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Intelligent Fault Detection and Diagnostic System for Smart Meter

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Abstract

The energy requirements of the growing population and industries are driving up energy demand in the twenty-first century. Fulfilling the increasing demand for environmental solutions is also a major challenge due to the use of fossil fuels. As a result, all existing infrastructure must be upgraded to create an efficient system. Smart Grid is a step toward more efficient power utilization. A smart meter is an important component of a smart grid that deals directly with the consumer, as well as the option of net metering. Net metering is a critical execution nowadays and a smart meter is the core component of this execution. Smart meters design is currently not fully fault free and there is a need for detection and diagnostic mechanism for a smart meter to accurately identify the faults. Therefore, design and development of a reliable smart meter is the need of the hour to cater for the said requirements. The research goal of this work is to create a system that detects and diagnoses faults in smart meters. In this study, an intelligent prototype leads to problems such as power theft, overvoltage, and long service interruptions. The presented work can intelligently identify common faults in smart meters such as overbilling, subassembly malfunction, power failure, calibration error, and subassembly failure. The proposed methodology consists of an integration of a system that collects data, analyses it, identifies the fault using mathematical models and fault identification logic and takes corrective action using modern control techniques such as State Estimators followed by ANFIS based decision making. Both modular and system testing of the protype was performed and all faults were detected and diagnosed accurately. The strategy adopted in this work will be very beneficial in modern applications, in particular, the system will provide quick and efficient treatment of equipment/system malfunctions, which will result in increased production and reduced downtime.

Keywords: smart grid, smart meter, faults detection, fault diagnostics

1. INTRODUCTION

SEM is smart metering equipment with a wireless protocol for data transfer and a smart meter chip for determining the amount of power utilized. The response of the user aids in the identification of the issue. Usage by approved and unauthorized users aids in the prevention of energy theft. A smart meter is a digital energy meter that detects electrical energy usage and provides extra information, as opposed to a traditional energy meter. smart energy meter system allows for automatic metering and invoicing. They won't have to travel to each residence to keep track of the meter readings. This meter's energy consumption, as well as the corresponding amount displayed on the LCD, will be displayed continuously, and communicated to the operations center station. The user's feedback contributes to the identification of the problem. Usages by authorized and unauthorized users aid in the prevention of power theft. A smart meter is a digital energy meter that detects electrical energy usage and provides extra information, as opposed to a traditional energy meter. The objective is to make energy monitoring as simple as possible for both consumers and providers. Because smart meters allow for more contact between customers and suppliers, they are a crucial aspect of the smart grid. Consumers and suppliers will be able to converse in both directions [1]. Smart meters are more advanced in that they not only measure usage but also communicate to the energy monitoring system and as such, meter readings are collected directly by the utility. They also allow for more sophisticated tariffs to be set up by the utility (this affects commercial users, where more is charged at times of the day when grid usage is at its peak). Most smart meters still work on the billing system (after the reading is sent electronically to the utility, a bill is sent to the consumer), however, some smart meters incorporate prepaid meter technology.

The traditional grid, the electrical grid of the previous century, is a one-way system. This means that electricity travels in a single direction from generators to substations, across transmission lines, and finally to consumer outlets. It should also be mentioned that the majority of the traditional power grid's equipment and lines were established many years ago. Because they are big investments, supplying them takes a long time. Work would be done at the consumer end (Smart Meter) as highlighted. The smart meter has many advantages over the conventional meter but there are some disadvantages as well that can affect the meter's reliability and functionality. Hence the goal of the project is to develop a system that makes the smart meter work more efficiently [2]. A traditional meter merely records total use without allowing for monitoring. A traditional meter requires a monthly reading by a meter reader and merely shows a reading. After the electricity is utilized, a bill is created based on this reading.

The following is how the rest of the paper is organized: Section 2 reviews existing technologies; Section 3 describes the proposed system in detail; Section 4 describes the system's operation; Section 5 describes the system's deployment, data collection mechanism simulation implementation, and simulation results; and Section 6 concludes the overall research and suggests future directions.

