Smart Meter Modelling and Fault Location Communication in Smart Grid

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ABSTRACT:
This paper includes a novice technique for locating single line to ground fault in electrical transmission network. Validation of the proposed algorithm is demonstrated using MATLAB Simulink. Simpower system tool box is used for the modeling of smart meter, transmission lines and single line to ground fault (1L-G). A novel method is proposed to countercheck whether the fault has occurred really or not. Data related to 1l-G fault has been collected at 220kV Lonikand substation and analyzed exclusively during the visit at Kalkitech (top manufacturing company of Intelligent Electronic Devices (IEDs) in Bangalore, Karnataka, India). Effect of harmonics on fault current measurement using smart meter is elaborated. Advancements in communication technology are illustrated from asset management perspective.

KEYWORDS*:* Smart Meter, 1L-G Fault, Client-Server Communication, Substation Automation System (SAS), International Electrotechnical Commission (IEC) 61850 Protocol, Intelligent Electronic Devices (IEDs), Remote Terminal Unit (RTU).

1. INTRODUCTION

Smart Grid is an integration of information and communication technology into the electrical technology. Conventionally, RTUs attain three phase voltages, currents, frequency, circuit breaker status and etc. communally known as Supervisory Control and Data Acquisition System (SCADA) measurements; and are sent to Energy Management Systems (EMS) in every two to ten seconds. With recent technological advancements, IEDs are being installed alongside RTUs. Smart (Numeric) meter is the key element in IED family. It plays crucial role in EHV transmission system. Smart meters can be functioned as high tension or low tension (HT/LT) meters, Time of Day Tariff (TOD) meters, Availability Based Tariff (ABT) meters. These meters are superior to the conventional meters due to high accuracy of the order of 0.2 class, polling approach, and storage capacity. That is why the electromagnetic, static meters are now getting replaced by smart meters. In electrical power system faults are classified into two categories: i) Transient (temporary): Automatic switchgear will take care of such faults within few seconds and supply will be restored in case of self-clearing faults. Some transient faults may lead to a permanent damage to the insulation in case of overhead line flashover ii) Permanent faults: These faults are caused due to the permanent damage of the insulation system, which will cause interrupted power supply which will last from few minutes to few hours [1]. Fault location plays a vital role in ensuring the reliability of the electrical power supply. Extensive research work related to fault location algorithms has been carried out over the years, still accuracy and speed is the major issue. Recently, fast fault detection and location algorithm for tightly coupled distribution systems is demonstrated. This new technique involves the local measurement of current, voltage and di/dt without any communication between the protective devices at different locations [2]. Fernanda C. L. Trindade has proposed a new fault location approach in which, initially, rough estimation of fault location is carried out by using impedance based method. Due to typical distribution topologies, multiple fault locations can be indicated using this technique. To overcome this issue, Low Voltage Zones (LVs) are identified using voltage measurements from smart meters [3]. In this paper, an effort is taken to develop a code in MATLAB Simulink based on a novel algorithm demonstrated for calculating 1L-G fault and fascinating simulation results are observed.

Numeric meters can communicate with IEDs, RTUs, Sequence Event Recorders (SERs), servers and the workstations. IEC 61850, a standard for network communication in electrical network provides interoperability and long term stability. Earlier the grid network topology was radial. To ensure connectivity through multiple routes, network topology has been adopted. In Indian scenario, the communication channel throughout the network is not yet fully integrated. Integrated communication will facilitate a real time control and will enhance the reliability of the electrical network [4]. AMI is provided to tamper pilferage data [5]. AMI communicates data through the communication channel to the Control Centre (CC). Meter Data Management System (MDMS) in CC does the data analysis [6].

Grid stability, accurate fault location in electrical network, ensuring healthiness of power system equipment, theft prevention etc. are the main functions of the modern grid. During the visit at 400/220kV Lonikand substation, the recent advancements in smart meter and Advanced Metering Infrastructure (AMI) have been observed.

Kalkitech is a leading manufacturing company of IEDs in Bangalore. Detail study of National Transmission Asset Management Centre (NTAMC) was carried out during the visit. Contribution of Kalkitech towards this project was discussed.

