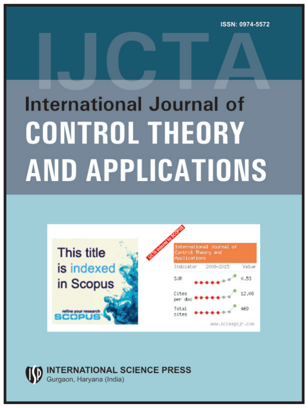

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Wavelet Based Fault Location Identification of Smart Meters in Smart Grid

T. Roosefert Mohan[a], R. Annie Uthra[b], J. Preetha Roselyn[c] and R. Dharmaprakash[d]

[a] *Department of Electrical and Electronics Engineering, St. Peters University, Chennai. Email: roosefert@gmail.com*
[b] *Department of Computer Science and Engineering, SRM University, Chennai. Email: annieuthra@gmail.com*
[c] *Department of Electrical and Electronics Engineering, SRM University, Chennai. Email: preetha.roselyn@gmail.com*
[d] *Department of Electrical and Electronics Engineering, Panimalar Institute of Technology, Chennai. Email: rdharmaprakash@yahoo.co.in*

Abstract: The entire electric power generated is not utilized efficiently and in a reliable way in power distribution system. By identifying the exact fault location and type of fault within a short time using smart meters is used to optimize the power utilization. Smart meters are used in smart grid for the better control and utilization of electric power. The smart meters are used to transmit or receive required data to and from the substation related to fault type and fault location. In case of any fault in the distribution line, a fault oriented travelling wave is generated with voltage and current transients for a short time and will be vanished. In this work, the travelling wave is analyzed by the Smart Meter using Discrete Wavelet Transform (DWT) in order to identify the fault location. The phase voltage is also measured to identify the type of fault in the system. In the conventional method, the fault location and type is analyzed from any particular location which is difficult in all three types of radial, ring and network power distribution system. In the proposed system, each smart meter can analyze the fault individually. All the smart meters send this calculated fault distance, faulted phase data, ID of the smart meter along with GPS time stamp to the master computer provided in the power sub-station. From this data, the master computer calculates the exact fault location with GPS position. The proposed DWT is an efficient mathematical, fast and accurate tool for transient signal analysis with less memory space, when compared to Continuous Wavelet Transform (CWT). In this paper, Daubachies 5 wavelet is used along with DWT technique which fault travelling wave is identified by the smart meter more efficiently which in turn calculates the fault location and the type of fault. This system is more accurate and reliable since all nearby smart meters identify the fault in any type of distribution system. Additions or alteration of network size have No. impact unlike existing fault finding system.

Keywords**:** Wavelet transformation, Smart meter, Fault location, travelling waves, wavelet packet decomposition.

1. INTRODUCTION

The industries across the world address numerous challenges in generation diversification, optimal utilization of expensive assets, demand, energy conservation and reduction of the industry's carbon footprint[1]. It is evident that such critical issues cannot be addressed within the existing electricity grid alone. The existing electricity grid is unidirectional in nature and it converts only one-third of fuel energy into electricity. Around 8% of its output is lost along its transmission lines and around 20% of its generation capacity is available to meet peak demand only (i.e., used only 5% of the time). In addition to that, the existing electricity grid incurred from domino effect failures due to its hierarchical topology.

The next-generation electricity grid called as the "smart grid" or "intelligent grid," is expected to overcome the major demerits of the existing grid. The smart grid is required to control, monitor the energy and rectify the fault in an efficient way. Figure 1 shows the procedures followed in conventional energy meter and Smart Meter (SM) system. Conventional electric energy meters is analogous, work independently to give accurate readings and consequently used to determine costs for service. The energy consumption data were taken manually.

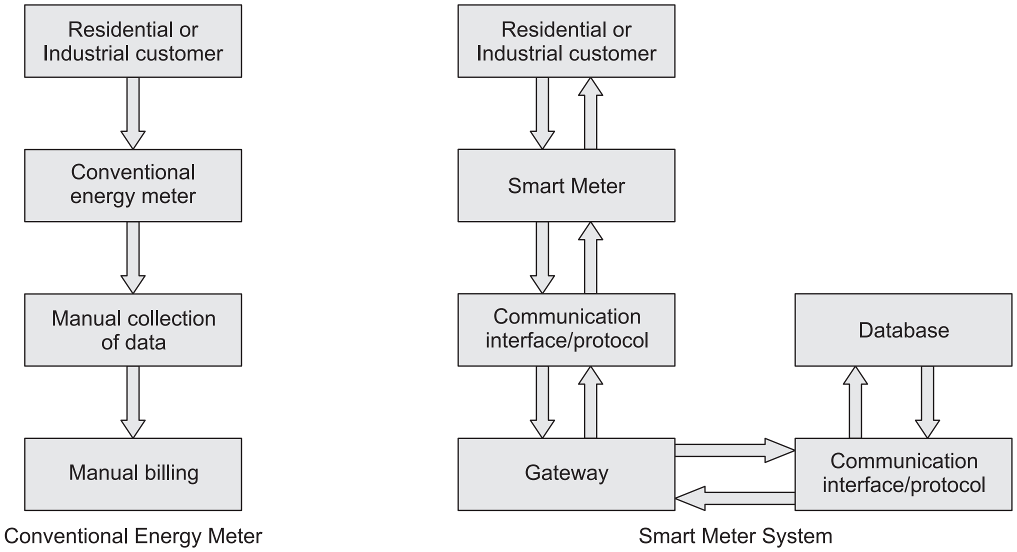


Figure 1: Comparison between conventional and smart meter systems

Smart meters are advanced utility meters that can record industrial, commercial or residential utility usage in real time, with more details. These meters identify energy consumption in an accurate and detailed way than a conventional meter. In a networked energy services the smart grid system, these meters can use power lines to communicate with its peers in a webbed network[2]. Using this smart meters operation and efficiency has been raised. They automatically send the electronic meter readings to energy suppliers giving real time detail on energy usage and consequent costing. Wireless mobile type smart meters can send and receive different types of data. Smart meters are normally fast and more reliable since they only send and receive short messages at set intervals throughout the day. This innovative technology will lead to optimize the energy consumption. Smart meters are not only the input element but also taking an important system of supervision and management.