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2. LITERATURE REVIEW

In [3] Muhammad Saad et al proposed a state-of-the-art technique for electrical power stealing detection. Initially, meter tempering was introduced by by-passing the relay and XOR gate was then used to detect the stealing by comparing the states of the relay i.e. energized or de-energized. Similarly, In [4] Mufassirin et al proposed an advanced technique for power theft detection. Initially, an Automated Energy Metering and Monitoring System with cutting-edge features including remote metering, theft detection, and control of the consumer's electricity supply was designed. The Wi-Fi module was interfaced with the embedded systems to ensure improved wireless data transfer stability. The suggested system was capable of continuous monitoring and notifying the energy source and consumer of the number of units consumed. Additionally, the Internet of Things (IoT) technology was introduced to update the bill once the energy consumption is computed. In [5] the multiple diagnostic methods were discussed and analyzed regarding the smart microgrid Diagnosis strategy for the system as well as alternative system designs to improve the monitoring capability of the micro-grid were studied. Fuzzy logic-based methods where the fault type, size, and location were determined using fuzzy logic along with state-estimation-based methods were typically useful when all of the state parameters are not observable. the accurate model of the system is lacking. An anomaly detection framework that can efficiently detect energy theft attacks against AMI has become significantly imperative for reducing costs and revenue losses incurred due to NTLs. In [6] the proposed system is to locate fraudulent consumers and discover faulty smart meters. Any non-zero anomaly coefficient is indicative of energy theft or metering defect. In addition, the proposed framework is also able to estimate the percentage of technical losses based on measurements at the data collector and the knowledge of the distribution network. Results from simulations and test rigs show that fraudulent consumers/defective smart meters can be detected regardless of whether non-technical losses take place all the time or at a random rate during intermittent periods in a day.

This [7] research studied the use of a robust artificial intelligence algorithm adaptive neuro-fuzzy inference system (ANFIS) to more efficiently detect power theft based on real smart meter data. The AFNIS acts as a classifier into which the most significant classification features are added which makes the theft detection phenomena more structured. Future researchers are suggested to investigate more cases of power thefts by especially taking into account the phenomenon of power thefts in consumers that demand a high amount of electricity such as industries. Moreover, it is also studied that the interconnection of RES (renewable energy sources) as distributed generation connected to the power distribution grid could have crucial effects on the overall process of power theft. In the work presented in [8] the research was based on the architecture automation, connectivity, and tacking monitoring of devices for the smart grid using IoT. The limitation is the lack of standardization on the IoT-aided SG system and fault diagnostic detection. In [9]Fault detection of the audio signal, and vibration signal,

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which is frequency based related to signal to process. The limitation is in the troubleshooting there is a limitation in fault diagnosis, both benchmarking and huge databases are lacking. In [10] GSM-based line fault the smart meter diagnostic only power theft and billing issues. The fault detection section monitors the type of fault and reports the type and location of the fault to the appropriate authority. Embedded-based hardware design is used for data acquired from the system. In [11] Machine learning algorithm for automatic Fault Detection and Condition Monitoring in District Heating Using Smart Meter Data for the smart grid. Though the control behavior of a district heating substation is due to a malfunction or failure, it can be discovered before the client notices. In outlier detection using diagnosis techniques using k-nearest neighbor (k-NN) classification, k-mean clustering, and simple linear regression. The Faults type is circulator pump breakdown, leaking control valve. In [12] this paper presented the system of energy metering was power theft, inaccurate meter reading and billing, and consumers' unwillingness to pay their electrical bills on time through various wireless communication technology (AMI, GSM, Zig-bee, WIMAX) used in the smart meter.