Communication Technology [7]:

Wireless/radio communication: Radio communication is owned by utility with licensed band and includes point to point and point to multipoint network.

Multiple addresses radio: It is reliable and flexible.

Spread Spectrum Radio and wireless LANs: It is used for the communication within substations, as well as between two substations at distant locations.

Zigbee: It is wireless technology. It is composed of Zigbee coordinator (ZC), Zigbee Router (ZR) and Zigbee end device. Mobile Communication System: It is wireless or radio communication system. It consists of Global Standard for Mobile Communication System (GSM) And Code Division Multiple Access System (CDMA).

GPRS (General Packet Radio Service) is packet based communication service for mobile devices. It facilitates data communication across mobile telephone network.

Wired Communication includes:

Power Line Communication System: The PLC is categorized in three networks: i) Indoor PLC ii) LV PLC and iii) medium PLC.

Fiber Optics: Optical Fiber cable (OFC) offers high band width and it prevents electromagnetic interference. Data in gigabytes/sec is transferred on the fiber. Fiber cable is composed of single or multi-mode fibers. Normally utility company makes use of Optical Power Ground Wire (OPGW). OPGW must perform the functions of the ground wire i.e. protection against lightning stroke; provide the path for the fault current. In addition to these features, it provides secure communication with the optical fiber at the center of the cable. Therefore, can be connected directly to the phase conductor. The drawback of fiber optic infrastructure is, it is costly.

Communication Layer: it is composed of medium (wired/wireless), Data Concentrator Unit (DCU) and interoperability communication layer. It facilitates two-way communication between smart grid control center and intelligent equipment like smart meters, DCU and Home Area Network (HAN).

Major challenge in Smart Meter: Smart meters' measures and records real time data of energy consumption in equal intervals. It facilitates bidirectional communication. Communication protocol and security: It is important to select appropriate communication protocol. Interoperability is one of the challenges. The control commands used in smart meter should be interoperable with the existing infrastructure.

In current power system, Information and Communication System (ICT) is being used, which include IEDs like sensors, numeric meters etc. These are nonlinear devices. They produce harmonics in the electrical network and cause power loss, excess heating in power transformers and maloperation of circuit switches. Voltage transformer is the key component in smart power system. Since the transformer core is composed of ferromagnetic material, it is a non-liner device. When transformer is stimulated by a sinusoidal voltage, secondary voltage includes harmonic components. Paper [8] explains how instrument transformers can introduce significant error when they are involved in measurements process associated with power quality measurements. Fathi M. Abouelenin and Karim Hassan Youssef have presented a case study, based on two models; first consist of linear load without harmonics and the other model containing nonlinear load with harmonics. This study explains a comparison of effect of harmonics on short and medium models of cables [9].

This paper covers the modeling of smart meter in section II. Section III describes the proposed technique to countercheck whether the fault has taken place actually or not. Data collected at 400/220kV Lonikand substation is displayed in section IV, Visit report of Kalkitech is included in section V to highlight National Transmission Asset Management Centre (NTAMC) project. An attempt is made to highlight the shortfall in current NTAMC project and propose a solution for it. Part V of the paper involves effect of harmonics on smart meter reading.

2. MODELLING OF TRANSMISSION LINES AND SMART METER

1L-G Fault is created at phase A. in Fig.1. Modulus of u denoted as IuI in Fig.1 gives the absolute value of current.