The difference between smart meters and conventional meters are shown in Figure 1. Smart meters are used to record the consumption of electric energy at a regular intervals of an hour or less. This recorded information is used to communicate between the utility and the customer so that energy consumption is optimized, But conventional meters can capable of recording consumption. Smart meters can calculate whether or not there is a surplus of energy, which can be sold back to the grid, The notable differences between traditional and smart meters are usability, costs, accuracy, sensitivity and battery effects, which obviously gives the traditional meter an advantage.

Smart meters communicate regularly through radio transmitters installed on each device, which is more sophisticated[3]. Each transmitter can communicate with other meters to create net grid information – called a smart grid. Smart meters are digital units with less moving parts. So it is more durable, and accurate. Its frequencies can interfere with health care treatments like pacemakers. The data from this can be hacked. The architecture of the smart meter is given in Figure 2.

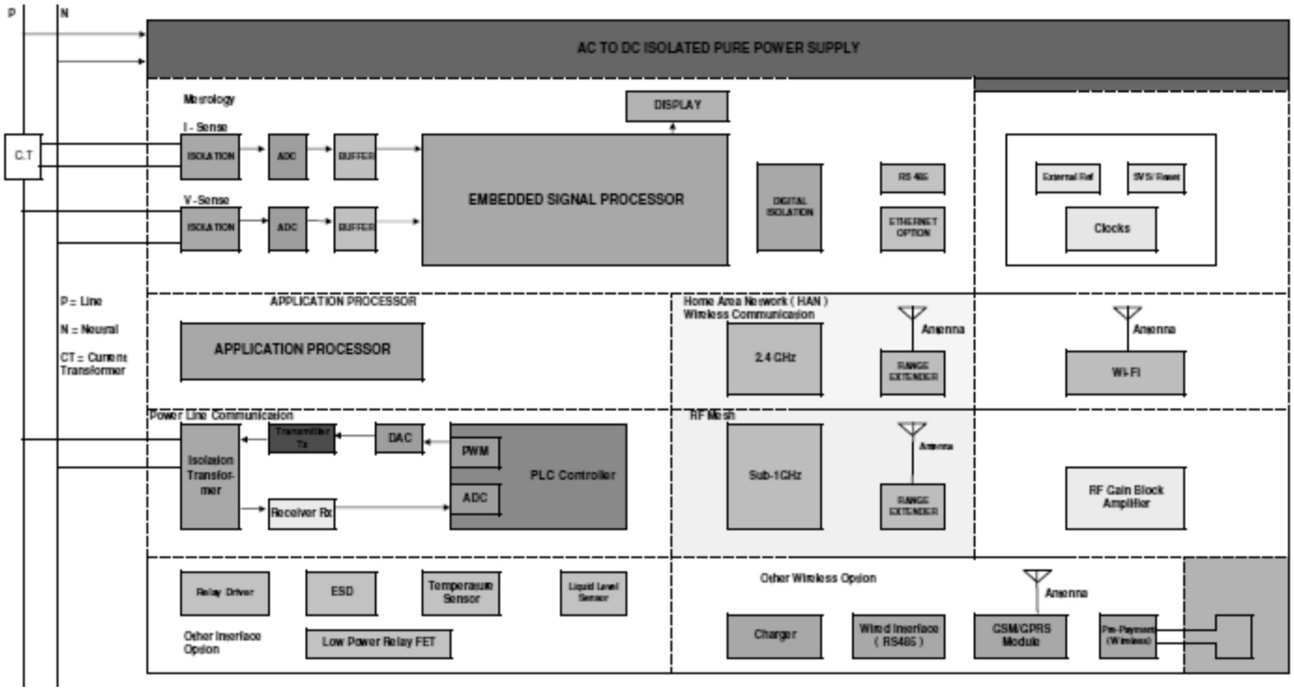


Figure 2: Architecture of Smart meter

The smart meters consists of the followings:

1. **Power supply layer:** The power supply layer converts ac to dc and feed isolated dc power to the smart meter.
2. **Metrology layer:** The metrology layer consists of measuring device which measures the load voltage and the current and convert this analog value to digital value using A/D converter and a processor which process the input values and displays the required parameters. These parameters can be sent to other system through RS485 and Ethernet port.
3. **Application processor layer:** This application layer collects the real time parameters for Energy Management System (EMS) and Distribution Management System (DMS) and process here using processors and feed the processed parameters to the communication layer. In this layer also the data can be communicated through WAN, HAN, WLAN.
4. **Power line communication layer:** This layer is a dual way communication layer which is used to transmit and receive the data through power line communication technique.
5. **Other interface layer:** This layer acts as peripheral layer which is having control over the input and output system.

There are different ways in which the fault information can be transferred to the sub-station. The ZigBee, wireless mesh or cellular network communication protocols are used for transferring the fault information to the sub-station.

1.1. Fault Location Identification

Electric power systems are constantly exposed to faults, which affect the system's reliability, security, and delivered energy quality[4-6]. Different stochastic events may cause systems faults, such as lightning, insulation breakdown, and trees falling across lines. Protection schemes are important to maintain system stability and minimize consumer and network damages as well as economical losses. In these aspects, fault-location techniques represent an important role in the fast and reliable power system restoration process.