In [13] C. Angeli et al proposed an isolation technique for Online fault detection. Based on Mathematical system models' fault is detected by using expert systems technology, artificial intelligence methods, and numerical methods in technical systems. Moreover, State estimation, parameter estimation, neural networks, and other signal processing techniques are used. Their limitation in the systems was running fault models in these techniques takes a long time. For the measurements required for the data collecting process, online systems employ a large number of sensors. For the evolution of online expert systems to continue, new approaches must be established. In [14] the paper presented the system of Fault Area Location by using Smart Meter Data for billing purposes. It can correctly identify medium-voltage transformers and low-voltage radials that are affected by a power failure, as well as provide good indications of electrical box damage. Fault location, Automated billing, and service activation are just a few of the uses. There was a limitation on whether or not electrical boxes are affected by a power failure. Chen et al [15] proposed an AI-based fault detection technique to detect overvoltage in smart grids. In this approach, initially, Stacked Sparse Autoencoder (SSAE) is used to extract the deep features from the Ferro resonance overvoltage waveforms. The extracted features are then fed to the output layer having SoftMax as an activation function to classify the overvoltage. Similarly, in [16] Wang et al presented fuzzy systems and support vector machine-based automatic fault detection in self-healing grids. In this approach, at the very first the frequency-domain statistical features are extracted by computing S-transform to train the machine learning algorithms to detect overvoltage.

Power System Technology
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3. PROPOSED METHODOLOGY

In this section, the proposed methodology is detailed, which includes Hardware and Software Design, fault detection and diagnostics.

3.1 Hardware design

The hardware components used throughout the project are summarized in this part, which would include the WIFI Smart Energy meter, backup meter, DAQ Card 6001 module, and Current Transformer to have a clear concept of each component, the complete explanation, demands, and implementations are briefly reviewed. The prototype will consist of a fault detection and diagnostic system. The main supply of 250 volts is given to the system, two meters will be used for this purpose. One main meter and the other will be used as a backup meter. These meters are connected to the main supply which can measure the current, voltages, and frequency. This data will be displayed on a laptop or PC through a Data Acquisition Card (DAQ), which is an interface between meter and PC. The maximum limit of the DAQ Card is10 volts and 20 mA current, so two transformers will be used to limit the current and voltage. LabView software will be used to make a simulation(logic) that detects seven Real-time faults, identify, and diagnose them accordingly.

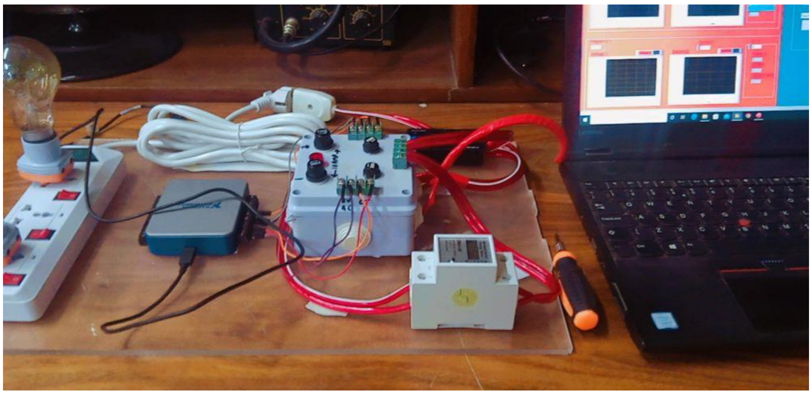

Figure 1 Hardware Design of the system

3.2 Software design

Software View of this project is based on Lab View, NI LabView Modules, sound and vibration module, and a signal processing module the system takes real-time input, and it is discussed below.

3.2.1 Data acquisition

DAQ assistant is the part of LabVIEW which can get the data from the DAQ card. Then signal splitter is used to split from one signal into four. Graph of These four signals voltage1, current1, voltage2, and current2 are displayed on the screen. Then RMS of voltage1, current1, voltage2, and current2 is calculated. A filter is used to smoothen the signals. The value of the RMS is

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fluctuating so the Array maximum is used to obtain the maximum value of RMS in a specific time. Voltage is measured in volts and current is measured in ampere. Frequencies of meter1 and meter2 can be measured by using the LabVIEW module of tone measurements. This is the front panel of the lab view which displays the data on the screen. Volage1 and current1 graph show the voltage and current of meter1 similarly voltage2 and current2 graph show the voltage and current of meter2 respectively. RMS of voltages and currents is displayed on the screen. power and frequencies of meter1 and meter2 are also shown on the front panel of the screen.