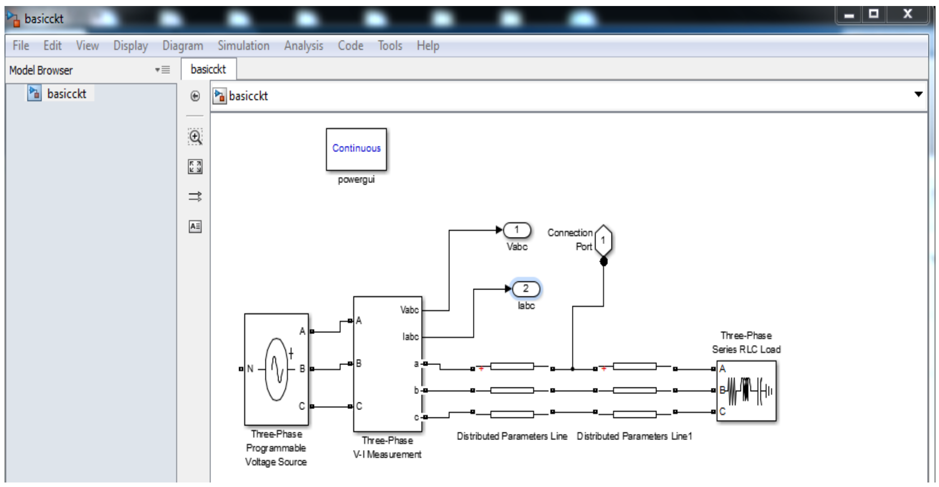

Fig. 1. Modeling of Transmission Lines.

2.1. Proposed Technique for Fault Location Modelled in MATLAB

The fault current is compared with maximum allowable current which is set. If the absolute value of fault current is greater than or equal to the set value of current, bitwise AND operator will give pulsating output. During logic 1, 220V D.C. supply gets connected across faulty line and ground. Circulating D.C. current (I_{dc}) can be measured. Knowing V_{dc} (220 V D.C.) and I_{dc}, R_{dc} can be calculated. This is the resistance of the faulty transmission line from the bus under consideration up to the fault point, which gets connected to the ground after the occurrence of 1L-G Fault. Getting the resistance per kilometers from the reference charts [10] the fault location is calculated.

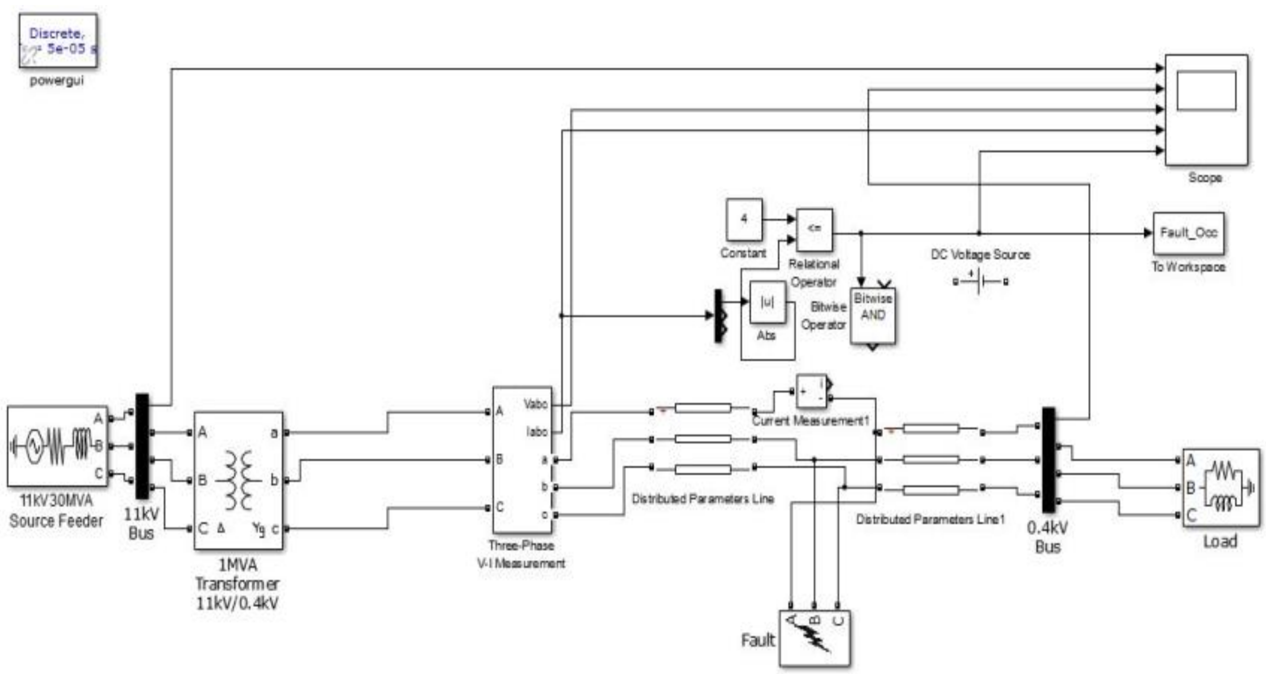

Fig. 2. Proposed Technique for fault location modelled in MATLAB.