Fault location in Electric Power Distribution Systems (EPDS), however, due to its specific topological and operational characteristics, still presents challenges[7-9]. Still today, fault location in EPDS is often made through visual inspection, field methods, and brute force methods[7]. These techniques are not feasible on underground systems and are very time consuming in large distribution networks. Therefore, a specific fault diagnosis method for EPDS becomes very important and useful.

The fault location identification approaches can be grouped[10] into the following main categories:

1. methods based on impedance measurement
2. methods based on the analysis of fault-originated traveling waves

This paper proposes a smart meter to find out the fault at the earliest possible and identify the faulty phase and location of fault automatically using the method based on the analysis of fault-oriented traveling waves without human intervention. Apart from all the existing layer and working style of the existing SM, the proposed smart meter consists of advanced processor in the metrology layer which can handle the DWT (a) calculation with less processor space. The idea to find out the fault is to identify the voltage transients that occur in the smart meters during fault. When such voltage transient travelling wave is detected by the smart meter, using DWT the distance from the smart meter to fault location is calculated and the location information, ID of the SM with GPS time stamp will be transmitted to the sub station from all smart meters. The sub-station computer which receives the ID of each SM, calculated fault distance data from all smart meters with GPS time stamp, analyses, calculates and identifies the actual fault location.

2. LITERATURE SURVEY

A distributed neural nets diagnosis system is proposed[11] for on-line estimate of the faulted section in a T&D system by using the information on the on-off states of protective devices. The diagnosis system has been implemented on six PC-level computers, each one takes charge of the fault diagnosis at a substation.

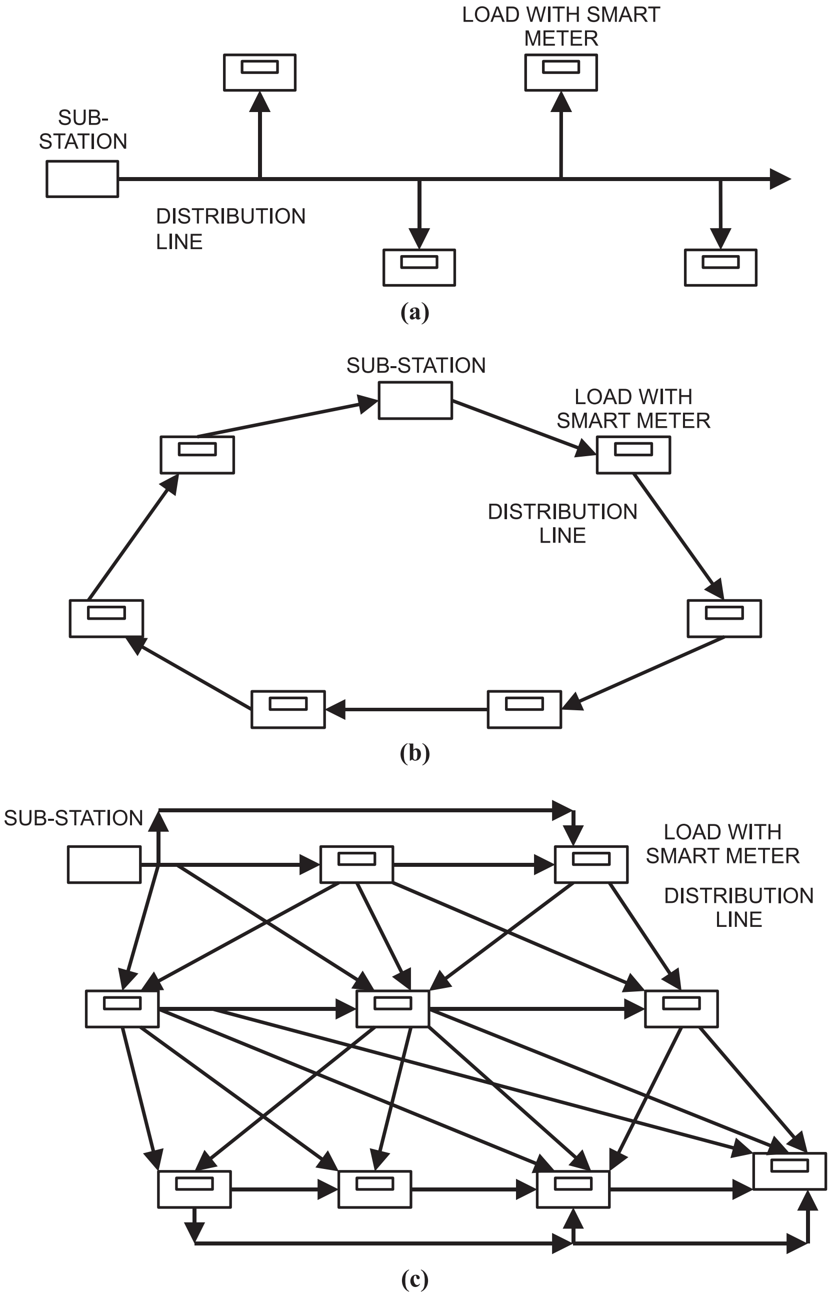
Navaneethan et. al.,[12] proposed an automatic fault location technique for permanent faults in Underground Low Voltage Distribution Networks (ULVDNs). They used the signals from an existing Time Domain Reflectometry (TDR) instrument and pre-processed TDR signals to eliminate reflections due to single-phase tee-offs, and to locate 3-phase open or short circuit faults and also uses adaptive filtering to compare the TDR signals to locate faults. A pulse is launched into the cable network from an accessible point in TDR. This pulse is partially or completely reflected by any impedance mismatches in the cable network. These impedance mismatches is identified as short circuit or an open circuit or tee joint. The reflected pulses (signals) are recorded for both faulty and sound (healthy) phases. These reflected signals are then used to locate any fault in the cable network either by visual comparison or subtracted one from the other.