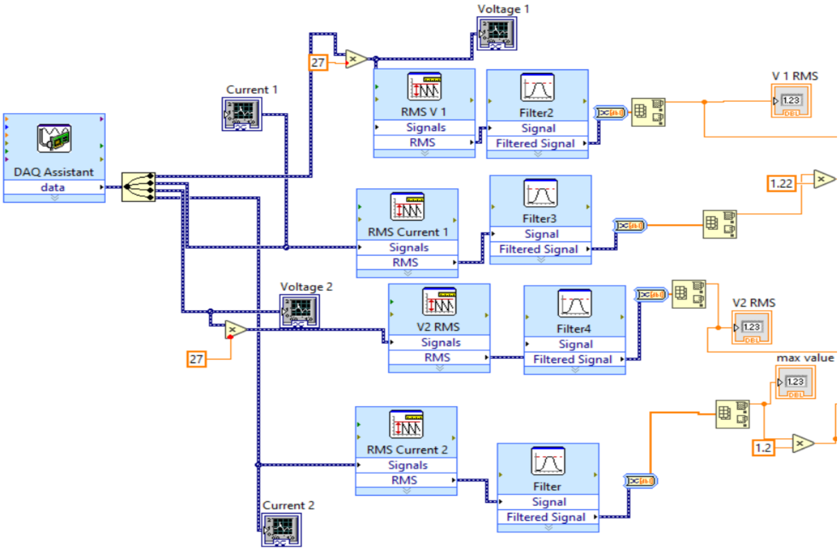

Figure 2 Lab View Presentation of Developed System

3.2.2 Pre-processing

The signal splitter is used to split from one signal into four. Graph of These four signals voltage1, current1, voltage2, and current2 are displayed on the screen. Then RMS of voltage1, current1, voltage2, and current2 is calculated. A filter is used to smoothen the signals. The value of the RMS is fluctuating so the Array maximum is used to obtain the maximum value of RMS in a specific time. Voltage is measured in volts and current is measured in ampere. Frequencies of meter1 and meter2 can be measured by using the LabVIEW module of tone measurements. This is the front panel of the lab view which displays the data on a screen. Volage1 and current1 graph show the voltage and current of meter1 similarly voltage2 and current2 graph show the voltage and current of meter2 respectively. RMS of voltages and currents is displayed on the screen. power and frequencies of meter1 and meter2 are also shown on the front panel of the screen.

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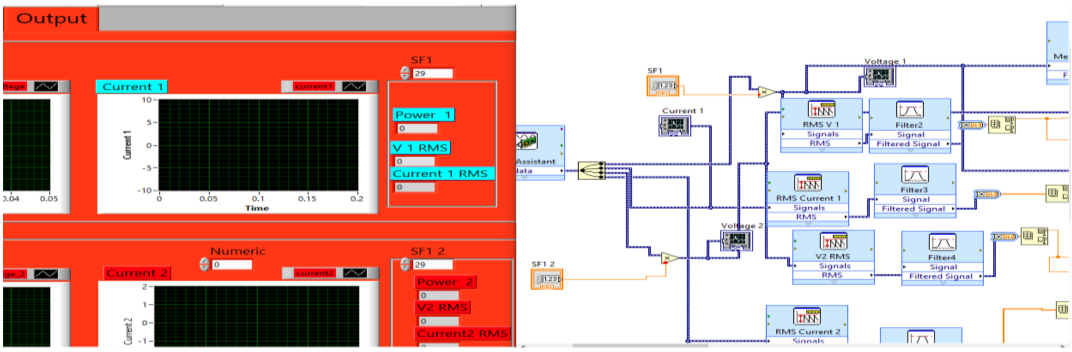

Figure 3 Preprocessing of Smart Meter Parameters

3.2.3 Fault detection

Through monitoring, fault detection, and diagnostics, FDD aims to reduce risk and enhance operations. Fault detection, fault isolation, fault identification, and fault evaluation are the four fundamental stages of FDD's core methodology. Automated Fault Detection and Diagnostics, or AFDD, has recently gained popularity. In general, FDD is used to refer to the process, whereas AFDD is used to refer to the technologies that are used to conduct FDD procedures. As a result, an AFDD tool can carry out automated FDD with as little human interaction as feasible.[17]. Meter tampering, bypassing meters, and tapping power lines are all examples of power theft. Tapping into neighboring premises, using illegal lines after disconnection, self-reconnection without consent, and electrifying fences are some of the less common crimes. There are several types of electricity power theft, each relating to a different aspect of the electrical system, such as meters, cables, and overhead lines. Furthermore, using service connections for purposes other than those authorized falls under the category of theft. This project will guard against power line tampering [18].