Table 1. Power circuit (Transmission Line, Load) data.

Load Data	
Nominal frequency	50Hz
Active power	10e3 W
Inductive reactive power	100 positive var
Capacitive reactive power	0 negative var
Line Data	
Nominal frequency	50 Hz
No. of phases	3
Resistance per unit length	[0.01273 0.3864] Ω/km
Inductance per unit length	[0.9337e-3 4.1264e-3]H/km
Capacitance per unit length	[12.74e-9 7.751e-9]F/km

2.2. DC Circuit Modelled in MATLAB

Taking in to the consideration that, the fault has occurred at t seconds. The 220 V D.C. supply gets connected across line and ground after t + Δ t time. Fault resistance is calculated as $V_{measured}$ /$I_{measured}$ and the fault resistance is displayed. It is saved as R_{fault} in the workspace where a MATLAB code is written for the fault location calculation.

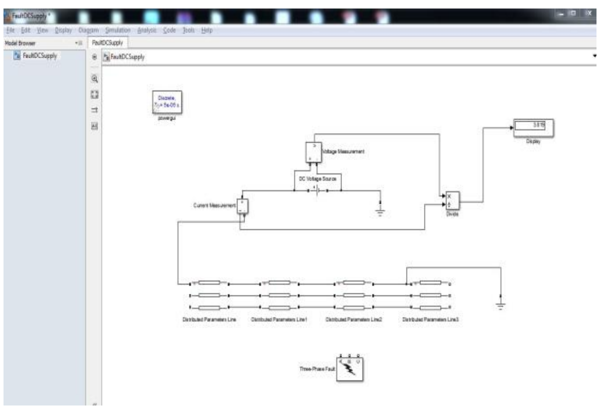

Fig. 3. D.C Circuit modelled in MATLAB.

2.3. Voltage and Current Outputs for 1L-G Fault:

Output 1: 11kV Bus Voltage
Output 2: 0.4kV Bus Voltage
Output 3: Phase Voltages after fault occurrence
Output 4: Phase currents after fault occurrence

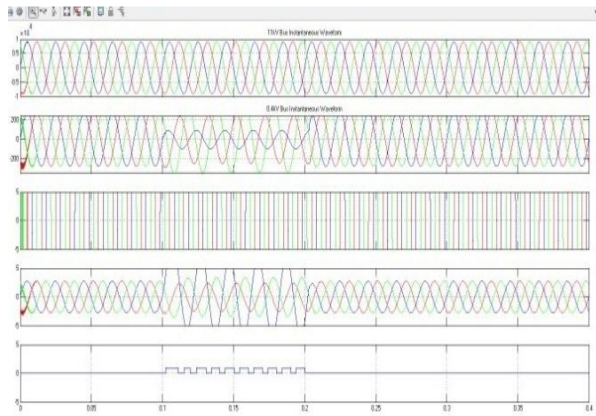

Fig. 4. Voltage and Current Outputs for 1L-G Fault.

3. PRINCIPLE OF COMPARISON IN NUMERIC METER

Many times it so happens that, there may not be a fault in real situation. Because of reasons such as higher order harmonics or current transformer (CT) saturation, power swing, starting of an induction motor, magnetic inrush current in transformer, CT gives incorrect information to the relay or the numeric meter. As a result, relay gives trip command to the circuit breaker and circuit breaker trips. This type of maloperation takes place on number of occasions. One of the objectives of this work is to suggest a method that will countercheck whether fault is occurred really or not.

Proposed arrangement comprises of the comparator which compares the signals coming from CT and circuit breaker contacts. i.e. NO_1 as shown in Fig. 5.

