DESIGN AND ANALYSIS OF LOW VOLTAGE SMART FEEDER PROTECTION USING PHOTOMOS AND PROFICIENT MONITORING MODEL OF REAL-TIME IoT APPLICATIONS

Thesis submitted for the fulfillment of requirements for the degree of

MASTER OF SCIENCE

in

Electronic Engineering

by

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DESIGN AND ANALYSIS OF LOW VOLTAGE SMART FEEDER PROTECTION USING PHOTOMOS AND PROFICIENT MONITORING MODEL OF REAL-TIME IoT APPLICATIONS

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As the candidate's supervisor, I have approved this thesis for submission.

Signed:- Date: 13 April 2021

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DECLARATION 1 – PLAGIARISM

I, **AKSHAY KUMAR** with Student Number **220105907** with the thesis entitled **“DESIGN AND ANALYSIS OF LOW VOLTAGE SMART FEEDER PROTECTION USING PHOTOMOS AND PROFICIENT MONITORING MODEL OF REAL-TIME IOT APPLICATIONS”** hereby solely declare that:

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DECLARATION 2 - PUBLICATIONS

Details of contribution to publications that form part and/or include research presented in this thesis (include publications that have been submitted, *in the press* and published and give details of the contributions of each author to the experimental work and writing of each publication).

LIST OF PUBLICATIONS

1. **Akshay Kumar and Viranjay M. Srivastava,** "Proficient model of monitoring and controlling of low voltage distribution smart feeder protection system using IoT application," ***International Journal of Advanced Trends in Computer Science and Engineering*** *(IJATCSE)***,** vol. 9, no. 5, October 2020 (Included in Chapter 5).

   [DoHET, SCOPUS]

2. **Akshay Kumar and Viranjay M. Srivastava,** "An efficient model for low voltage distribution smart feeder overcurrent protection system using microcontroller," ***IOP 1st Int. Ninevah Conf. on Engineering and Technology*** *(INCET 2021)*, Mosul, Iraq, 5-6 April 2021 (Included in Chapter 4).

   [DoHET, SCOPUS]

3. **Akshay Kumar and Viranjay M. Srivastava,** "A new age model of feeder protection system using fast switching PhotoMOS relay," ***11th Int. Conf. on Computing, Communication and Networking Technologies (ICCCNT),*** India, 1 – 3 July 2020, pp. 1-4 (Included in Chapter 3). ***[IEEE Xplore]***

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ABSTRACT

The feeder system, being an intermediary element for the distribution of power to the regional transformer, protects against the occurrence of any fault, becomes a requirement in the power systems. A Smart feeder is a rising energy distribution framework that is implanted with the combination of various types of energy distribution sources (e.g. sustainable power sources, consolidated heat, power, etc.) and dispersed energy resources. The advantages of smart feeder arrangement are low transmission, high dependability, high effectiveness, and low natural effect. Additionally, the management of the electrical feeder system is gradually troublesome. The power system protection devices are used to avoid such developing fault conditions. The relay circuits serve as the fundamental part of feeder protection systems. They are responsible for controlling the overload voltage and current to ensure device safety. The absence of data at the base feeder, the electricity administration network's status, has been distinguished as the significant obstruction to its successful monitoring and control of the electrical distribution system.

In this research work (thesis), a novel model for feeder protection systems has been proposed to monitor, control, and incorporate the enhanced switching characteristics of PhotoMOS solid-state relay. The used PhotoMOS relay is operating at cut-off time 1.2 ms, 1.3 ms, and 1.4 ms with respect to the overcurrent value 0.8 mA, 1.0 mA, and 1.2 mA, respectively, which is significantly less than the EMR protection system. The significant switching time for the open-circuit and closed-circuit operations was obtained using the PhotoMOS device, which resulted in switching time ratios (T_{OFF}/T_{ON}) 0.03 and 0.06, respectively. A 220 V electricity network was utilized to test the reliability and quality of the microcontroller-based PhotoMOS circuit. The result shows the considerable gain in the operational switching time parameter using the PhotoMOS device over the conventional Electro-Mechanical (EM) relays. The obtained results also assure that the PhotoMOS is a functional relay circuit element and makes it suitable for the Internet of Things (IoT) applications.

At the later stage, this research work also presents an advancement of the IoT based monitoring and controlling of various parameters (as Voltage, Current, and Temperature)

of the Low Voltage (LV) smart feeder system. The framework acknowledged continuous observation of feeder system operational devices and working conditions, information knowledge examination, alert linkage, and visual showcase. It helps in backing to feeder operation, and maintenance improved the activity and the intelligent smart feeder's management level. The arrangement of IoT technologies in a smart feeder system would revive the smart feeder improvement and redesign the power movement organizations getting progressively lively, engaging, responsive, and open.

Finally, a software system has been developed to show the feeder system's live monitoring, and in any fault, the case system can send an alert signal. Overall, in this research work, a smart feeder protection system has been proposed with the IoT based monitoring and controlling of Voltage, Current, and Temperature (V, I, and T) of the system.

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LIST OF SYMBOLS

Torque	s
Angle	θ
Angular Frequency	ω
Damping Factor	K_d
Conductivity	σ
Applied current	I
Current value when LED illuminates	I_p
Diameter	D,d
Efficiency	η
Gigahertz	GHz
Kilo	K
Millimeter	mm
Resistance	Ω
Speed of light 3x 10^{-8} m/s	c

LIST OF ABBREVIATIONS

Solid State Relays	SSR
Internet of Thing	IoT
Double Negative	DNG
Double Positive	DPS
Electric Field	E
Smart Feeder	SF
Electromagnetic	EM
Smart Grid	SG
Programmable Logic Unit	PLU
Microcontroller Unit	MU
Photovoltaic Cells	PVC
Photovoltaic Effects	PVE
Inductor, Capacitor	LC
Magnetic Field	M
Network Absorber	NA
PhotoMOS Relay	PMR
Low Voltage	LV
Medium Voltage	MV
Signal Absorber	SA
Solid-State Devices	SSD
Home Area Network	HAN
Local Area Network	LAN
Information and Communication Technologies	ICT
Supervisory Control and Data Acquisition	SCDA
Remote Terminal Unit	RTU
Public View Monitor	PVM
Multi-Point Injection	MPI
Compute Unified Device Architecture	CUDA

Chapter-1

INTRODUCTION

This thesis investigates the design and analysis of low voltage smart feeder protection using PhotoMOS relay fast switching and proficient monitoring model of smart feeder using real time IoT applications. In this segment of the thesis, the research foundation, presentation, and introduction have been discussed. Additionally, the segment likewise contains the research objectives, problem statement, methodology, scope of research work, motivation, the contribution of the thesis, and outlines of the thesis.

1.1 Research Background

A critical challenge in modern days is to transmit the generated electricity from generation to consumers without any interruption or loss and monitoring of their equipment. Electricity generation comprises different fragments (generation, transmission, and distribution) from producing stations to the point of associations of various voltage levels. Further, contingent on the voltage range, customers have been given the name as the voltage they have devoured low voltage (400/230V), medium voltage (11kV/33kV/66kV), and high voltage (132kV or more) users. Power generation stations generate the electricity, and the combination of transmission and distribution lines transmit that power from generator stations to the sub-stations, feeders, and end-use users, as shown in Fig. 1.1. A smart feeder is a developing power distribution network embedded with a blend of different kinds of energy distribution sources, as sustainable energy sources, united heat and power, and scattered energy assets. The term 'smart feeder' alludes to a class of advances that are being made and utilized by utilities to pass on electrical frameworks into the 21st century combining IoT (Internet of Things) and Computer-based remote control and automation. The smart feeder system, being an intermediary component for the distribution of energy to the local transformer, protects against the event of any fault, turns into a necessity in the power systems [1]. A novel study and model for feeder protection systems have been proposed to monitor, control, and incorporate the enhanced switching characteristics of PhotoMOS solid-state relay, which is connected with a microcontroller for continuous observation of the system the help of IoT systems.

Smart feeder system performance and constant electricity distribution to the consumers are some of the significant problems nowadays. Therefore, fast safety and protection plans must be effective enough to conquer issues within a short period. Fault occurrence has to be detected rapidly by the distribution framework and promptly separated the forestall risks to overall public and utility staff [2-4].

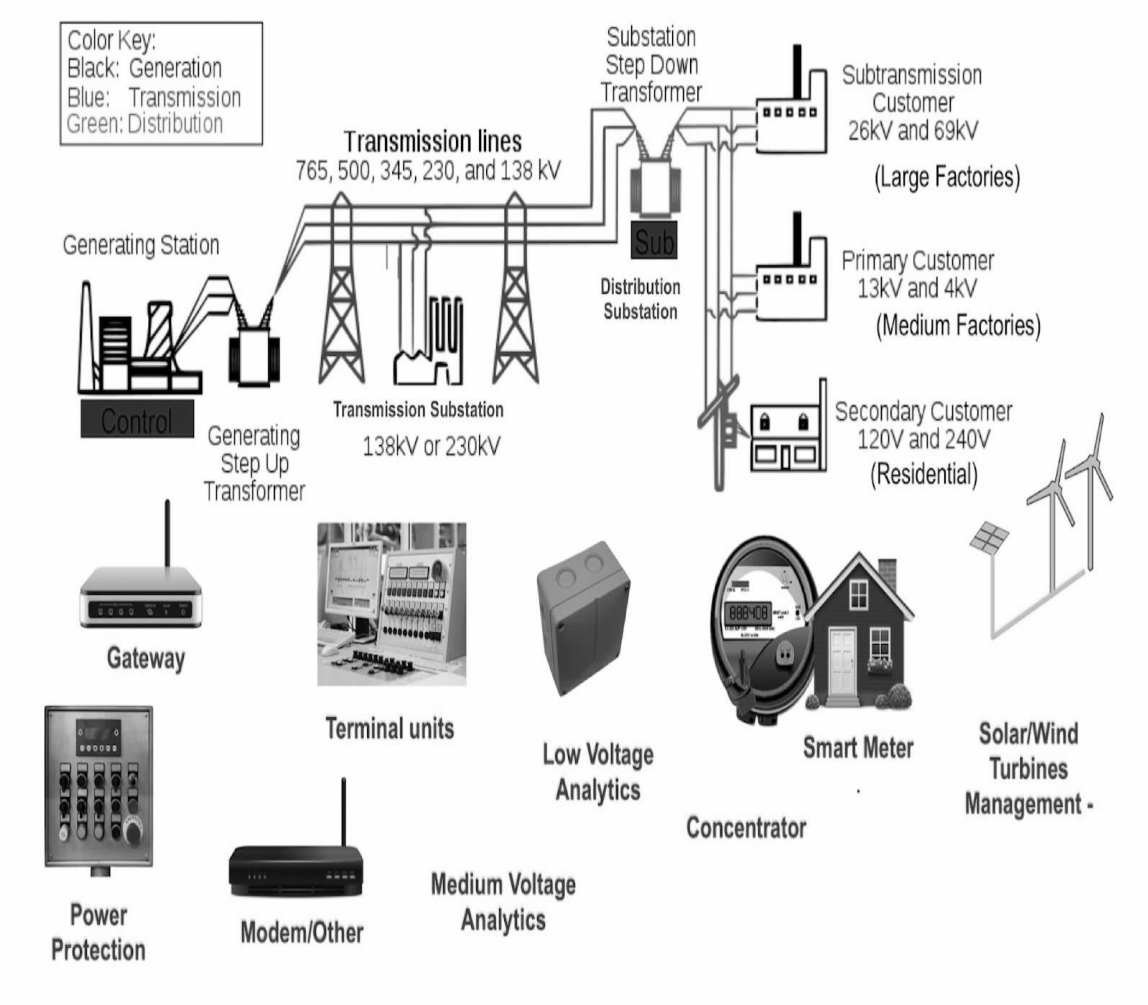

Fig. 1.1 Power Distribution Network and Components [3].