Rodrigo et. al.,[4] proposed a fault-location method which uses local voltages and currents as input data. This method is based on the apparent impedance calculation. The time-varying load profile of EPDS based on the sending-end measurements is also considered in this system. For distribution systems, a power-flow-based analysis is executed to determine the possible fault locations in each path.

A fault location procedure for distribution networks based on the wavelet analysis of the fault-generated traveling waves is proposed by Alberto et. al.,[10]. In this method the continuous wavelet analysis is applied to the voltage waveforms recorded during the fault in correspondence of a network bus. An algorithm is proposed to build specific mother wavelets inferred from the fault-originated transient waveforms.

3. FAULT LOCATION IDENTIFICATION USING DWT

There are three types of power distribution networks[13] namely, radial, ring and network. The load arrangement with SM is depicted in Figure 3.



(a)

(b)

(c)

Figure 3: Power Distribution Systems (a) Radial (b) Ring and (c) Network

An example scenario is shown in Figure 4 using radial power distribution network. In Figure 4, A and B represent the load attached with smart meter along the transmission line. When fault occurs in between load A and B, a fault generated travelling wave with voltage/current transients will be generated and it will be captured by all SM A, B, C and D.

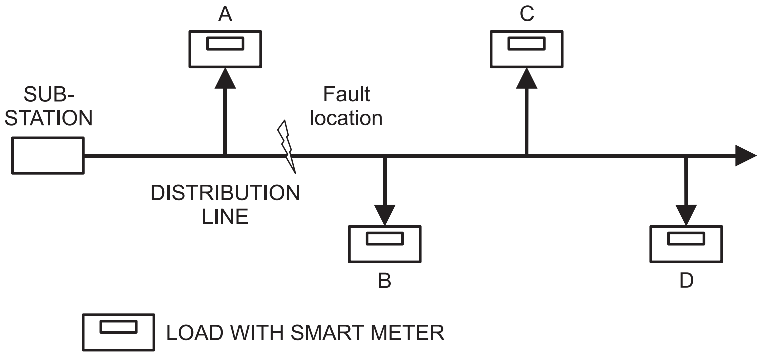


Figure 4: Example of the path with fault in radial power distribution network

3.1. Phase Fault Identification

The phase fault is identified using the following steps.

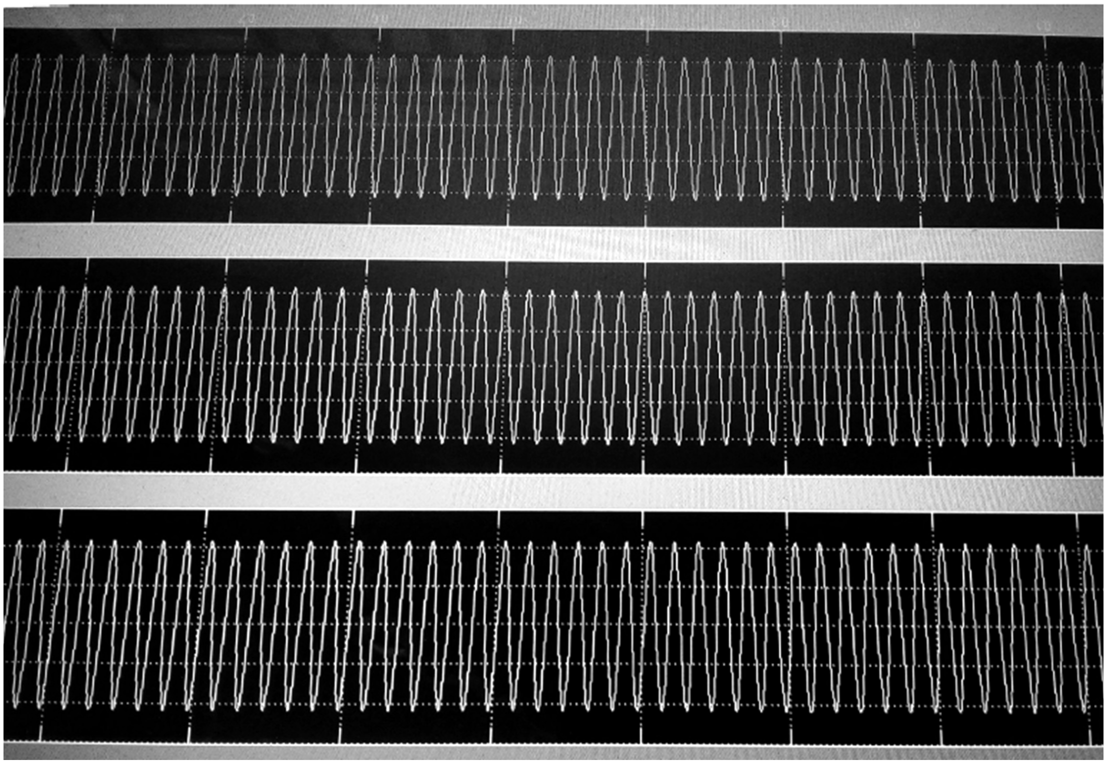
1. Let R, Y and B are the phases. V_a, V_b and V_c are the RMS value of phase R, Y and B respectively. The fault levels of phases R, Y and B are R_1, Y_1 and B_1 respectively. V_{ry}, V_{yb},V_{br} are the RMS values of RY, YB and BR respectively and the fault levels of RY, YB and BR are R_y, Y_b and B_r respectively.
2. By comparing the RMS value and fault value the fault type in phase is identified.
3. If $R_1 > R_a$ the fault is LG fault of R phase. Similarly it is calculated for the other Y and B phases. The digital condition High (1) denotes fault and Low (0) denotes No. fault.
4. $R_y > V_{ry}$ then it is LL-G fault. Similarly it can be calculated for other two combinations.
5. If $R_y > V_{ry}$ and $Y_b > V_{yb}$ and $B_r > V_{br}$ then it is LLL-G fault.