- *The issue of overbilling* continues to plague electricity users. Discos continue to manipulate electricity units to control their substantially larger distribution losses." It also highlights the retail electricity sellers' incapacity to reduce transmission and dispatch losses, which is one of the primary causes of consumer overcharging. Another factor for overbilling is the distribution companies' failure to completely collect their costs. Discos have been allowed to use revenue-based blackouts in high-loss areas instead of improving their recovery ratios [19].
- *The circuit is broken*. If a fault in an appliance causes too much current to flow, the fuse will blow, and the circuit will be broken. If something goes wrong, this protects the wiring and the appliance. A piece of wire that melts easily is contained within the fuse. If the fuse's current is too high, the wire heats up until it melts, and the circuit is broken.
- *Mistakes in calibration* Instrument technicians must be able to identify and correct instrument calibration errors quickly and accurately. Routine calibration consumes the majority of the time for some technicians, particularly those who work in industries where calibration accuracy is required by law. While calibration may be a one-time task

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for some technicians, these technicians must be able to quickly diagnose calibration errors when they cause problems in instrumented systems. This section discusses common instrument calibration errors and the procedures for detecting and correcting them.

- *Subassembly* A standard subassembly of components that can be readily plugged into or pulled out of and no failure occur throughout the full life of the subassembly.
- *Subassembly malfunction* defects account for a large number of reliability issues in many systems. Defects in a system due to any reason like change in the product change. Fault detection method for making it possible Use this technique from the beginning of the product development process to help designers avoid specific subassembly malfunctioning quality difficulties.
- Function and principles of the sub-assembly malfunction are obtained by using equipment manuals, simulation on LabVIEW, and other sources. The sub-assembly fault is monitored and analyzed with the proper testing equipment to detect and diagnose the fault. Created test functions are used, as well as fault indicator error codes and relevant maintenance records.

3.2.3.1 Overvoltage

When the voltage in a circuit or part of it is raised above its upper desired limit, this is known as overvoltage. Similarly, under-voltage in a circuit or part of it is below its upper desired limit, this is known as Undervoltage.

The actual voltage which is to be received from meter 1 and meter 2 is to be measured to check for over voltage or under voltage so that faults arising from overvoltage or under voltage can be detected. Since a three-phase meter is used so expected voltage should be 250 volts. A limit of 10 volts has been applied to the expected voltage, meaning that voltage can either increase by 10 volts and can be 260 volts maximum, or it can decrease by 10 volts being a minimum of 240 volts. If the actual voltage is lie in within the limit the volts will ok. This refers to the conclusion that if the actual voltage exceeds 260, from the expected voltage then there is over-voltage, and if it goes below 240, then there is under voltage of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in fig 4.

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Power System Technology
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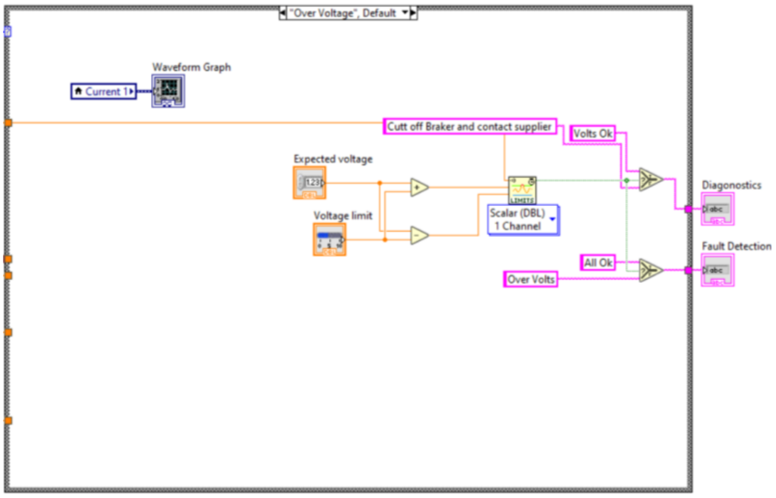