The absence of data at the base feeder, the electricity administration network's status, has been distinguished as the significant obstruction to its successful monitoring and control of the electrical distribution system. To tackle the issues in the current smart feeder controlling, monitoring, utilizing the IoT innovations, present-day communication, and data handling of smart feeder controlling and monitoring framework dependent on energy system IoT. The software system has been developed to show the feeder system's live monitoring, and in any fault, the case system can send an alert signal [5]. This research work presents an advancement of the Internet of Thing (IoT) based monitoring and controlling (Voltage, Current, and Temperature) of the LV Smart Feeder system.

1.2 Problem Statement

There has been a significant gap between electricity generation and its continuously increasing demand. The absence of data at the base distribution feeder, the electricity administration network's status, has been distinguished as a significant obstruction to its successful monitoring and control of the electrical distribution system. The continuous real-time observation and fast protection of the base feeder is the necessity of the distribution. We planned and achieved a smart feeder controlling and monitoring framework dependent on the energy to handle the issues in the current smart feeder controlling, monitoring, utilizing the IoT innovations, fast switching PhotoMOS, present-day communication, and data handling of the IoT system [6]. The developed framework should acknowledge continuous observation of feeder system devices and working conditions, information knowledge examination, alert linkage, and visual showcase. It gave help backing to feeder operation and maintenance improved the activity and the management level of the intelligent smart feeder [7]. The arrangement of IoT technologies in a smart feeder system would revive the smart feeder improvement and redesign the power movement organizations getting progressively lively, engaging, responsive, and open.

1.3 Research Objective

This study aims to investigate and address the problems related to the smart feeder system data monitoring and fast protection from fault occurrence. With this research objective, a model has been developed for Smart Feeder protection to live to monitor and to control of Voltage, Current, and Temperature with microcontroller-based IoT systems. For better control and protection, fast switching solid-state relay (PhotoMOS) has been introduced in the protection system. The implementation of microcontroller and PhotoMOS relay has been developed in this research work. The software system has been developed to show the live monitoring of the feeder system, and in any fault, the case system is able to send an alert signal. This research is focused on Low Voltage (LV) smart feeder systems. It is envisaged that this research will significantly impact the improvement of power delivery in LV smart feeder networks.

1.4 Methodology

Because of the research idea, it is begun by inspecting reviewing literature with electricity distribution and unwavering quality issues. The data gathered from the fieldwork is then dissected. For the assessment of the system, power simulation programming is used to develop the IoT monitoring system. For the most part, the accompanying methodology is followed in leading this thesis work, site visit, specialized information assortment at chose feeder investigation of intensity dissemination issues and unwavering quality issues for power circulation frameworks, design of smart feeder system, dissecting the financial practicality of the planned framework, system design of the dependability upgrades of the developed system.

1.5 Scope of the Research Work

Smart Feeder innovation enables the proper administration and conveyance of manageable energy sources like sun, wind, and hydrogen. Electric feeder configuration provides renewable green energy while living on the earth's green life, which is capable of energy feeder conveyance. Smart feeder offers two-route communications between the individual consumer and energy providers with the help of IoT applications [8]. Along these lines, consumers can decide their energy utilization and deal with their financial plan likewise. Moreover, it encourages every consumer to check out energy grid exercises to diminish their capacity bills. This system can be utilized from slanted house-top foundations to level roof tilt-up bunches and building composed models. Possible results for business sunlight based power generation are moved and into different areas of power generations. Associations taking an interest in the sun-oriented influence-based example have the uncommon prize of providing the energy for cash as credits and reserve funds.

With real-time monitoring and PhotoMOS, the relay protection system smart feeder can recognize specific frameworks over-loads and rerouting the energy grid to limit expected power outages or stay away from potential energy unsettling influence in the areas [9]. Smart feeders can fundamentally recognize manageable energy sources from natural resources like air, water, and sun, just as joining alternative power stockpiling innovations.

1.6 Motivation

The study's motivation is to give network detectability, controllability of advantages, update energy structure implementation, and safety of the system, the massive decline in work, construction cost, backing, and system controls. Objectives are clear and appropriately surveyed. The primary motivation of the smart feeders is providing the best service to each consumer with the privacy, safety, security effectively accessible, minimum budget, machine to machine data transmission line up, outsider alliance and so on this will consider the overall endeavors to be various of equipment's and planning to pass on assurance to electrical feeder benefits. Feeders are amazingly extensive and entrapped thought that can be continuously compelling when intentionally changed and deliberately planned. They dedicated authority of the most raised solicitation can convey clearness and consent to the various points of view that will add to smart feeder system accomplishments are;

- To suit a wide arrangement old enough united and scattered, intermittent and dispatchable,
- To talk with essentialness the master's system in splendid structures,
- To enable customers to manage their imperativeness use and lessening their imperativeness budget, provide better power standard to every customer, provide continuous information, with minimum movement costs, & power availability, to everyone,
- Use of information in the development of monitoring & controlling to propel operation cost, envision and rapidly respond to structural issues with respect to protect the system against any fault situation and better energy issues [10],
- To make world imperativeness self-governing, to give business, Smart feeders are felt in need to be only for the compromise to flowed generation, economical energy resources and developed (cream) automobiles in energy cross-section yet to be furthermore for active help to the customers in redesigns for as a rule system capability, fulfill the zenith need without enthusiasm for age and variable esteeming structure.
- The present moment and long haul, preferences, and goals get suitable weighting.

Various parts in the electrical feeder framework are implemented in a solicitation that coordinates the energy requirements. The electrical feeder system has a better haul and prior information that solitary specialists will not be covert [11]. The Timing diagrams of utilization & a bit of leeway affirmation are viable.

1.7 Contribution of the Thesis

This thesis contributes to the design and analysis of a low voltage smart feeder protection using PhotoMOS relay fast switching and effective monitoring model of smart feeder using real time IoT applications. The extensive smart feeders are not merely adjusting brilliantly within system requirements and solicitations in the present scenario, smart feeder is very likely way anticipated to will have reliable effects. For example, new technology is overhauling equipment and upgrading the system for the required fast speed. The updation will be helpful within the diminishing probability of power outages, fire incidents, and overvoltage. The developed protection and controlling model can be used in LV feeder locations for easy monitoring and protect the system from any fault conditions. With the development of smart feeder systems, expenses in imperativeness usage and production will be significantly less. Within the maximum utilization of the developed model, the electrical feeder structure shall produce unlimited power conceivable and implement a system that can satisfy broadening electricity requirements. Even adding fundamentally, that as it might, the advancement will give consumers near-continuous controlling the equipment's, essentialness expenses and support immense degree EVs charging points in the near future. In any case, the rigid smart device and renewables sources to provide in neighborhood power generation were very essentially can save up to 1.4% [12]. Within the essential obligation for sensible power resources, the world may maintain a strategic distance from the nation's significant emergency at present gone facing. Authors need to organize sensible power resources with the power structure as a competent, expenses plan, authors should re-examine and plan our essentialness system. Smart electrical feeder, or intelligent system, will be the leading segment in magnificent energy infrastructure change [13]. The benefit of monitoring and controlling allocation with the development shall empower families and spare the immediate billings and spare sum. By providing persevering data in energy utilization, this progression shall oblige buyers to reduce expenses & power by more than 5 % to 10 % [14]. Exploration has shown that whenever clients or consumers know precisely the exact quantity of the energy, they shall consistently utilize it to take measures to diminish their power utilization. This system will be a topic of research for more IoT applications.

1.8 Outlines of Thesis

This thesis has been organised as follows:

Chapter 1 introduces the research background, motivation, problem statement, objective of the study, methodology, scope, and main contributions of the research work. In addition, it provides an outline of the smart grid and components, key benefits, objectives, and scope. This section also includes a list of publications related to the research work.

Chapter 2 describes the literature reviews general aspects of LV smart feeder protection, solid-state relay (PhotoMOS) protection devices, and IoT monitoring of the system.

Chapter 3 presents the analysis of solid-state relay (PhotoMOS based relay), construction, working model, sectional diagram, fast switching characteristics, PhotoMOS protection system for the latch, and non-latch type for the efficient model in Feeder Protection.

Chapter 4 presents the proposed LV distribution model, working, design, simulation, relay timing calculation, relay interfacing and control, Interfacing SSR with a microcontroller, microcontroller protection, and algorithm for the microcontroller, relay cut-off time characteristics for smart feeder overcurrent protection system.

Chapter 5 presents the developed IoT model, implementation, architecture, microcontroller and IoT aspects, hardware, software implementation, live monitoring, and alert system with Feeder Protection applications.

Chapter 6 presents the results of this work, the conclusion, and future aspects of this research work.

1.9 List of Publications

1. **Akshay Kumar and Viranjay M. Srivastava,** "Proficient model of monitoring and controlling of low voltage distribution smart feeder protection system using IoT application," ***International Journal of Advanced Trends in Computer Science and Engineering*** *(IJATCSE)***,** vol. 9, no. 5, October 2020 (Included in Chapter 5).

   [DoHET, SCOPUS]

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Chapter-2

LITERATURE REVIEW

This part of the thesis covers the extensive relevant literature review. It provides a brief understanding of the concept of the smart feeder system, relays (EMRs and SSRs), microcontrollers, IoT (Internet of Things) monitoring, controlling, its impact on the distribution systems, and work done around the analysis of this impact.

2.1 Smart Feeders

In the 21^{st} century, the implementation of IoT applications and computer-based controllers and automation is necessary for the power distribution infrastructure. A smart feeder is an intensifying energy distribution framework that is implanted with the combination of various types of energy distribution sources (e.g. sustainable power sources, consolidated heat, power, etc.) and dispersed energy resources. The advantages of smart feeder arrangement are low transmission, high dependability, high effectiveness, and low natural effect. Electrical feeders are energy distribution system which smartly joins and provides energy distribution to all the connected consumers and also connect the power generator, buyers, & also capably pass on sensible, financial, and ensure about energy supplies as appeared in Fig. 2.1. The term 'smart feeder' insinuates a category for innovations that can be made and implemented for the advantages to pass on to the energy infrastructure [15].

A smart feeder as shown in Fig. 2.1 utilizes innovative advances and organizations along with continuous monitoring, controlling, machine to machine (two-way) communication, and self-data recovering improvements as well: Greater administration of all the associated devices and working of all the equipment with essentialness, provides users more other options so they can help with impelling power use, outfit customers with progressively basic data and the decision of energy supply, by and large, reduce the biological effect of the entire power distribution system, pass on refreshed degrees of unflinching standard & safety to the distribution supply [16]. Feeders technology should be effective for turns of innovations, market and business opportunities, biological effect, definitive structure, normalization, ICT (Information and Communication Technologies), and advancement strategies. That degree of progress is recognized to upgrade the trustworthiness, adaptability, pliability, and ability of the electrical distribution system [17].

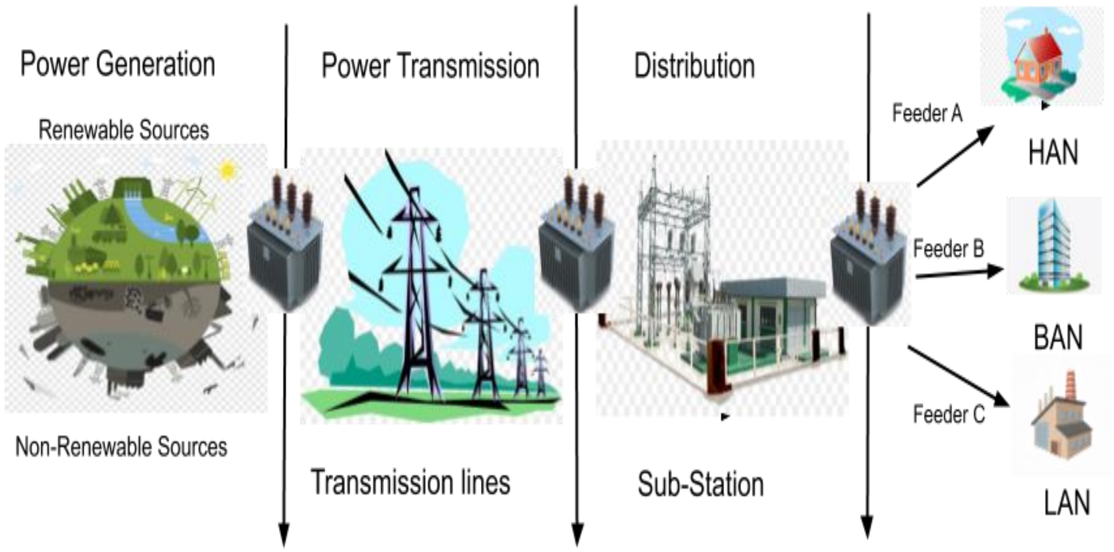


Fig. 2.1 LV Distribution feeder sectional diagram.