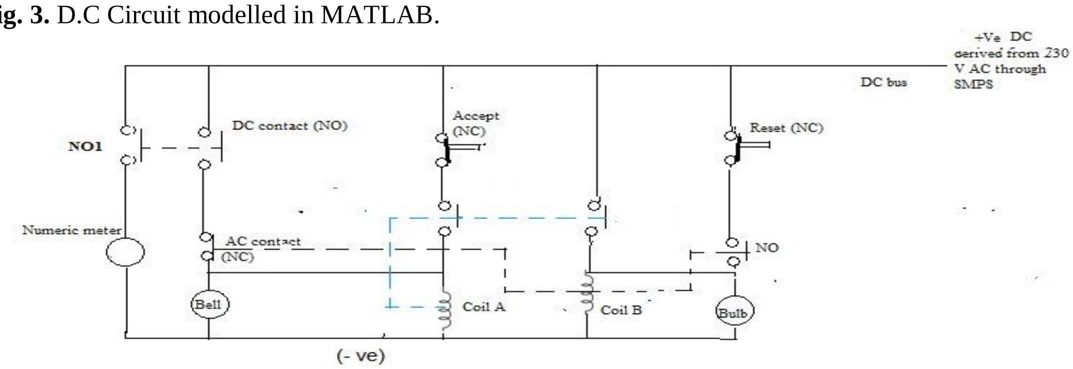

Fig. 5. Circuit on control panel.

These signals are brought at par level by using ADC. CT output is connected to terminal 1 through ADC. Output of NO_1 is connected to terminal 2 of comparator through ADC as shown in Fig.6.

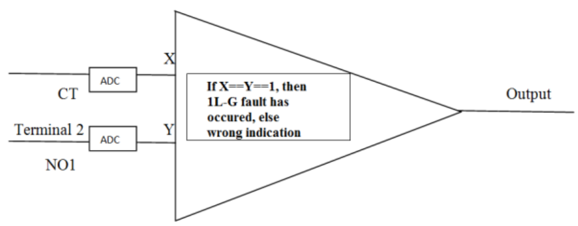

Fig. 6. Principle of comparison in Numeric meter.

Truth table

X	Y	Output of comparator
0	0	Wrong indication due to maloperation of relay or CT saturation
1	0	
0	1	
1	1	1L-G fault occurrence

4. DATA COLLECTED FOR SINGLE LINE TO GROUND FAULT (TRANSIENT) ON 220KV LONIKAND II – BHOSARI LINE

Occurrence I:

❖ Single Line to Ground fault on Lonikand II – Bhosari line:

Single line to ground fault was caused due to touching of the branch of the tree to phase B. Following observations were noted down.

- B phase – neutral shorted.
- Zone 1 fault.
- Distance protection operated
- Length of the line: 25.7 km
- Conductor type: 0.4 ACSR Deer/Zebra
- Fault location (displayed on the numeric relay): 10.68 km from Lonikand II end; and 10.68km from Bhosari end.
- Frequency :49.93 Hz

Table 2. The magnitude of phase currents at the time of this fault event.

Phase currents at the time of fault event		
I_r	I_y	I_b
503.6 A	156.6 A	7.612kA

❖ Single Line To Ground Fault (Transient) on 400kV Lonikand –Parali Feeder:

1L-G fault was caused due to the insulation failure because of the lightning surge. Y phase – neutral got shorted.

Occurrence II:

- Zone 1 fault.
- Distance protection operated
- Length of the line: 289.8 km
- Conductor type: 0.5 ACSR Moose
- Fault location: 150 km from Lonikand

Table 3. The magnitude of phase currents at the time of this fault event.

Table III		
phase currents at the time of fault event		
Ir	Iy	Ib
459.8 A	2.3kA	496A

Single Line to Ground Fault (Transient) on 400kV Lonikand–Parali Feeder:

Occurrence III:

Breakdown of the transmission line has resulted into the 1L-G fault and Y phase and neutral got shorted.

- Distance protection operated
- Length of the line: 289.8 km
- Conductor type: 0.5 ACSR Moose
- Fault location: 116.8 km from Lonikand
- Fault current: I_y= 2.8 kA

Single Line to Ground Fault (Transient) on 400kV Lonikand –Parali Feeder:

Due to improper installation of the transmission line, 1L-G fault had occurred and R phase and neutral got shorted.