Figure 4 Over Voltage Block in Labview

3.2.3.2 Overbilling

If the bill received from the supplier is greater than an estimated bill, then it is regarded as overbilling Expected bill can be calculated by using this formula

$$bill = (normal\ unit * per\ unit\ price) + (peak\ hour\ unit * per\ unit\ price) \tag{i}$$

$$GST=(bill*17)/100 \tag{.ii}$$

$$Estimated\ Bill= Bill + GST \tag{iii}$$

$$Limit= (expected\ bill*Tolerance)/100 \qquad where\ tolerance=5\% \tag{iv}$$

$$Upper\ limit= Estimated\ bill + limit \tag{v}$$

$$Lower\ limit= Estimated\ bill-limit \tag{vi}$$

The expected bill is calculated by taking the units consumed times the rate specified for consumption. If the bill received from the supplier is less than the upper limit and greater than the lower limit then the bill is ok, there is no issue of overbilling. Beyond these limits, there is a fault of over/under billing. As shown in fig 5.

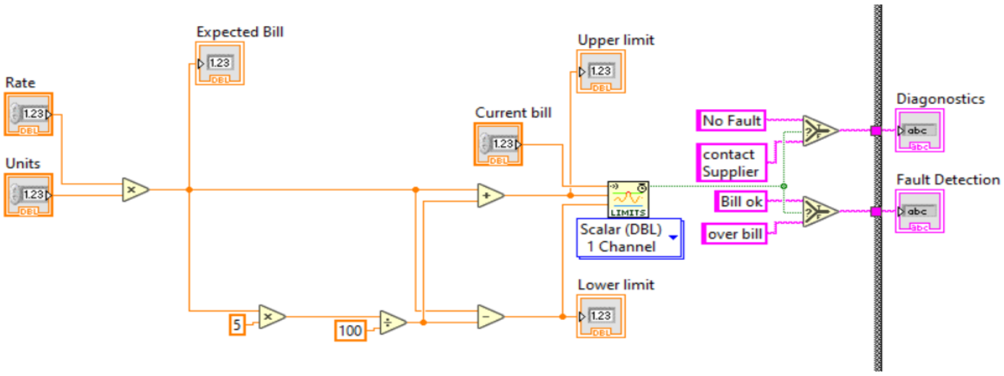

Figure 5 Over Billing

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

3.2.3.3 Power Failure

Power failure is a period when the electricity supply to a building or area is interrupted (cut off). If the main supply is off, then both the actual and backup meter will show zero volts. This is because of the logic used that at both the actual and backup meter when voltage is less than 10, the meters will show zero volts. When zero volts are shown, this means the condition is TRUE, hence, there will be fault detection leading to power failure. As shown in fig 6.