2.2 Smart Feeder Visions and Objectives

The introduction of smart feeder development is a key enabling impact to achieve the developed distributing power. Concerning administration distribution, innovation is advancing the usage of incorporated structures and systems in the city condition, thusly advancing efficiencies and ampleness never found in the metropolitan condition. Vision and objectives of smart feeders as follows: -

- Changing and all the additionally increasing consumers demands,
- The distribution of energy will be Secure forever,
- Transformed (appropriated) power distribution and all the more progressively feasible energy distribution,
- Economical structure prepared to backing monetary developments and quick innovation headways,
- Machine to Machine, IoT, and Computer-based controlling and mechanization.

2.3 Feeder Equipment's

Electrical feeders have a wide degree of technologically advanced equipment for better monitoring and controlling of the system. A feeder cannot call smart if feeder does not have smart equipment. Thus, the progressions should also execute closely by the feeder and shall exceptionally valuable in conquering faults conditions. There are some segments utilized in the energy feeder presented in the following sections.

2.3.1 Substations and Feeders

The substation digitalization is getting attention these days with the help of IoT devices, Supervisory Control and Data Acquisition (SCADA), Information and Communication Technologies (ICT), Remote Terminal Unit (RTU), and Microcontroller based systems, and these advancements applicable for the world [18]. Later on, the microprocessor and Microcontroller based relay (SSR (Solid State Relay) & PhotoMOS) circuit has been introduced at the control system of the substation for better efficiency and monitoring.

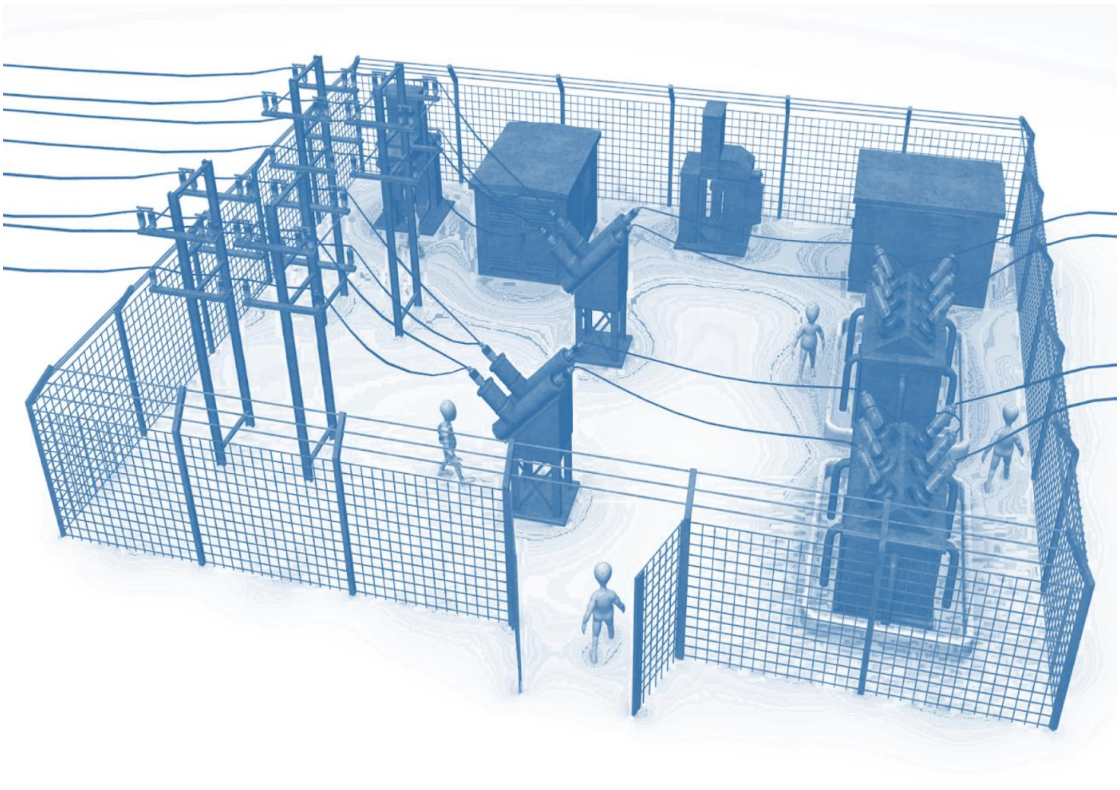


Fig. 2.2 Smart electrical substation [8].

The substation includes watching fundamental and nonessential operating data management, and so on appeared in Fig. 2.2. The substation is also utilized for the variable voltage and current at express functions for various sections, feeders, and areas. It is providing the end consumers to purchase with strong, convincing, and safe electrical power. It is also committed to isolating the power stream technique into a couple of directions [19]. The motivation of this advancement in the substation software & hardware also system equipment’s to work properly and continues observation of all the hardware and software part of the substation.

2.3.2 Solid State Devices

Solid-state devices are those in which power moves through semiconductor precious crystals (Silicon, Gallium, Arsenide, and Germanium) instead of through vacuum tubes. The primary device was the "cat's whisker" (1906), in which a fine wire was moved over a crystal to distinguish a radio sign. Transistors made of at least one semiconductor, are at the core of current solid-state devices; on account of incorporated circuits, a great many transistors, MOSFET can be included. Solid-state devices get their name from the way that electrical signs take through strong bits of semiconductor material [20] Fig. 2.3. Preceding the utilization of the SSD, for example, the basic semiconductor, the power went through the different components within a warmed vacuum tube.

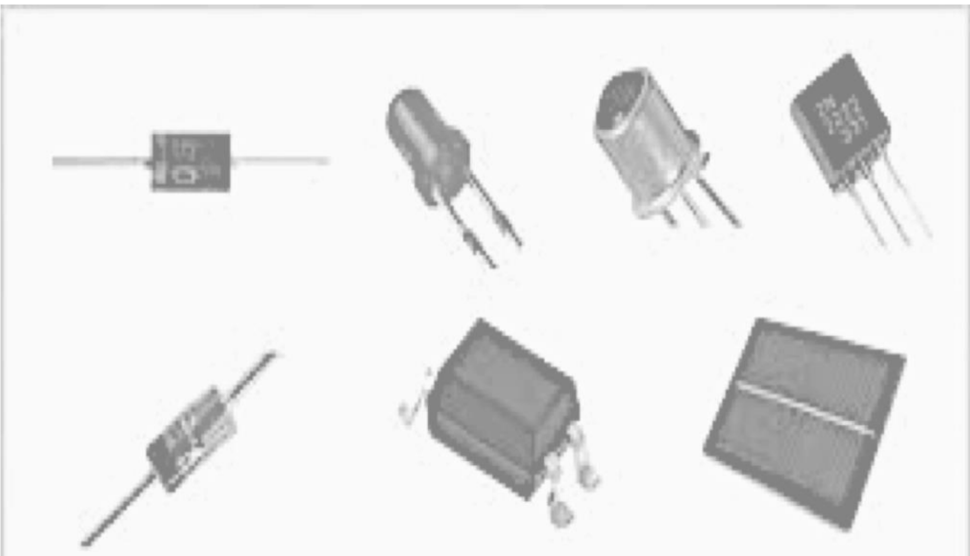


Fig. 2.3 Solid-State devices [24].

The Solid-State Devices (SSD), for example, a transistor, uses conductors to control the progression of signs through a circuit. In a semiconductor intensifier, a little change on the information sign's playfulness is promptly reflected in bigger adequacy in the yield inside a semiconductor [21]. In the sandwich-like development of a transistor, the emitter, base, and authority do a comparative undertaking at much lower DC voltages, with no "warm-up" time. In advanced circuits, an incorporated circuit chip isn't anything more than an assortment of transistors and wires that snare them together. For faster switching capacities and easy operations, SSD has been used in smart feeder systems as relays and circuit breakers to protect the system from fault situations.

2.3.3 Smart Feeder Communications

Supervisory Control And Data Acquisition (SCADA), Programmable Logic Controller (PLC), Microcontrollers, IoT devices, PLC, and Machine to Machine (M-2-M) communications are the necessities of the electrical feeder system for the communications as shown in Fig. 2.4.

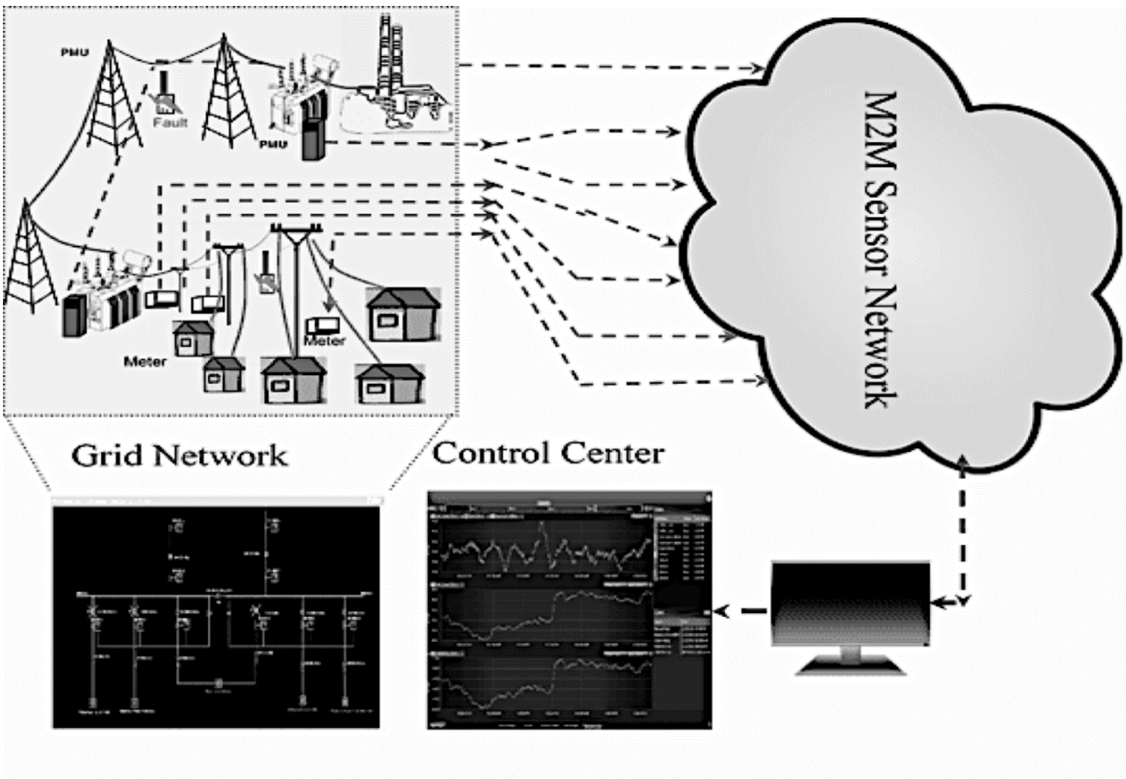


Fig. 2.4 Smart grid M2M Communication [11]

In the feeder system arrangements, a big part of the system has been used to monitor the power outage and administer the fault situation. These days Phasor Measurements Units (PMU) demand is growing increasingly, the system operations are moving towards a wide range of dynamics. As of now, various efforts have been made in Microcontroller and IoT based devices, or basically to improve the machine to machine (M-2-M) communications of a full range of feeder equipment [22]. In a basic electrical feeder system, monitoring and controlling of the grid are one of the key parts. With the help of communication technologies monitoring and controlling is easy.