These phase faults are shown in Figure 5.

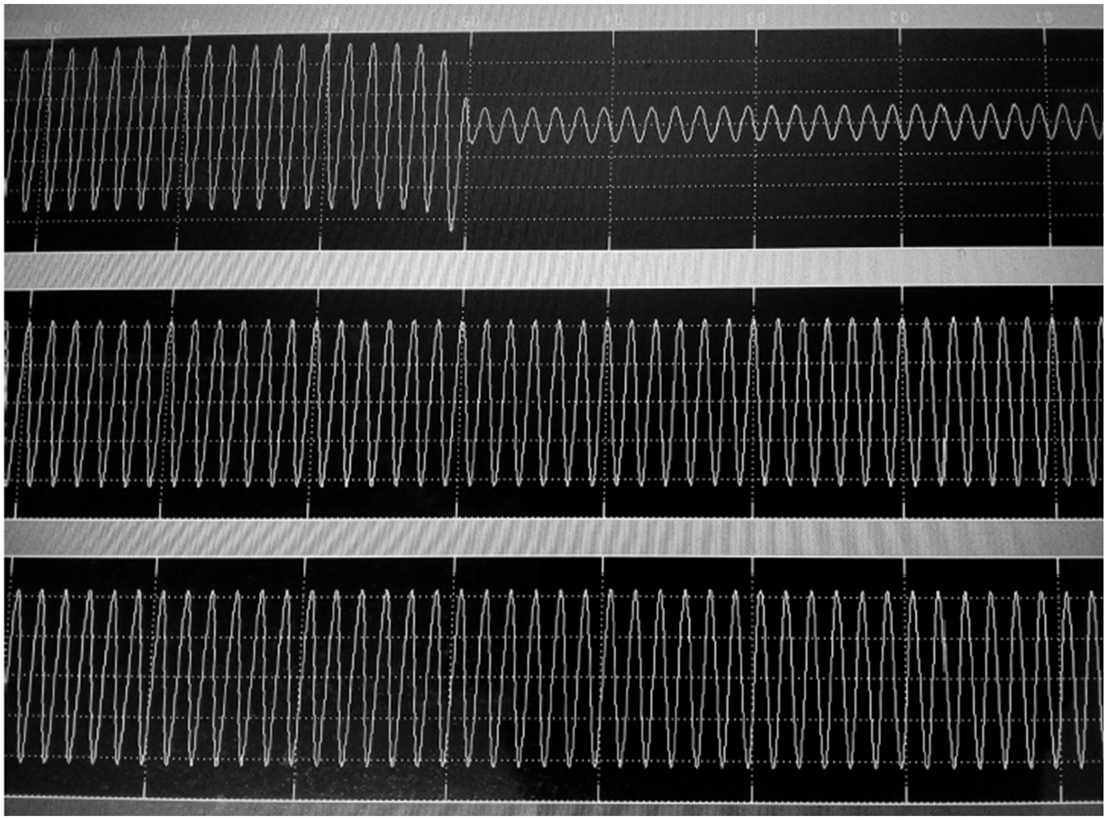
3.2. Distance Calculation using Discrete Wavelet Transform

The proposed smart meters should be a three phase smart meter with battery backup power to analyze the signal during blackout time. In the proposed smart meter, the embedded processor should be selected and programmed for handling discrete wavelet analyzing method. This SM will continuously monitor the signal for regular work. Once the fault is detected, the wavelet calculation will be performed in all the load smart meters. The smart meter is designed such that it performs the calculation on a 5-megapixel wavelet image. Hence the proposed wavelet transform requires 200 times less memory and is five times faster than the regular one[14].

The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations .This transform decomposes the non stationary signal into mutually orthogonal set of wavelets, which is the main difference from the continuous wavelet transform (CWT), or its implementation for the discrete time series sometimes called discrete-time continuous wavelet transform (DT-CWT).



(a)



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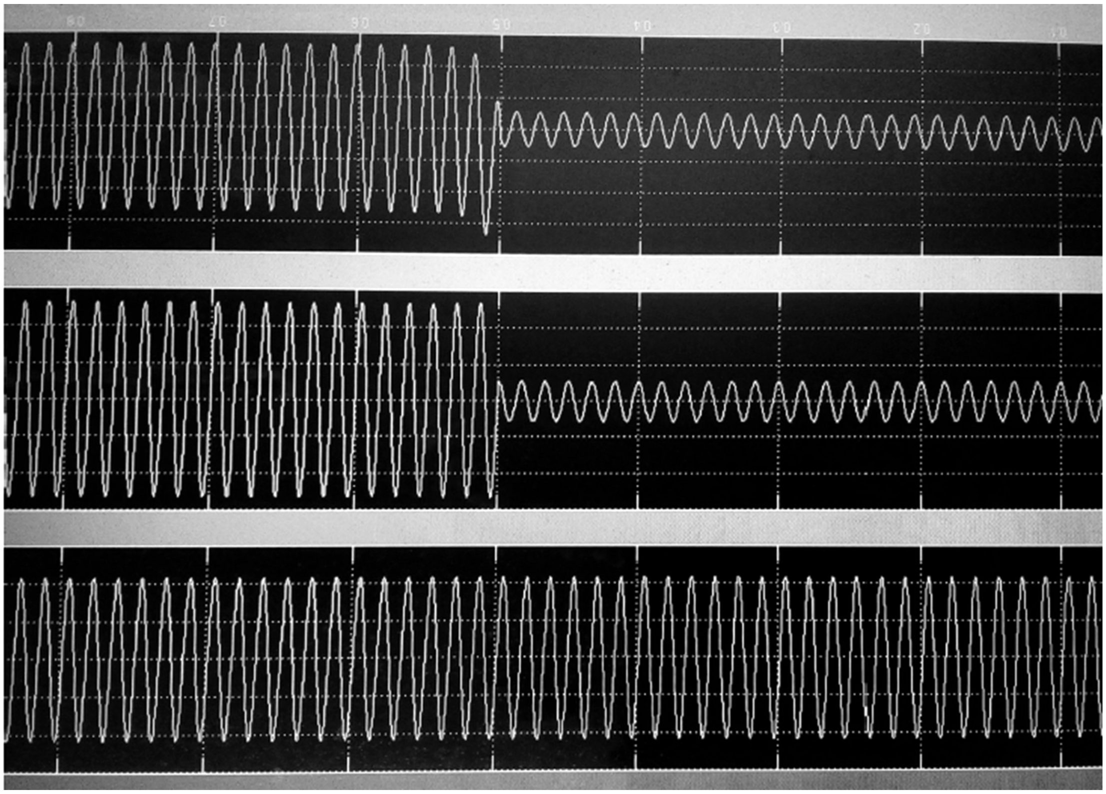