Occurrence IV:

- Distance protection operated
- Length of the line: 289.8 km
- Conductor type: 0.5 ACSR Moose
- Fault location: 64.97 km from Lonikand
- Fault current: Ir= 4.557kA
- Fault Resistance: 12.79 Ω

5. NATIONAL TRANSMISSION ASSET MANAGEMENT CENTRE (NTAMC)

A. Virtual power plant

Aggrigator is an organization or an individual who brings various distributed energy resources eg. wind, solar, or battery storage together at a cloud based central or distributed control center that takes an advantage of ICT and Internet of Thing (IoT) .

SCADA systems in an IoT-cloud environment [11]: Normally , SCADA contains hardware, software, Human Machine interface (HMI), sensors, actuators, supervisory stations. General architecture of SCADA systems in an IoT-cloud environment is as shown in Fig.7.

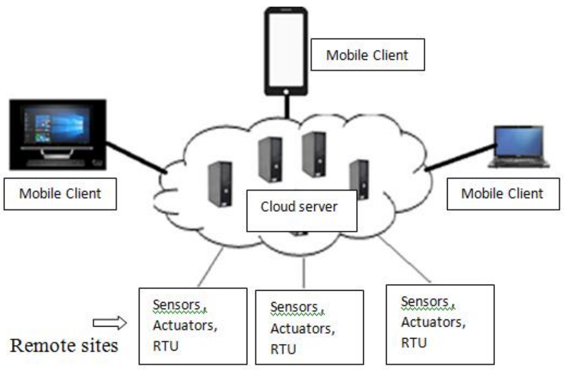

Fig. 7. The general architecture of SCADA systems in an IoT-cloud environment [11].

Smart Grid is the convergence of information technology, Telecommunication and energy markets.

B. Automation Evolution and Roadmap

In 1980's RTU was an integral part of SCADA. Monitoring and simple control were the main features of this system. Further in 1990's, SCADA came up with ethernet based/private protocol based SAS, providing monitoring, protection, and slow automation. The latest version of SCADA consists Ethernet /standard IEC 61850 based SAS enabling monitoring, protection and fast automation [12].

As per current scenario, proposed pilot which projects a lot of money is invested by the utility company. The provision should be there for scaling up the setup. Data Acquisition System (DAS) should be advanced; wherein there should be a provision to build new applications. There is no need to build a separate DAS. Continuous monitoring and control of system are the prerequisites for maintaining security of the system.

C. Application of ICT in power system operations

There is paradigm shift of convntional grid to the smart grid. Large, centralized generation has become decentralized as well as distributed. One directional power flow has changed to multidirectional now. Former monitoring and control by central SCADA is shifted to data collection and control by head end systems. Head end systems is centralized data collection point.

D. Asset Management

It is necessary to construct existing power transmission system suitable for remote operation i.e. monitoring and control. Forthcoming substations should be integration ready for remote operation from control center. From this constraint the model of Asset Management Center has come forward. Fig.8 describes asset management system model. The data communication flow will be as follows:

- Substation has to report Zonal Transmission System Management Center (ZTSMC)
- ZTSMC has to report state Transmission System Management Center (STSMC)
- STSMC has to report State Load Dispatch Center (SLDC)
- STSMC has to report corporate office

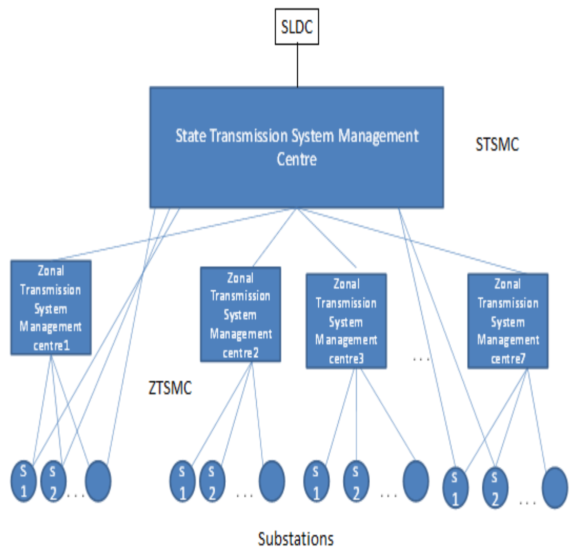

Fig. 8. Asset Management System [13].