2.3.4 Smart Meters

The suitability of the smart meters is growing very rapidly, which is helpful for consumers in power savings and reduced the response time to check whether electricity outages and faults in equipment and to improve the consumer experience through the handling types of equipment with remote control a smart meter has been shown in Fig. 2.5 [23].

Fig. 2.5 Smart electric meter [7].

The main advantage of a smart meter is that it provides two-way communication to power distributors and the consumers. If any fault condition in the distribution line or equipment location of the fault is traceable, the fault can be fixed as fast as can be. Besides all the benefits, smart feeders can provide the programmed data and monitoring of the household [24]. This technology creating business area has very good incentives for the managerial masters and the customers equivalent. These meters are getting notoriety, also passed on to the prepaid framework, and is anything but difficult to utilize. Clients using prepaid meters can energize their meter whenever utilizing online interfaces and get consistent data on intensity with a shrewd force meter [25].

2.3.5 Wires and Cables with Superconductivity

The most innovative and efficient way of transferring electrical energy and data are superconducting transmission wires and cables, which are already being tried and acknowledged by various researchers and administrators as the electricity distribution system as a feature. In Fig. 2.6, the construction of the cable is shown.

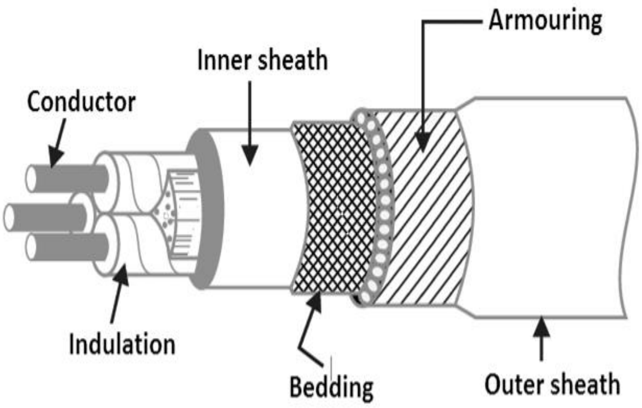


Fig. 2.6 Construction of the cable [24].

The cables and wires have been used in very long-distance power transmission and distribution. The cables are used to provide lengthy-eliminate energy distribution similarly as providing customized monitoring, analysing equipment to predict and perceive weaknesses and frustrations on the contraption reliant on the power blackout history and persevering information environment gauge [26]. Transmission incidents are incredibly less in these connections.

2.3.6 Smart Appliances

In-Home Area Network (HAN) and Local Area Network (LAN) so many smart appliances have been used for communication, monitoring, and controlling equipment as shown in Fig. 2.7. A machine that joins the information and exchanges to enable modified or regulators subject to client inclinations or outside signs from a utility or untouchable significance supplier. A keen machine may use a HAN to talk with various different gadgets in the client's explanation or various channels to visit the utility framework [27].

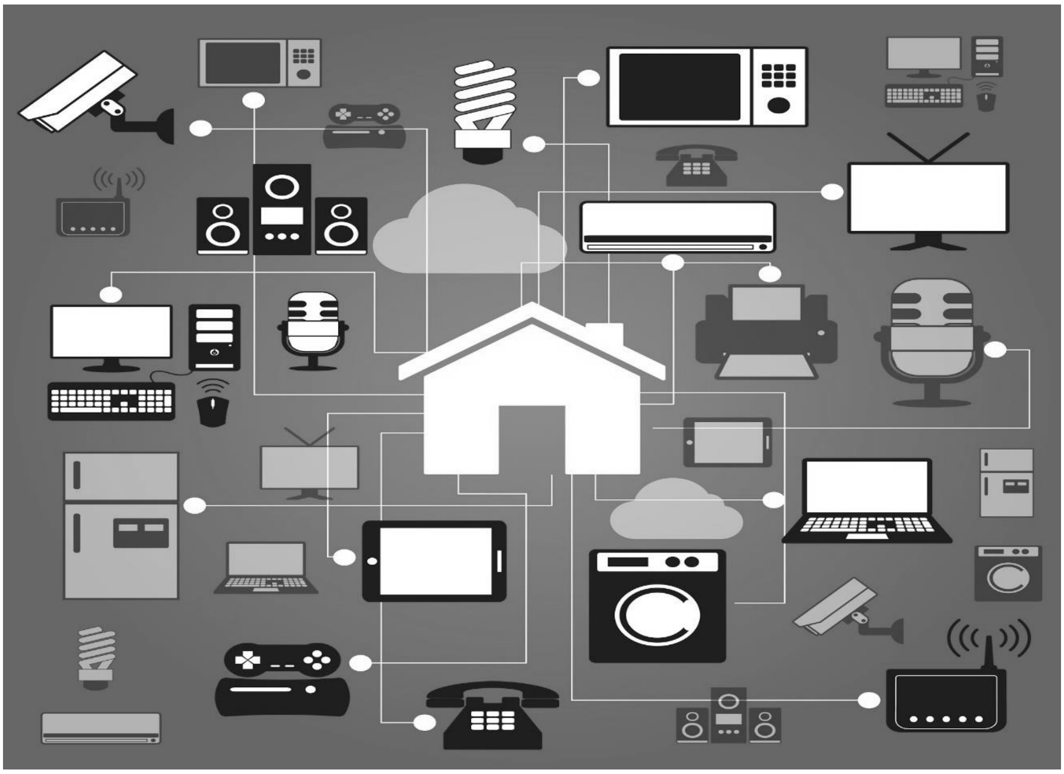


Fig. 2.7 Smart appliances controlled IoT [19].

As showed up in Fig. 2.7. brilliant machines can get when to consume power through the client's pre-set propensities. This is done to lessen electrical loads so it can't influence the purchaser's capacity age costs.

2.4 Relays

The basic fundamental part of the feeder protection system is relay circuits wherein relay circuits are responsible for observing and controlling the fault condition (overload voltage and current) to the full safety of the system and devices. The relays, being the most significant aspect of the feeder's framework, provide protection against the overhead lines, cables, and devices [27]. A relay is a moderately simple switching device gadget that automatically close or opens a set of contacts between two circuits. This cycle is triggered by an electrical input or control sign or something to that effect, because of which the hand-off switch, as a rule, moves from an OFF' to an ON position. The electrical grid and feeder must provide power continually without any interference or fault occur in the system that is the most important phenomenon of protection relays [28]. To keep the relay circuit operational, a relay circuit must protect the system from fault and keep the electrical network operational.

2.4.1 EMRs

The Electromechanical Relays (EMRs) were consisting of a magnetic coil and a mechanical switch for protection in electrical circuits [29]. The electromechanical relays had a significant breakthrough over the manual switching in their initial developments, as shown in Fig. 2.8. As reported in the past literature, several research efforts have been made to combat protection deficiencies in the relays that operate on electromechanical principles [30, 31]. The primary advantage of the EMR mechanism was the suitability for both the AC and DC circuits and, thereafter, have undergone vast improvements that make it suitable for use in several applications. However, EMRs have several limitations such as higher power consumption, increased noise due to mechanical vibrations, inability to operate with high EM stray forces, and comparatively, EMRs have very slower switching times less than 0.01 to the Solid-State Relays (SSRs) [32].

Since the introduction of SSRs in the early 80s, the scope of utilities of EMR has started diminishing. Due to SSRs having reportedly more accurate, small-sized low-power devices, and above all, it was compatible to integrate with the microcontroller circuits [33].

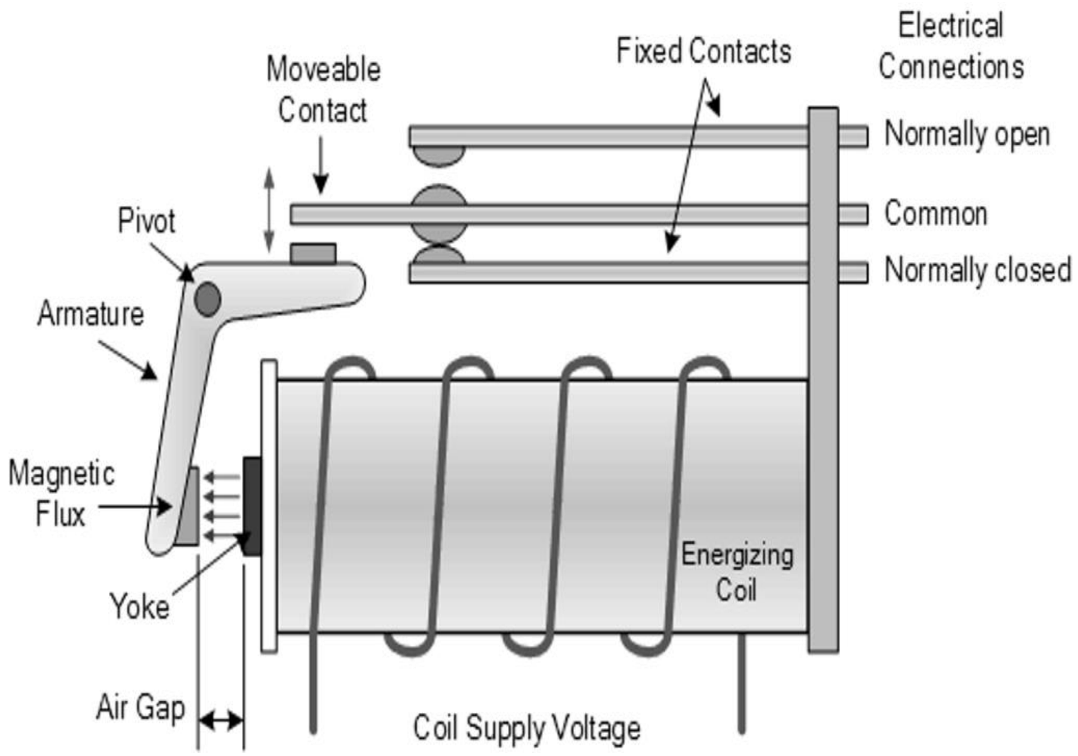


Fig. 2.8 Electromechanical relay [31].

2.4.2 SSRs

The industrial use of solid-state relay (SSR) started in the early 80s with the advancement of operational switches. A triac based SSRs relays have been used initially. The triac SSR relays are basically semiconductor-based electronic switches which turn on and off the AC supply that is applied over its control terminals. The triac based SSRs having inclusion of a sensor device which always response to a provided information (control signal), a solid-state electronic switching device which changes the ability to store equipment data, and a coupling network to engage the control signal to activate this switching without mechanical parts [34, 35]. A Solid-State Relay (SSR) Triac comprises four fundamental parts: An optoisolator or optocoupler has been used regularly to disconnect the low voltage DC control from a microcontroller to the HVAC. The input signal applied to an optocoupler is regularly a light-emitting diode, and the output is frequently a photograph semiconductor & photograph Diac has been used to provide the switching for a triac. Solid-State Relay frequently has an inside zero intersection finder circuit that turn-ON the triac during transgression signals are near a value of past zero or 180 degrees [36]. That forestall causes heap and unwanted energy waste. The triac circuits only work as AC switches.

At the time of DC supply in Triac SSR output should be power semiconductor and does not works on DC supply. The SSR circuit with AC supply shown in Fig. 2.9 at the input LED has been implemented and at the output solar cell to attract the signal from LED. When the light passes through the translucent resin and reaches the output side, the solar cell circuit will complete, and the relay will be at ON condition. At the OFF condition, LED stops elimination and SSR stops working.