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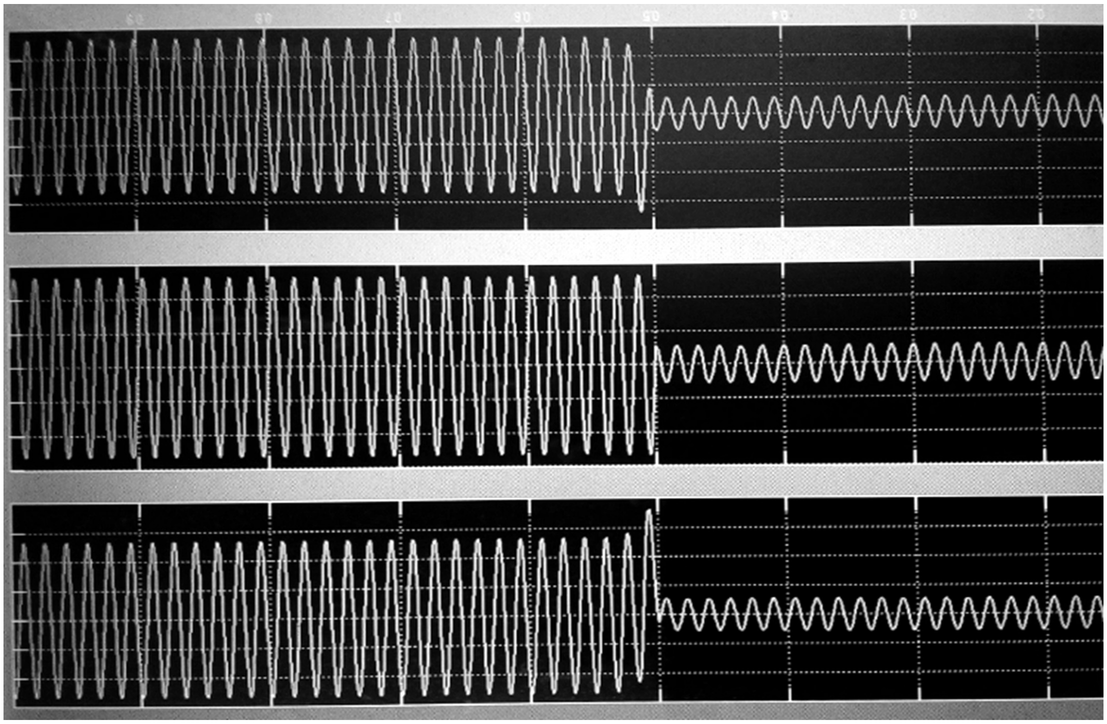

(d)

Figure 5: Phase faults analysis (a)NO Fault supply (b) LG fault (fault between phase A and Ground) (c) LL fault (fault between phase A and phase B) (d) LLL fault (fault between phase A, phase B and phase C)

Wavelet analysis is similar to Fourier analysis which breaks down the signal into a series of sine waves of different frequencies for analysis. The wavelet transform breaks the signal into its "wavelets", scaled and shifted versions of the "mother wavelet". Debauchies 5 (D-5) wavelet[15], is used for fault analysis. The properties of being irregular in shape and compactly supported that make wavelets an ideal tool for analyzing signals of a non-stationary nature. A sample faulty voltage/current transient waveform is shown in Figure 6. Figure 7 shows the pure supply voltage sine wave and the wavelet.