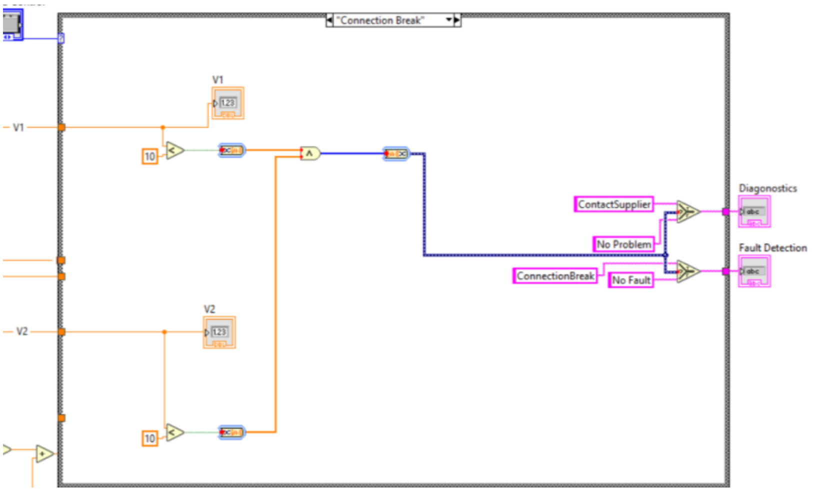

Figure 6 Power Failure

3.2.3.4 Power theft

Power theft occurs when individuals tamper with electric service by trying to bypass the electric meter at the service panel. It is a criminal practice of stealing electrical power. The situation of electricity in Pakistan has been alarming for escaping huge amounts of electricity bills, the consumers commit illegal and unethical connections. A load estimator is used for calculating the load generated from the usage of different electric appliances used in the house. Two meters are set up parallel, which divides the load. Power from meter 1 is named P1 and power from meter 2 is named P2. The sum of P1 and P2 will be the actual power and it should be equal to the estimated load. A load limit of 50 is applied to the estimated load, meaning that the load can vary (increase or decrease) by a maximum of 50. If actual power is within the limit, then there is no power theft. If actual power is more than the estimated load, then fault for "power theft" will be detected as shown in fig 7.

Power System Technology
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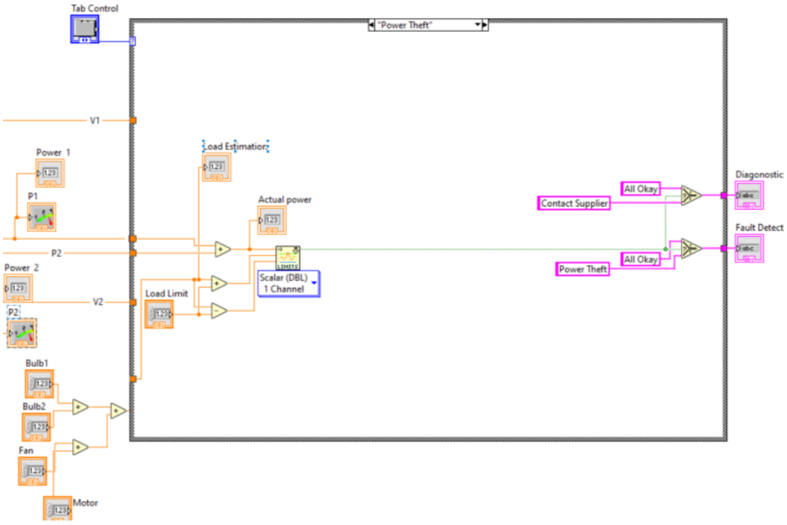

Figure 7 Power Theft

4. Results and Discussion

All types of electronic sensors and smart modules are tested in phase 1 for smart meter fault detection and diagnostic system. The Ni DAQ Card is attached to the laptop and the current Transformer, from which it receives data and information. The working of the meter's module is evaluated using LabVIEW simulation. The data is shown on the meters' LCD screens and in LabVIEW software.

In phase 2, the working performance of meters one and two are evaluated. A primary meter and a backup meter are utilized, and they are connected to the current transformer module, the load, and the DAQ card. For simulations, both meters use LabVIEW software to receive data from the meters via the DAQ Card and turn on/off the main supply. While turning the relevant main supply On and Off, it is verified that the DAQ Card is acquiring data. as well as turning on and off the linked equipment the information is shown on the meter's LCD and the laptop's screen.

4.1.1 Voltage altering

If the actual voltage is lie in within the limit the volts will ok. This refers to the conclusion that if the actual voltage exceeds 240, from the expected voltage then there is over-voltage, and if it goes below 220, then there is under voltage of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in table 2.

Table 1 Alteration of Voltage

The voltage on meter 1	235
Voltage on meter 2	234
Tolerance	10
Expected voltage	230
Final result	Voltage is OK

If the actual voltage is lie in within the limit of the volts, then it is the fault of over/under voltage. This refers to the conclusion that if the actual voltage exceeds 240, from the expected voltage then there is over-voltage, and if it goes below 220, then there is under voltage of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in Table 3.