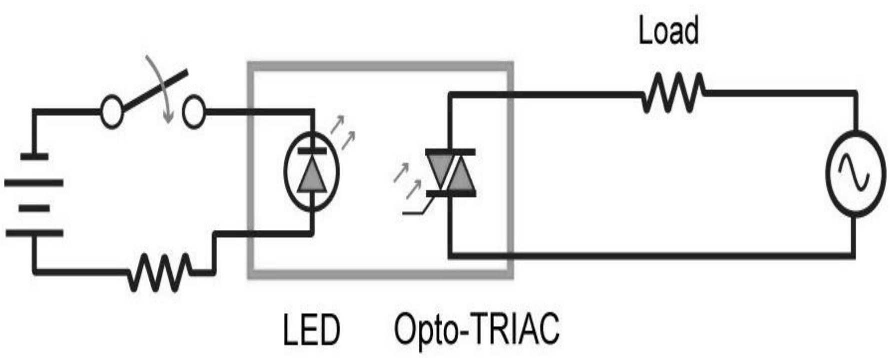


Fig. 2.9 SSR (Triac).

Opto Triacs are used for AC Switching devices only. The zero load current characteristics have been shown in Fig. 2.10, When ac supply applies to SCRs or Triacs relay turns off characteristically with the purpose of zero current. The relay terminals shall not have hindered with the sinusoidal signal top, forestalling the huge transient voltages this will be somehow, or another happens because of the unexpected breakdown of the attractive area nearby the inductance. The separate SCR's could be exchanged back on toward the beginning of another wave within its expansion for the zero-point locator (not unfriendly circuit inductance and resultant back-e.m.f.). This component is called zero-hybrid exchanging [37].

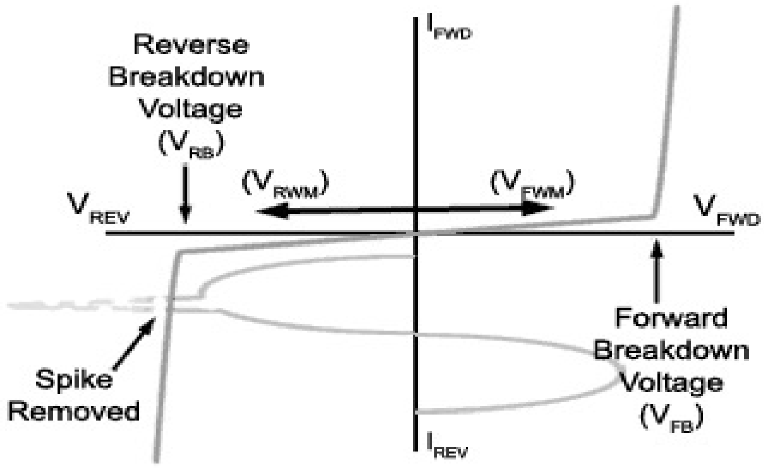


Fig. 2.10 SSR (Triac) transient voltage suppression [33].

SSRs can likewise incorporate zero intersection equipment to possibly neutralize the voltage value or whenever AC voltage value is at zero. Asynchronous and Synchronous (Zero Crossing) switching characteristics are shown in Fig. 2.11. Relative SSRs can defer the beginning of voltage after the zero intersection so as to bring down the current output. SSRs are described by various parameters, including the necessary enacting input voltage, current, output voltage, and current, regardless of whether it is AC or DC, voltage drop or resistance influencing output current, thermal obstruction, and thermal and electrical boundaries for safe working operation area.

Some SSRs incorporate 'Zero Crossing' or 'Coordinated Switching' circuits, which lessen the chance of presenting quick evolving 'spikes' onto the mains (line) gracefully by guaranteeing that their output will just turn on as the mains voltage cycle goes through zero volts. On the off chance that the control voltage demands a switch on at once during the voltage cycle when the AC voltage isn't going through 0V, the exchanging activity is deferred until the voltage next crosses 0V at the finish of the current half-cycle [38]. The zero-voltage crossing circuit doesn't have any influence in turning the output off notwithstanding; this is constrained by the activity of the triac, which once turned on will possibly kill when the yield load current falls beneath the triac predefined holding current, which it will do as the current waveform goes through zero.

Difference between EMRs and SSRs

Detailed classification and difference have been given in Table 2.1 Since the introduction of SSRs in the early 80s, the scope of utilities of EMR have started diminishing. Due to SSRs having reportedly more accurate, small-sized low-power devices, and above all, it was compatible to integrate with the microcontroller circuits [39]. In particular, the SSRs use semiconductor devices such as thyristor or power MOSFETs for fast switching and provide the smooth implementation of the relay circuits in an integrated chip [40]. In particular, the SSRs use semiconductor devices such as thyristor or power MOSFETs for fast switching and provide the smooth implementation of the relay circuits in an integrated chip [45].

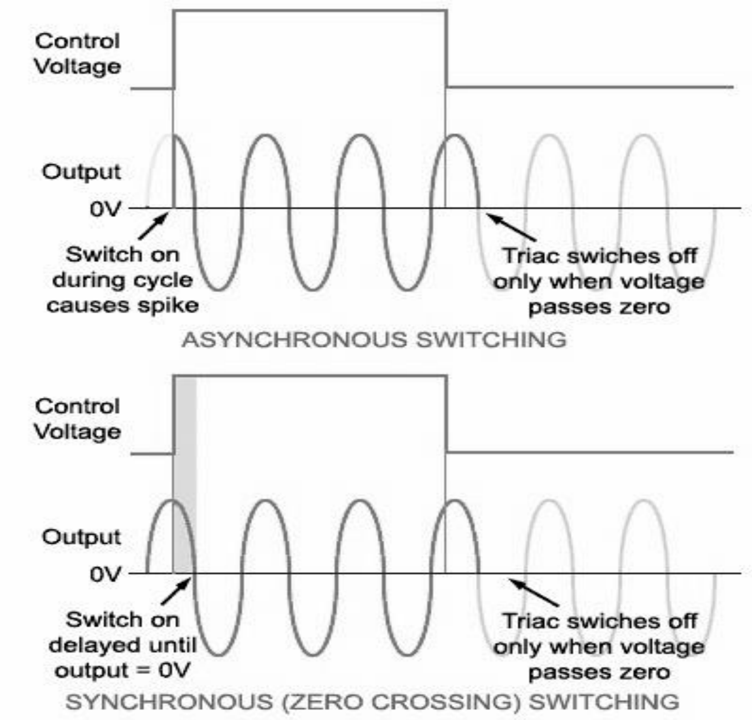


Fig. 2.11 SSR zero-crossing action [34].

Table 2.1. Difference between EMRs and SSRs

Parameters	**Electromechanical Relays**	**Solid State Relays**
Mechanism	Electromagnetic Induction	Photo-Voltaic effect
Noise	Significantly noise-affected due to moving parts	No noise generation
Power Consumption	Higher operating input power [41] > 12 V	Very low input power to operate < 5 V
Switching	Switching time is quite long due to induction delays 10-15 ms	Shorter Switching time because of high-speed MOSFETs operation (~100 μs)
Lifetime	Average life-span of 1 million cycle	Average life-span nearly more than 100 times to EMR
Arc generation	On higher load, undesirably arc occurs [42]	No arc generation
Overheat protection	Much complicated as operation mode and relay material need to change.	Simpler, heat-sink can protect
Cost	Very less Costly (Approx. 10$) but limited in applications	The comparatively high cost (Approx. 40-50$), not limited to any applications
Environment	Affected adversely by the stray-magnetic environment [43]	Free from environmental and surface conditions
Contact Poles	EMRs holds Multiple contacts poles.	Single contacts available
Mechanical Parts	EMRs have mechanical moving parts i.e. chuck, shaft, bearing, etc.	No mechanical part in SSRs
Resistance	Less than 100 milliohms [44]	Less than 10 ohms

2.5 Microcontrollers

In the early 70s, Microcontroller was introduced for the first time, including 4-8-bit Microcontroller Units (MCUs). After advanced developments, most microcontrollers being used today are inserted in other machine devices, for example, the auto sector, phones, machines, grid solutions, and peripherals for PC frameworks [46]. A microcontroller framework can be utilized for identifying issues in the feeder systems. The continuous observation of the various parameters and types of equipment in the feeder framework to recognize electrical faults [47].

There is extensive existing research for Microcontroller based distribution system protection. A microcontroller is an Integrated Circuit (IC) gadget utilized for controlling different parts of an electronic framework, ordinarily through a Microprocessor Unit (MPU), memory, and a few peripherals. Feeder automation is the quickest developing pattern among utilities to improve the dependability of distribution systems [49]. One of the primary uses of feeder automation is programmed by fault management. The future smart distribution feeder will comprise of new parts, and advancements with improved capacity whose fault conduct cannot be resolved with sureness [50]. The smart protection system is important to fulfill customer demand [51]. The primary goals are to decrease the line losses, responsive power flows on the line, and to abstain from switching surge overvoltage because of turning on/off the capacitors [52].

The microcontroller in smart grid technology is essential with any electric apparatus that stores, measures, shows data, or computes a microcontroller chip inside it [53]. The microcontroller device for the monitoring and controlling of the Smart distribution feeder is one of the most utilized ways to provide efficient and reliable electric power to users [54]. Microcontroller additionally gives monitoring and protection to loads. We, for the most part, have some critical and non-critical loads.

Critical loads ought to never be turned off. Non-critical loads can be turned on or off contingent upon Power utilization and distribution. Microcontroller and connecting devices have been shown in Fig. 2.12. In-home, we have an unbounded supply by distribution feeder. Be that as it may, power utilization is restricted by current suffering constraints of distribution wiring. At the point when the consumer turns more loads on, the current flowing into principle wire increments [55]. In the event that the consumer keeps on turning an ever-increasing number of loads, at that point, a cut-off is arrived at where the current surpasses the wiring limit causing the PhotoMOS relay to send a signal to Circuit breaker to open the circuit [56]. It may be that switch all loads off if overload current exceeds definitely not a smart idea. Here is our efficient model of LV distribution smart feeder overcurrent protection system that comes to play a crucial role and save the circuit and equipment from overcurrent [57].

Fig. 2.12 Microcontrollers applications [53].

2.6. IoT Applications in Smart Feeders

In the early 80s, the Internet of Things (IoT) was introduced by Carnegie Mellon University to refrigerator appliances to check if their drink is available [58-60]. Constantly 2013, the Internet of Things had developed into a system utilizing different technology, extending from the Internet to wireless communication and from micro-electromechanical systems (MEMS) to embedded systems.

The customary fields of automation (counting the computerization of structures and homes), wireless sensor systems, GPS, control frameworks, and others all help the IoT

[58]. IoT systems have the capability to be interconnected with any other devices, privacy, and security of the system are the main advantages [59]. The IoT is the update of mobile, home, and implanted applications to be essential for a system of associated physical devices with sensors that both import and export information [60].

The devices, utilizing embedded sensors, assemble information about the nature in which they are working and how they are being utilized, as shown in Fig. 2.13. The sensors are incorporated into each physical device, from electrical machines to lights to cell phones and tablets to scanner tags on non-electrical things. At that point, the devices share the information progressively about their operational state through the Cloud to an IoT stage where there is an all-inclusive language by which all IoT gadgets impart [61]. The accumulated information is then dumped or coordinated, and an information investigation is performed. Smart feeder system performance and constant electricity distribution to the consumers are some of the significant problems nowadays.