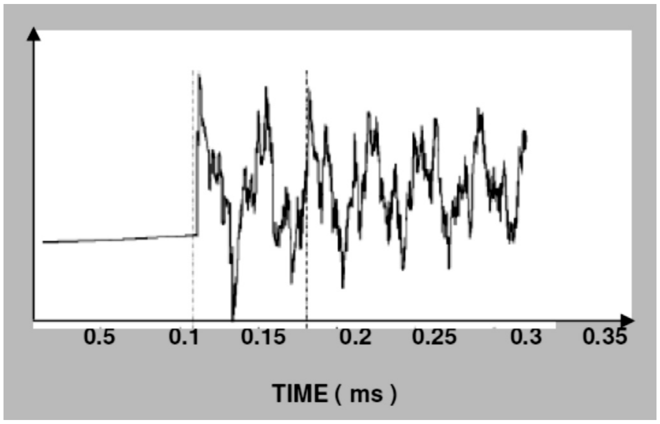

Figure 6: Fault originated voltage/current transient waveform

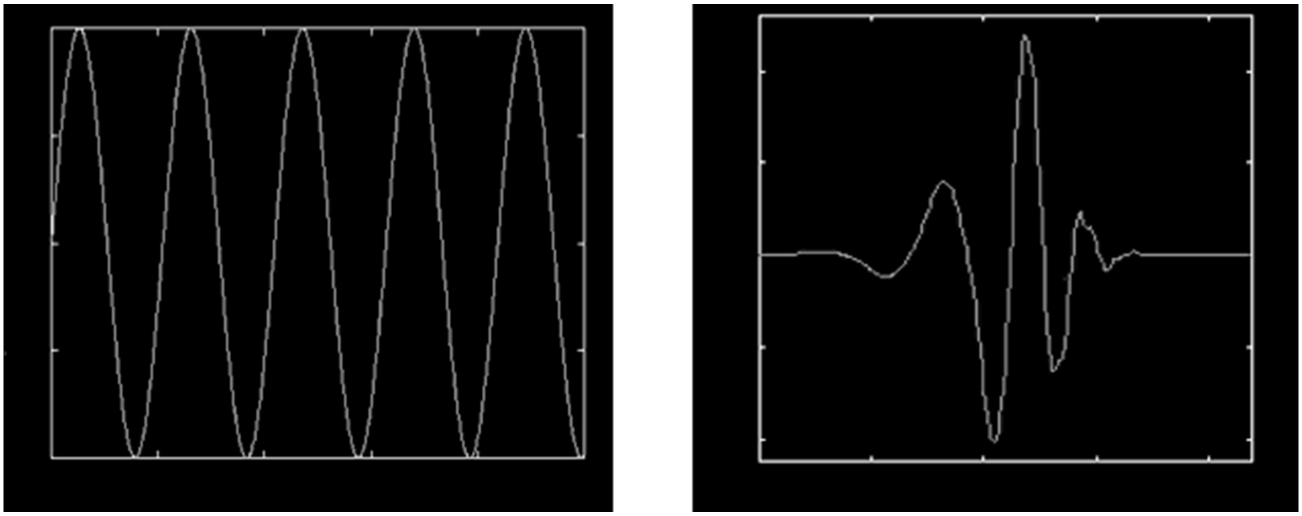

Figure 7: The Sine wave and the Daubechies 5 wavelet

Wavelet transform allows exceptional localization in both the time domain via translations of the mother wavelet, and in the scale (frequency) domain via dilations[16]. The translation and dilation operations applied to the mother wavelet are performed to calculate the wavelet coefficients. This coefficient is used to represent the correlation between the wavelet and a section of the signal. The wavelet coefficients are calculated for each wavelet segment. The process of shifting and scaling the wave is given in Figure 8.

The scaling and translation of mother wavelet $y(n)$ and the input signal $x(n)$ using DWT[17] is given in equation (1).

$$\mathrm{DWT}(t, f) = \frac{1}{\sqrt{a^m}} \sum_n x(n)\, y\left(\frac{f - nba^m}{a^m}\right) \tag{1}$$

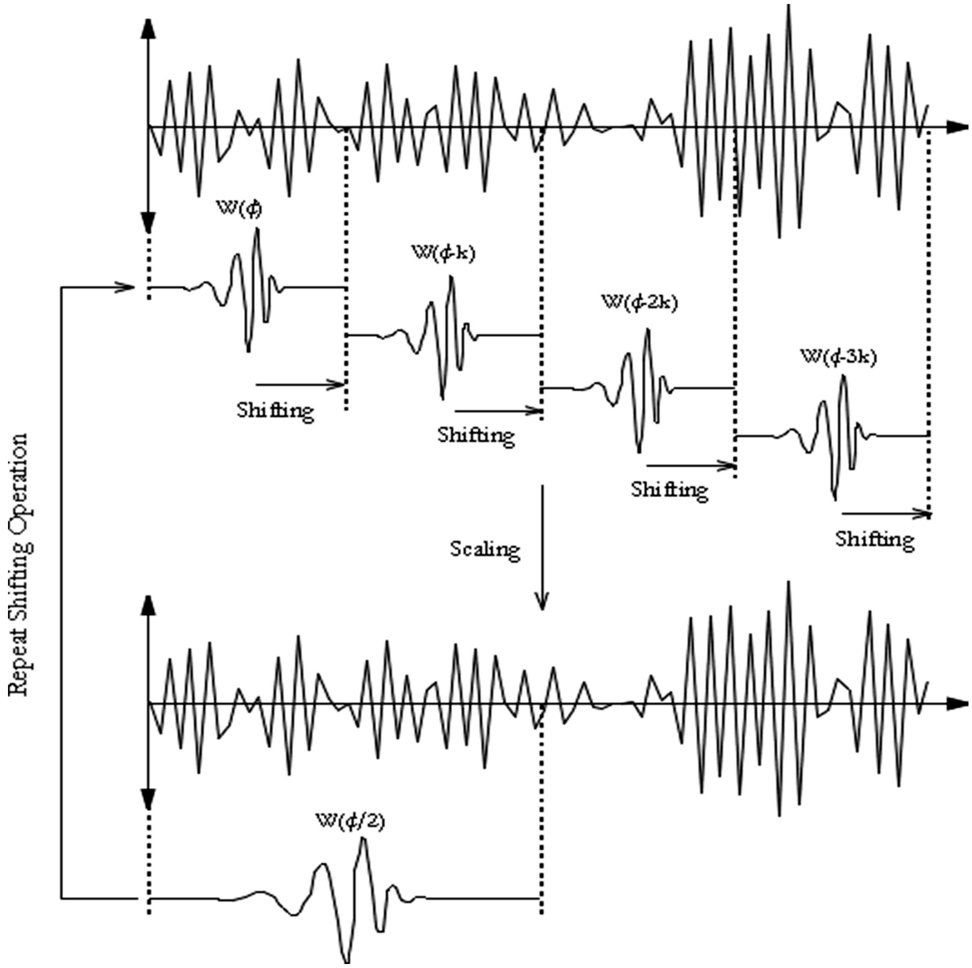

Figure 8: The scaling and shifting process of the DWT

where, a is the scaling parameter and b is the translation parameter. The translation is repeated for 0, n, $2n$, ... and the geometric scaling is performed with respect to the scale factor a.