Table 2 Alteration of Voltage (Under Voltage)

the voltage on meter 1	250
Voltage on meter 2	247
Tolerance	10
Limits of meter 1	(240-260)
Limits of meter 2	(237-257)
Expected voltage	230
Final result	It is the fault of over/under voltage

4.1.2 Billing

If an actual bill is lie in within the limit of the bill, then it is no fault. This refers to the conclusion that if the actual bill exceeds 2470, from the expected voltage then there is overbilling, and if it goes below the limit, then there is underbilling of meter 1 and meter 2. The system detects the fault and diagnoses it accordingly.As shown in table 4.

Table 3 No-Fault Billing

Bill from supplier	2500
Expected bill	2470
Tolerance	5%
Upper limit	2590
Lower limit	2590
Final result	No-fault

4.1.3 Calibration

If the actual voltage is lie in within the limit the calibration will ok. This refers to the conclusion that if the actual voltage exceeds 240, from the expected voltage then there is a calibration error of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in table 2.

Table 4 Calibration Table

The voltage on meter 1	250
Voltage on meter 2	247
Tolerance	10
Limits of meter 1	(240-260)

Power System Technology
ISSN:1000-3673

Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

Limits of meter 2	(237-257)
Reference voltage	230
Fault detection	YES
Final result	Calibration is okay

4.1.4 Power failure

If actual power is lie in within the limit the power failure will ok. This refers to the conclusion that if actual power exceeds 240, from the expected voltage then there is a power failure of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in table 6.

Table 5 Power Failure Table

the voltage on meter 1	250
Voltage on meter 2	247
Tolerance	10
Limits of meter 1	(240-260)
Limits of meter 2	(237-257)
Expected voltage	230
Fault detection	NO
Final result	No Faults

If actual power is lie in within the limit the power failure will ok. This refers to the conclusion that if actual power exceeds 240, from the expected voltage then there is a power failure of meter 1 and meter. The system detects the fault and diagnoses it accordingly. As shown in table 2.

Table 7 Power Failure Table

The voltage on meter 1	0V
Voltage on meter 2	0V
Tolerance	10
Limits of meter 1	(240-260)
Limits of meter 2	(237-257)
Fault detection	YES
Final result	Power Failure

4.1.5 Subassembly Failure

Table 8 Sub Assembly Failure

the voltage on meter 1	0V
Voltage on meter 2	247V
Tolerance	10

Limits of meter 1	0
Limits of meter 2	(237-257)
Expected voltage	230
Fault detection	YES
Final result	Subassembly Failure

4.1.6 *Subassembly Malfunction*

Total harmonic distortion (THD) and specific harmonics are calculated. If THD is greater than 2000 then there is no fault of malfunction but if THD is lesser than 2000 then it detects the fault of malfunction

Table 9 Sub Assembly Malfunction

Total harmonics distortion	4700
If THD	>2000
Specific harmonics	2230
Fault detection	NO
Final result	No fault for subassembly malfunction

The entire system is verified and tested in the final phase to achieve the desired end output. All of the devices are interconnected together, and data is transmitted using LabVIEW software. On the PC/Laptop, defect detection is presented.

5. CONCLUSIONS

The Fault Detection and Diagnostic System for Smart Meter were designed with better performance and results. The main purpose of this project is to design a fault diagnostic system that can help consumers to understand and diagnose common faults. The research focuses on the development of a system that will allow consumers/users to detect common faults in smart meters and self-diagnose the cause of these faults. Because of its low cost, the convenience of real-time operation, simplicity of payment and fault detection, removal of human involvement, and ease of monitoring the entire process from a remote place, this is a very remarkable contribution. In this way, a user can self-diagnose the cause of these faults without any effort. The experimental results are conducted 100 percent accurately. The data will be acquired and analyzed first by the system. Then fault will be identified using mathematical models, fault detection logic, and Artificial Intelligence (AI) techniques will be taken utilizing modern control approaches such as defect identification diagnostic operation and state estimators are used.

The system will be equipped with malfunction monitoring capabilities to detect upcoming failures and predict their impact on the system's future behavior utilizing fault diagnosis methodologies. This will not only enable consumers in reducing downtime on the premises, but it will also raise awareness and understanding of electrical system malfunctions and failures. This project is extremely simple and straightforward. It is simple to know and learn in

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a short period. This defect detection system is also extensible and adaptive. This system can also be used in industries and office buildings.

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