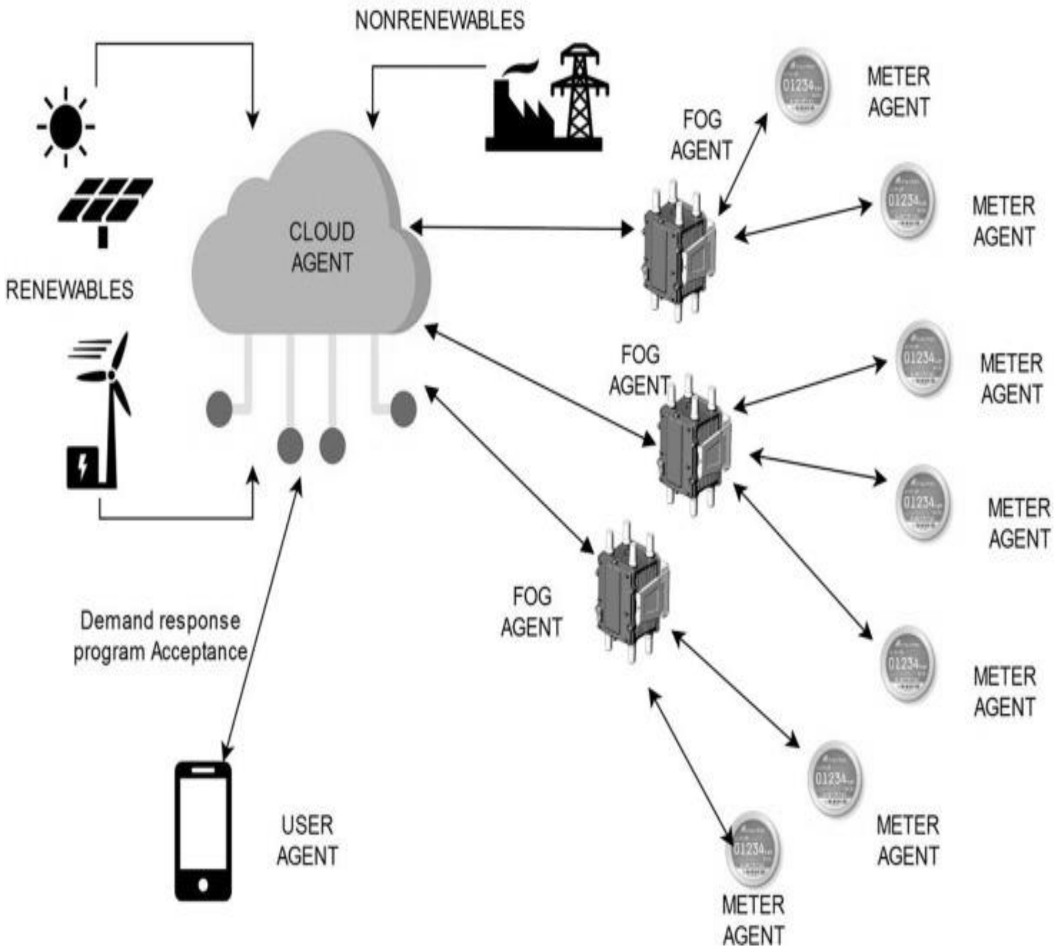


Fig. 2.13. Smart Feeder with IoT Components.

Therefore, fast safety and protection plans must be effective enough to conquer issues within a short period of time [62]. Lately, the Smart grid technologies have grown quickly, and IoT innovation has been broadly utilized in the grid distribution network and naturally incorporated with the power innovation, significantly improving the intelligence degree of the grid distribution. In any case, at the current stage in the smart grid network, the degree of setting up intelligent feeder data monitoring in joins smart feeder and understanding the general controlling, monitoring, and the understanding of feeder hardware and operation status should be improved [63].

IoT Technologies provides two-way communication systems between the electricity provider and consumer. As an idea, the smart feeder is a combination of power generation, transmission, and distribution network improved by advanced digital control, monitoring, and broadcast communications abilities [64]. These days the Internet of Things (IoT) allows effective data execution and working at all stages.

Chapter-3

DESIGN & ANALYSIS OF PHOTOMOS RELAY FOR EFFICIENT FEEDER PROTECTION

The feeder system, being an intermediary element for the distribution of power to the regional transformer, protects against any fault, becomes a requirement in the power systems. The power system protection devices are used to avoid such developing fault conditions. The relay circuits serve as the fundamental part of feeder protection systems wherein they are responsible for controlling the overload voltage and current to ensure the devices' safety.

Being the most important part of the feeder's system, the relays provide essential protections to overhead lines, cables, and equipment. A relay is a moderately simple switching device gadget that automatically closes or opens a set of contacts between two circuits. This cycle is triggered by an electrical input or control sign or something to that effect, because of which the hand-off switch, as a rule, moves from an OFF to an ON position. The protection relays ensure that the energy grid continually powers the system without any interruption [65]. In case of disturbances, a relay must prevent the faults and keep the electrical network operational. Therefore, a relay must detect the fault and respond at the utmost fast switching to see the abnormalities. The demonstration of the basic Solid-State Relay (SSR) circuit is presented in Fig. 1. Besides switching capabilities, the relays' desired features also include parameters such as low power consumption, noise mitigation, and a longer lifetime [66].

3.1 Solid State Relay Circuit

A solid-state relaying circuit has been shown in Fig. 1, that connects to the secondary of the Current or Potential Transformer (CT/PT) and then to the bridge rectifier to convert to DC supply. The DC supply is connected to a relay measuring circuit to compare the supply value with the device's threshold value. If the supplied signal's value is more than the described value trip circuit sends a signal to the circuit breaker to break the supply from the main load.

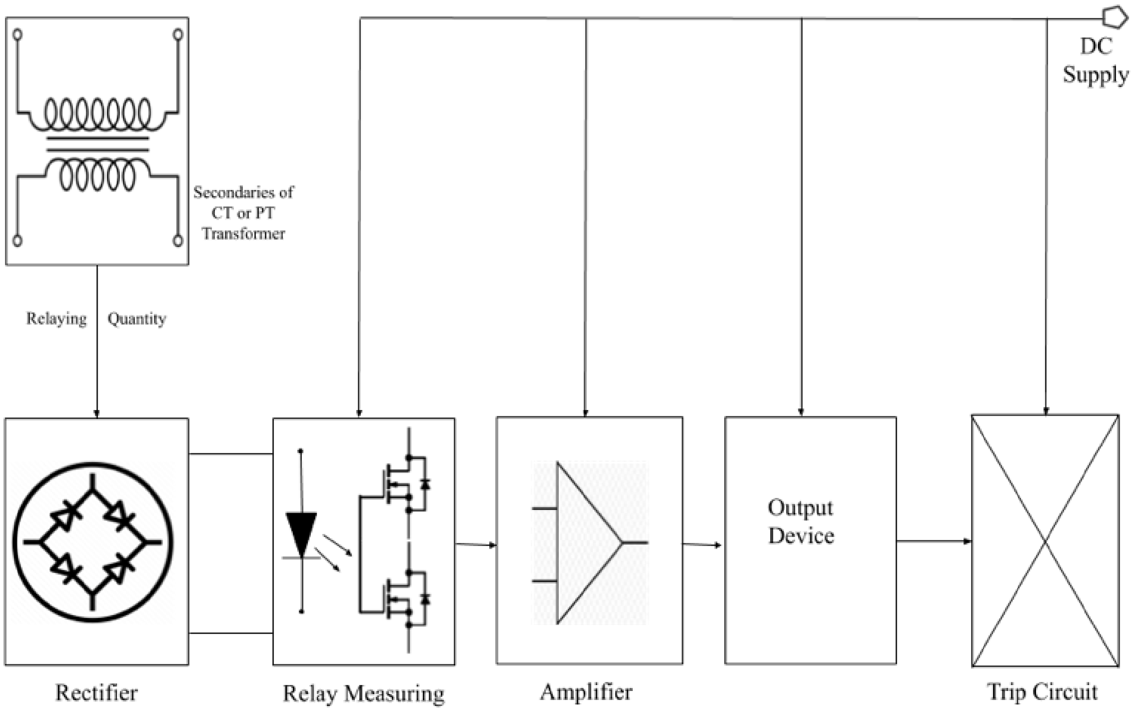


Fig. 3.1 Solid-state relay circuit.

The amplifier circuits have been used to convert minimal electrical magnitude signals to large electrical magnitude signals. The relay circuits take action only for the overshooting of signals of the electrical form. Therefore, any other form of non-electrical over-signal such as temperature, pressure, strain, frequency is needed to be changed into the electrical equivalent analog/digital quantities—feedback to the input of the relay circuit for signal correction. Owing to MOS technology's remarkable growth, the SSR devices for electrical protection are greatly in demand and contemporary to the research and developments [67]. Table 3.1. shown the Difference between Triac SSRs and PhotoMOS SSRs.

3.2 PhotoMOS Relay Protection

With the help of semiconductor devices, there has been extensive advancement in the electronics market. There have been many effective modern electronics measures: less switching time, the impressive working capacity of devices, and less size of the products. The extensive research in semiconductor devices like SSRs has been developed with the benefits of less time, power consumption, and size. The relay circuits, being the most significant aspect of the feeder's framework, protect the overhead lines, cables, and devices. A relay is a moderately simple switching device gadget that automatically closes or opens a set of contacts between two circuits [71]. This cycle is triggered by an electrical input or control sign or something to that effect, because of which the hand-off switch, as a rule, moves from OFF to ON position. For the very high number of switching operations, optocouplers or Light Emitting Diode (LED) with the combination of MOSFET and analog CMOS circuits switch has been used to turn-ON or turn-OFF the PhotoMOS relay circuit. The required power supply and an increasing number of equipment and space on the PCB are the requirements for fast switching solutions. In the PhotoMOS relay circuits, there has been no need to add a snubber circuit at the output side to observe the increment in voltage. PhotoMOS operations perform within a maximum rating of the voltage. Since there is no leakage current generating in the PhotoMOS relay, the devices' operating cost and durability are additional advantages [72]. The PhotoMOS relay circuits do not work on the automation mechanism that has been used in SCR and Triac SSR circuits. That's the reason PhotoMOS never turn-ON accidentally. Moreover, the noise concealment qualities of optoelectronics equipment make them profoundly impervious to surrounding noise for operating at temperatures up to 80°C.

3.3. PhotoMOS Construction

In the PhotoMOS circuit construction, the power supply is very interpreted, which is unnecessary since the optoelectronic device at the input side directly operates the two power MOSFET at the output side. PhotoMOS is a semiconductor device that consists of a Light Emitting Diode (LED) at the input and two power MOSFETs (depletion type) with photo (solar) cells controlled circuit at the output. There is a translucent resin molded between LED and solar cells, which allows light to pass, as shown in Fig. 3.2 PhotoMOS relay circuit works on the principle of light operated MOS technology conduction [73].

Table 3.1. Difference between Triac SSRs and PhotoMOS SSRs

Parameters	**Solid State Relays (Triacs)**	**PhotoMOS Relays**
Mechanism	Opto-Electric Induction	Photo-Voltaic effect
Working	Current or Voltage	Current
Load Current	Triac’s works only on AC supply [68]	PhotoMOS works on AC and DC, both supplies.
Output Element	Triacs	MOSFET
Output	Output side has nonlinearity	Output side has linearity
Current Ratings	High current ratings	Low current ratings
Zero-Crossing	Turn-off on zero crossing	No zero crossing
Cost	Very less Cost (Approx. 30-40$) but limited in applications	The comparatively high cost (Approx. 40-50$) but not limited to any applications
Leakage Current [69]	High leakage current	Low leakage current
Controlling	Small analog can't control signal.	Can control small analog signal
Reverse Voltage	Triac can handle reverse voltage	PhotoMOS can’t
Resistance [70]	Less than 100 Ω	Less than 10 Ω

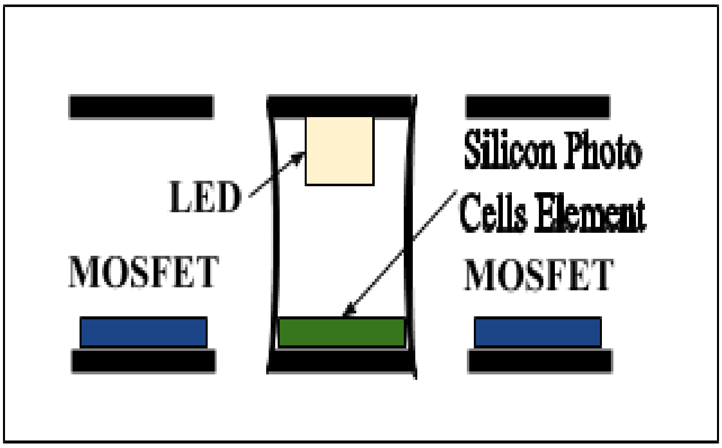


Fig. 3.2 PhotoMOS sectional diagram.