Asset management system involves real time SCADA, operation support system e.g. Remedial Action Scheme (RAS), Automated Fault Analysis System (AFAS), Virtual Machines (VMs). RAS, AFAS, VMs will be located at SLDC centrally with main server and STSMC, ZTSMC and substations will have client applications.

In today's grid, there is direct communication between the numeric meters located at substations and SLDC. It is essential to establish client server based communication between substation, ZTSMC, STSMC, and SLDC to control and monitor the data.

POWERGRID Transmission system has proposed computerized control centers NTAMC & Regional Transmission Asset Management Centre (RTAMC) along with the telecommunication system. The idea behind the project is to perform all the substation operations without manual intervention. Telecommunication department will play vital role in providing fast communication links between NTAMC, RTAMCs and Sub-stations [14].

NTMC will enable centralized control of the whole transmission system through one location with the help of fully automated remotely operated substations [15].

E. NTAMC project structure

NTAMC project is composed of one National Transmission-Asset Management Centre (NTMC), nine Regional Transmission-Asset Management Centers (RTMC), a backup NTAMC & disaster recovery centre at Bangalore.

Power Grid Corporation of India Limited (PGCIL) is the Central Transmission Utility (CTU) of India. The implication of NTAMC is that all the 186 substations throughout the country are running without any manual interference. These substations would be monitored from one point i.e. at NTAMC Manesar. All substations will be interlinked through fiber optic communication. The communication system will be supported with HD cameras installed at all the substations to capture videos for 24x7 operations [16].

Data concentrator unit (DCU) [17]: Main function of data concentrators is to gather data from various meters and to store locally, which can be used for any application. Meters located at substations can be communicated with DCU using wired communication or low distance radio. DCU would have a channel GPRS or GSM to facilitate communication with the utility software. This could be a cost effective solution for advanced communication.

6. EFFECT OF HARMONICS ON SMART METER READING

Harmonics affect the performance of metering equipment.

Smart meter itself acts as a nonlinear load. It draws a nonlinear current from meter to source V_g as shown in fig.9. This current will get added to nonlinear current flowing from the numeric meter to source V_g. This total current will get subtracted from the fundamental current I, flowing from the source V_g to a nonlinear load.

Thus, the smart meter will record energy less than the energy recorded by a normal energy meter.

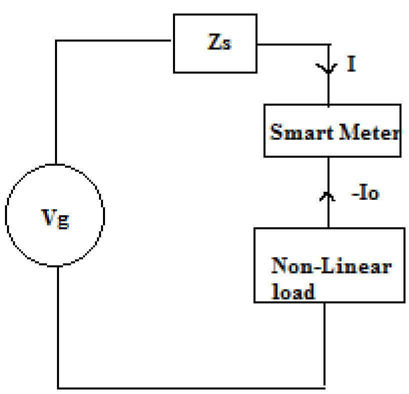

Fig. 9. Effect of harmonics on smart meter reading [18].

7. CONCLUSION

The work presented in this paper revolves around the fault location in electrical transmission network and communicating the data to its different segments. A novel approach of fault location is proposed. The salient contributions are as follows:

i) Validation of proposed algorithm for 1LG fault location using MATLAB simulink software.

ii) Proposed a method that will crosscheck whether fault is taken place really or not.

iii) An extensive discussion about NTAMC project at Kalkitech, Bangalore has been carried out. The finding emerged out of this study is that, in existing system, there is direct communication between the smart meters at substations and SLDC. It is suggested to have communication between the intermediate stages; i.e. substation, ZTSMC, STSMC, and SLDC.

iv) Effect of harmonics on smart meter reading is highlighted.

8. ACKNOWLEDGMENT

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