The dilation function of the discrete wavelet transform can be represented as a tree of low and high pass filters, with each step transforming the low pass filter as shown in Figure 9. The original signal is successively decomposed. The maximum number of dilations that can be performed is dependent on the input size of the data to be analyzed, with 2N data samples enabling the breakdown of the signal into N discrete levels using the discrete wavelet transform. In this paper the wavelet coefficients can be calculated using Wavelet Packet Decomposition (WPD) dilution method Multi-Resolution Analysis (MRA). In WPD the approximation coefficients are decomposed to create the full binary tree. Whereas in the DWT, each level is calculated by passing only the previous wavelet approximation coefficients through discrete-time low and high pass quadrature mirror filters.

Wavelet Packet decomposition is performed over 3 levels. $g[n]$ is the low-pass approximation coefficients, $h[n]$ is the high-pass detail coefficients. For n levels of decomposition the WPD produces 2^n different sets of coefficients (or nodes) as opposed to $(3n + 1)$ sets for the DWT. However, due to the down sampling process the overall number of coefficients is still the same and there is No. redundancy. The output of the high pass and low pass filter is shown in equation (2) and (3).

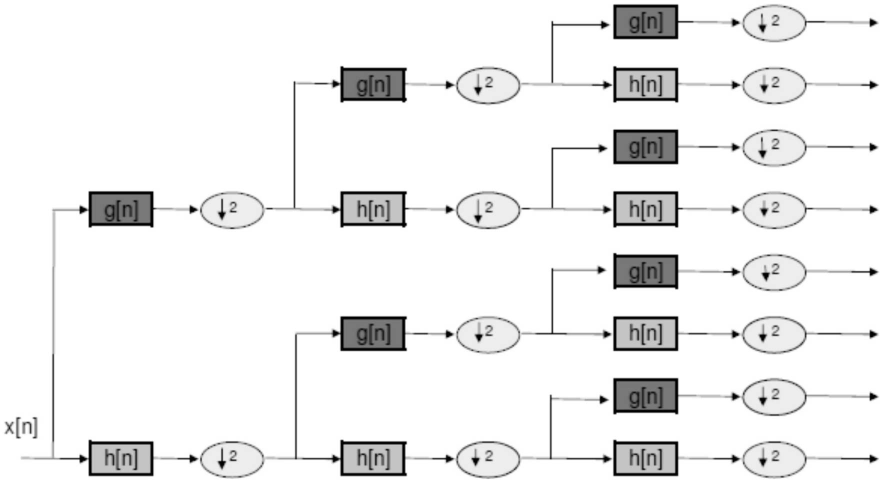

Figure 9: The dilution method using Low and High pass filter

$$\text{Filter}_{\text{high}}[k] = \sum_{n} x(n)\, g(2k-n) \tag{2}$$

$$\text{Filter}_{\text{low}}[k] = \sum_{n} x(n)\, h(2k-n) \tag{3}$$

where, $x(n)$ is original signal.

The signal can therefore be sub sampled by 2, simply by discarding every other sample. This constitutes one level of decomposition and can mathematically be expressed as follows: where $x[n]$ is the original signal to be decomposed, and $h[n]$ and $g[n]$ are low pass and high pass filters, respectively. The original signal is then obtained by concatenating all coefficients starting from the last level of decomposition (remaining two samples, in this case). The WPD will then have the same number of coefficients as the original signal. The distance of the fault location depends on the calculated coefficient value.

When the smart meter identifies the fault generated travelling wave using wavelet transform, each SM transmits packet which contains (ID, TIME-STAMP, d). d is the fault distance from each smart meter, TIME-STAMP is the time at which fault is identified and ID is the identifier of the smart meter. The Fault Location identification in sub-station computer is performed using the following steps.

Algorithm: Location Identification

1. Arrange the received packets (ID, TIME-STAMP, d_{ID}) in descending order with respect to d_{ID}.
2. Let d_i and d_{i+1} be the first 2 distance from the SMs i and $i+1$ such that the SMs are collinear.
3. Each SM location is identified using its own ID. The SM location is represented as GPS coordinate positions (x, y).
4. The fault location $F(x, y)$ is identified as

   $$F(x, y) = \left(\frac{x_2 d_i + x_1 d_{i+1}}{d_i + d_{i+1}}, \frac{y_2 d_i + y_1 d_{i+1}}{d_i + d_{i+1}} \right)$$

   where, (x_1, y_1) and (x_2, y_2) are the coordinate positions of SM_1 and SM_2
5. Translate/ Map fault location $F(x, y)$ into location name using GPS.

4. CONCLUSION

In this paper, DWT Daubachies 5 wavelet is used with DWT. The fault in distribution system validated using MATHLAB. Wavelet Transform was used to extract distinctive features in the input signals. The fault originated travelling wave is captured by the smart meter and analyzed using wavelet. The various types of fault (LG, LL, LLG, and LLLG) are identified. The fault location length from the SM is identified. All the captured date from the SM is transmitted to the computer in the sub-station. This computer display the exact location of fault with GPS. The method utilizes a set of quite simple rule base approach for identification of faults is quite simple to adopt and extremely fast for the fault identification and location. Since the proposed fault location finding method is implemented through smart meters the accuracy is more and also the reflection of fault oriented travelling wave at terminal junction can be ignored since smart meters are connected to each load. The change in network topology will not affect the fault length calculation method. Most of the system used to work in radial power distribution system only, whereas the proposed system is suitable for all types of distribution systems.

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