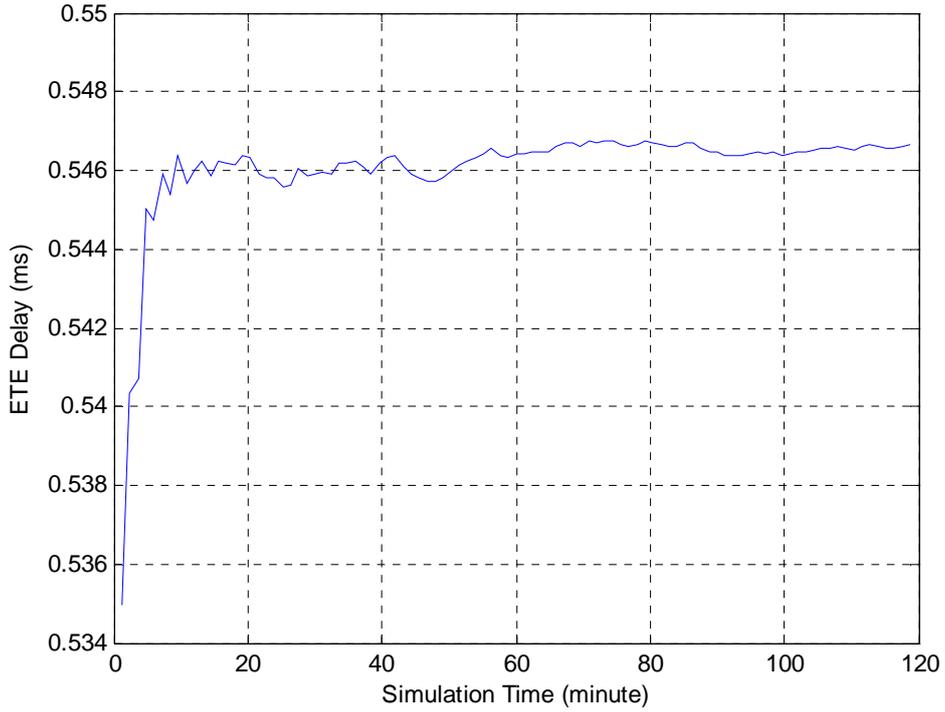


Fig.6. IED Ethernet LAN ETE Delay

Table 4 IED Ethernet LAN ETE delay

Simulation Time (min)	Delay (ms)	Simulation Time (min)	Delay (ms)
1.2	0.534954	12.0	0.546011
2.4	0.54033	13.2	0.546228
3.6	0.540711	14.4	0.545871
4.8	0.545026	15.6	0.546223
6.0	0.544727	16.8	0.546206
7.2	0.545918	18.0	0.546126
8.4	0.545372	19.2	0.54636
9.6	0.546388	20.4	0.546311
10.8	0.545676	21.6	0.545925

The completed procedure to deploy the Ethernet network delay attribute to a distribution power system is illustrated in Fig. 11. As shown, by using the EMTDC/PSCAD functions of choosing “file reference” as the component to add in the main PSCAD file. In the next stage, by attaching the data file with the “PSCAD time related data components”, to fulfill the connection between the power system and the communication system. Finally the output of the “PSCAD time related data components”, i.e. “T_d”, as shown in Fig.11, is defined as the command signals transferred between the relevant IEDs in power system, which is used to control the components in a distribution power system.

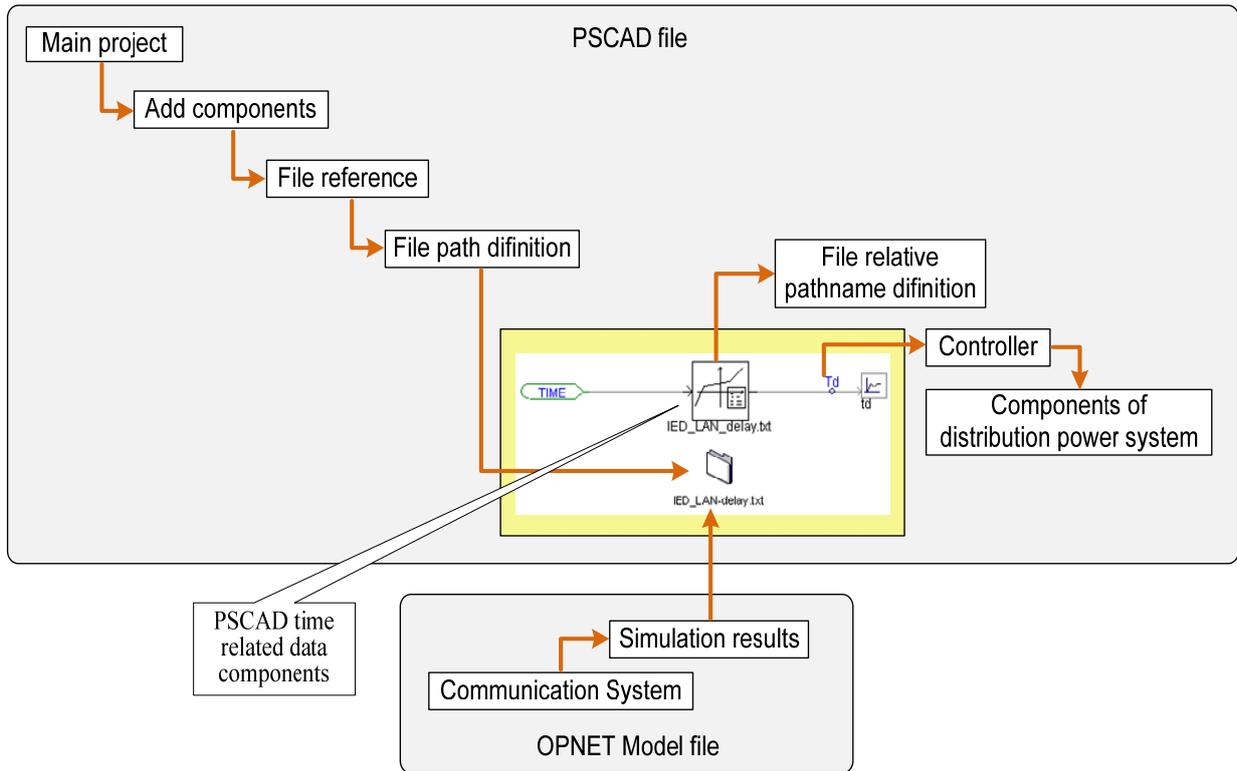


Fig. 7. The procedure of deployment of communication attribute in distribution power system

5. CONCLUSION AND FUTURE WORK

This paper introduces an Ethernet-based, IED formed LAN. The LAN ETE delay attribute are simulated. Furthermore a novel study method of deploying the communication characteristics, such like ETE delay attribute, into the distribution power system study is presented. By this approach, some component responses of the distribution power system can be studied with considering the corresponding communication network, which is very useful in study the active distribution automation. Therefore the performance of the distribution power system by the communication system can be investigated

Some further work will be done to examine the performance of the distribution power systems in different scenarios by this method. Moreover the future studies will also focus on the applications of various communication technologies on power system control, protection and monitoring.

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