Fig. 3.3 and Fig. 3.4 shows the pin diagram and basic circuit structure of a PhotoMOS relay device. The Drain-Source region's design controls the breakdown voltage at the output side of MOSFET, prompting a specific n-drift area, which is primarily liable for the semiconductor devices and MOSFET with the resistance. The length of the cross-section area and chip surface structure parasitic capacitors, which impact the relay circuit switching times and saturation characteristic for the higher continuous load supplies. The parasitic parts of the output MOSFET are delineated in Fig. 3.2, indicating a solitary to the MOSFET. For high accuracy applications like estimation or information procurement equipment, switches with low ON-resistance and low capacitance are required. The previous necessity causes a low signal misfortune, and the last prerequisite impacts switching times and disengagement attributes for higher incessant load signals [74].

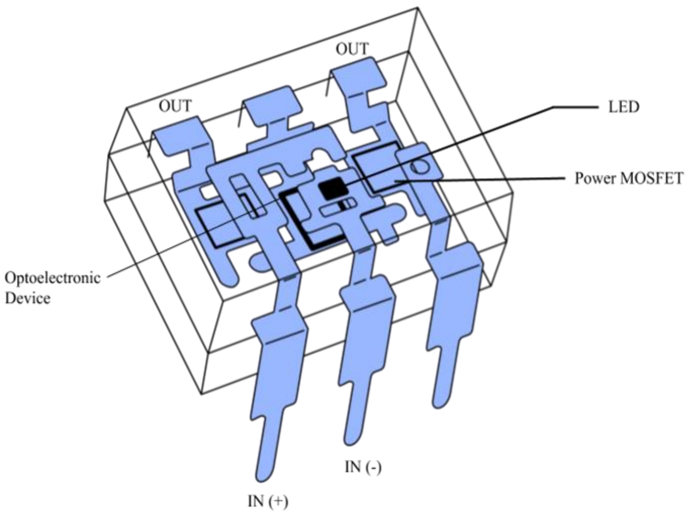


Fig.3.3 PhotoMOS pin diagram.

Accordingly, another relay circuit output side MOSFET with low ON-resistance and low capacitance should have been created. For high accuracy applications like estimation or information procurement gadgets, switches with low ON-resistance and low capacitance are required, whereby the previous necessity causes a low signal loss, & the last prerequisite will impact switch times and confinement qualities for higher continuous load signals. Low CxR relay circuits with decreased ON resistance are utilized to switch DC signals causing low signal losses in the switches. Alternately, relays with a decreased capacitance are utilized to switch AC signals giving improved disconnection. Other than utilizing low CxR PhotoMOS relays for switching signs and I/O lines to gadgets being tried, these relays may likewise be utilized in information procurement circuits, such as choosing the increase of operational amplifiers. With the assistance of the relay, the device's advanced control unit and the analog sign framework are galvanically isolated, along these lines upgrading the gadget's exactness by limiting commotion.

3.4 PhotoMOS Relay Working

A PhotoMOS relay is turned ON when the input circuit provides forward bias to the LED that inputs the light energy to the secondary circuit. The emitted light passes through translucent resin and reaches to Photocells, which are mounted aligned to the LED, as shown in Fig. 3. When the light passes through a translucent Silicon resin, the lights have been observed by an array of solar cells that leads to a voltage drop across the array.

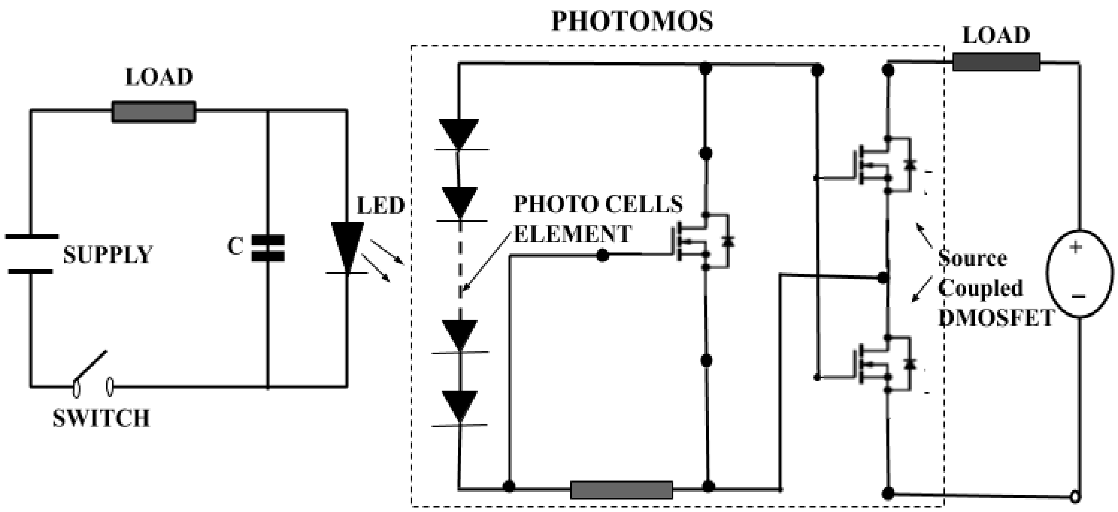


Fig. 3.4 PhotoMOS relay circuit.

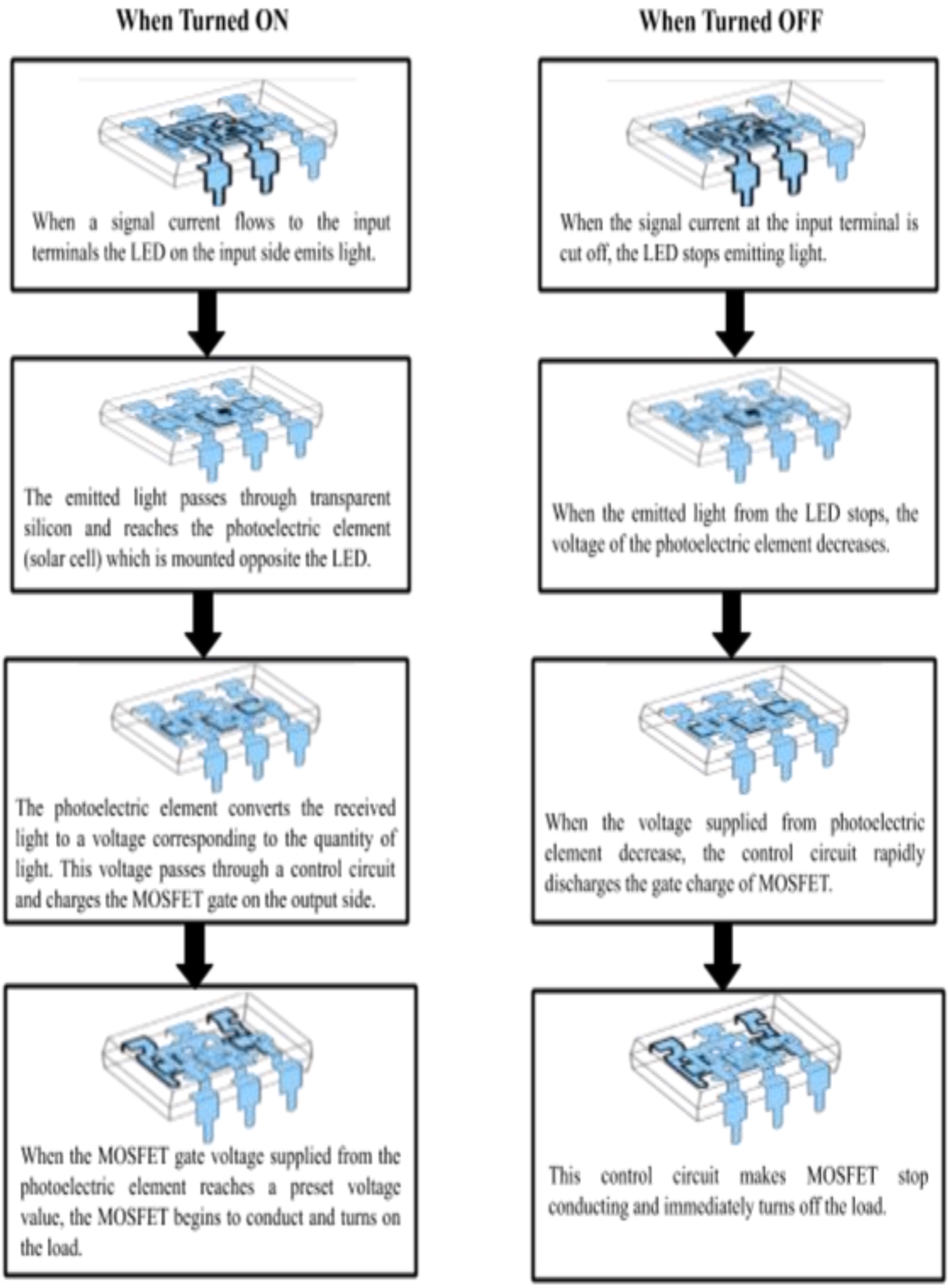


Fig. 3.5 PhotoMOS working structure.

The photocells convert this emitted light into voltage, and this voltage activates the MOSFET gate terminal at the output side [75]. The observed voltage drop across the array is helped to control two source-coupled MOSFETs, therefore less switching time the output from turn-ON to turn-OFF state and vice versa.

The PhotoMOS relay switching characteristics can be influenced by the output side MOSFET, which is very often. When the gate voltage approaches a prescribed threshold, then the relay circuit is turned-ON due to the switching of both the depletion MOSFETs [76]. To turn-OFF the PhotoMOS relay, the input supply stops flowing and cut-off the LED. Then LED stops emitting light to the solar cell; thus, the voltage generation has been decreased. Due to a decrease in photocells voltage, gate voltage also discharges the power MOSFETs and turns-OFF the relay circuit. Basic PhotoMOS working structure has been shown in Fig. 3.5. Particularly estimation applications, for example, the information obtaining gadgets or mechanized test frameworks will benefit from these highlights of semiconductor (MOSFET) innovation which PhotoMOS relay circuits. Different applications like media transmission, security gadgets, sensor advancements, or modern applications can also use the upsides of the PhotoMOS relay.

3.5 Short Circuit PhotoMOS Protection (Non-Latch Type)

Small size, reliability, and low energy use are requirements for segments used to switch signals output in sensors, control units, or in monitoring cards. A critical limit is the galvanic seclusion of sensitive equipment from potential dispersion impacts on the output side, for instance, overvoltage or overcurrent, which can develop as a result of short-circuit or fault conditions. It ideally merges high switching speed with low control current and overcurrent assurance. The inward structure of a PhotoMOS relay circuit and the protection limit are illustrated below [77].

The currently restricted sort identifies a transient overcurrent and limits it to a less basic worth. In the wake of applying an info current, the load circuit is conductible, and the current moves through the heap. In the event of a fault, this current increment and is distinguished by the protection circuit. The event of such a case is spoken to in Fig. 3.6. The PhotoMOS closes and opens the load circuit then again. By delimiting the voltage top, an incentive at the output side obstruction of the relay circuit to a limit of 6 V, and the switching change of output opposition, the load current starts to sway. After the output aggravation has vanished, the current restricted PhotoMOS carries on like a traditional semiconductor switch once more. The load current's root implies the square worth is diminished by the wavering of the output. This is controlled with the end goal that the subsequent energy loss doesn't surpass the part's most extreme reasonable power dispersal. Hence, the relay circuit forestalls an extreme expansion in power dispersal and an ascent in temperature in part. This contrasts from ordinary current-limiter equipment that expands their on-opposition, whereby power scattering ascends to a falling to pieces level. The defensive circuit detects a short out with the assistance of a control circuit. This control circuit introduces an information signal for an astable trigger stage, which controls the D-MOSFET's entryway voltage [78]. These outcomes in the substitute switching of the load circuit and the decrease of the current RMS estimation.

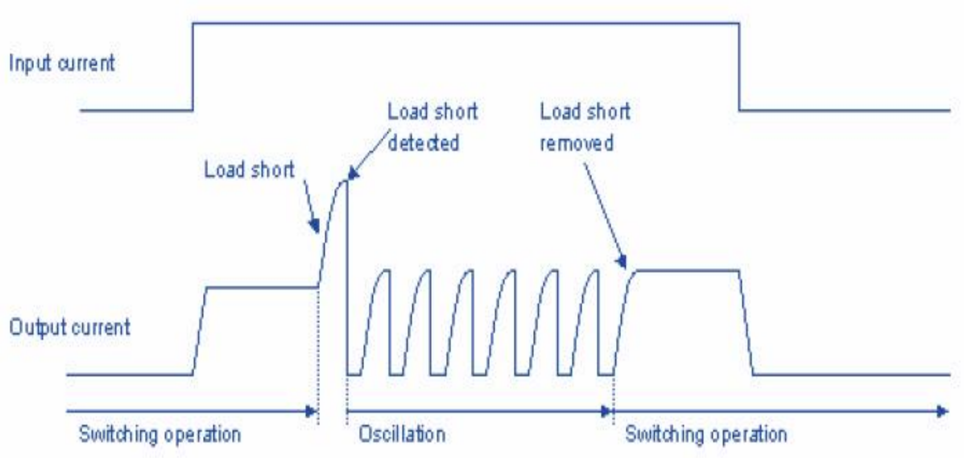


Fig. 3.6 PhotoMOS with short circuit protection non-latch type [26].

An essential addition to the incorporated defensive circuit is temperature conduct. With an expansion in temperature, electrical resistance rises. In this way, a load current produces higher energy loss in the circuit's parts and may prompt the glitch. But since of expanded resistor esteems at higher temperatures, the voltage drop in the control circuit rises. The defensive circuit reacts to bring downflows, accordingly has a negative temperature coefficient. Subsequently, it can secure the load circuit all the more successfully against expanded energy loss and annihilation. Notwithstanding this defensive capacity, there are different motivations to incline toward overcurrent ensured PhotoMOS to ordinary arrangements with assurance gadgets: by incorporating the defensive component in the relay circuit, costs are decreased, building up the circuit is facilitated, and space is spared.

3.6 Short Circuit PhotoMOS Protection (Latch Type)

If there should arise an occurrence of such a fault, the conduct is represented in the accompanying figure. With the short circuit protection PhotoMOS (latch type), the load circuit is turned off and can be turned on again simply after the information signal has been reset. This is spoken to in Fig. 3.7. If an information current or more moves through the LED, the O/P of the semiconductor relay circuit has a low impedance, and a load current starts to stream. The off chance that the load current increments over the restricting value (Load SC) are recognized by the defensive circuit (Load short detector). The load current is interrupted, even if, as appeared in Fig. 3.7, a constant information current is provided. Simply after resetting the information signal, the output can be turned on again, and the relay circuit expects its typical switching activity [79]. The defensive circuit detects a short out with the assistance of resistors (shunts). These are situated on the output side of the PhotoMOS relay circuit. The shunts don't fundamentally build the on-obstruction of the relay. Unnecessary current in case of a fault prompts a voltage drop over the shunt.

With the short circuit verification PhotoMOS type, the shunt's voltage drop is utilized as an information signal for an unbalanced flip-flop door. The flip-flop controls the gate voltage of the D-MOSFET and switches off the output circuit. The flip-flop and the typical switching activity can be reset simply by eliminating and applying the current LED input.

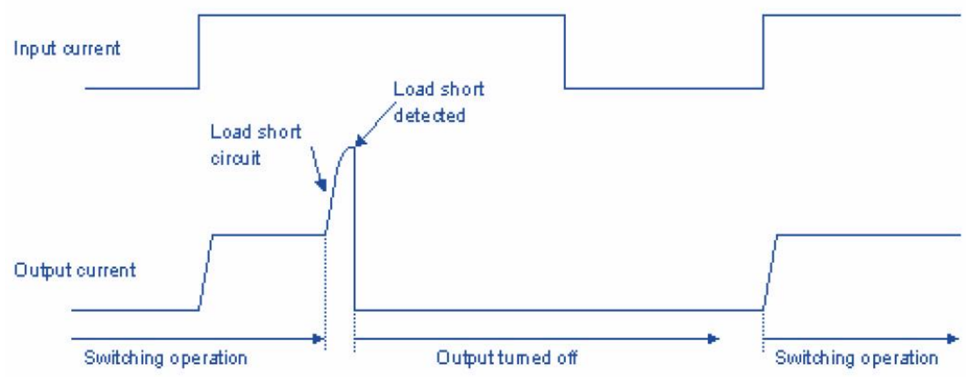


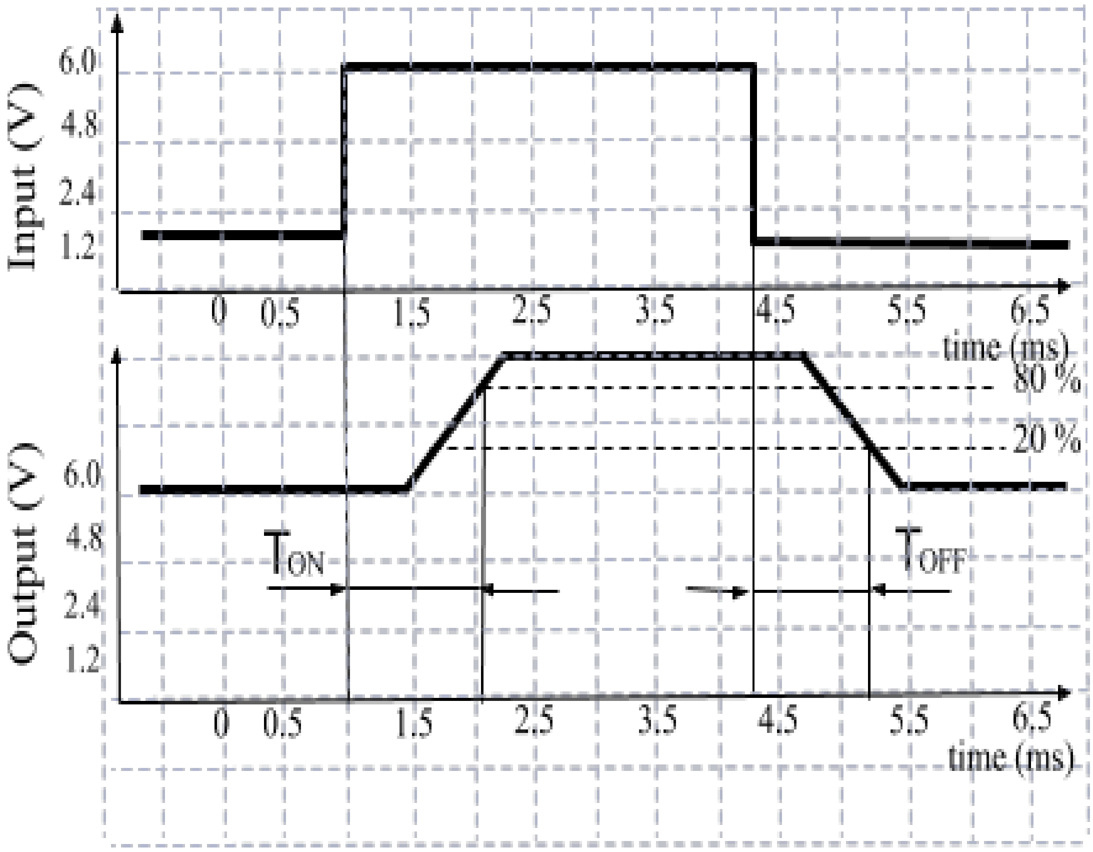
Fig. 3.7 PhotoMOS with short circuit protection latch type [26].

A critical addition to the incorporated defensive circuit is temperature conduct. With an expansion in temperature, electrical resistance rises. Consequently, a load current delivers more powerful dissemination in the circuit's parts and may prompt glitch. But since the expanded resistor esteems at higher temperatures, the voltage drops over the shunt in the relay circuit ascents [80]. The defensive circuit reacts to bring downflows, along these lines has a negative temperature coefficient. Consequently, it can secure the load circuit all the more successfully against expanded energy dispersal and devastation. Notwithstanding this defensive capacity, there are different motivations to incline toward overcurrent secured PhotoMOS to customary arrangements with insurance gadgets: by coordinating the defensive component in the relay, costs are diminished, building up the circuit is facilitated, and space is spared.

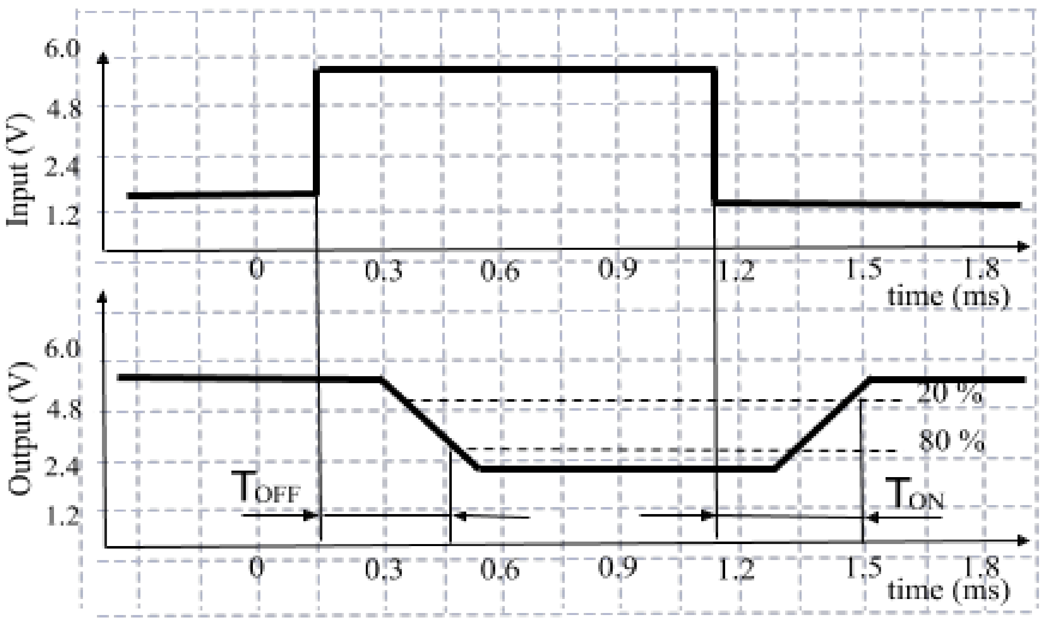
3.7 Results

The open and closed-circuit operations have been analyzed using the PhotoMOS device, which resulted in shorter switching time and T_{ON}/T_{OFF} ratios. The achieved results show the operational switching parameter with considerable gain over the conventional Electromechanical (EM) relays while using the PhotoMOS device. In Fig. 3.8, the authors have shown the turn ON time (T_{ON}) is 0.04 *ms* to 5 *m*s and 1.2 *ms* to 0.3 *ms* as the device turns OFF time (T_{OFF}) for its Normally Open (NO) and Normally Closed (NC) conditions. The transfer characteristics ratio (T_{OFF}/ T_{ON}) for the normally open circuit is 0.03, and for the normally closed-circuit ratio is 0.06. PhotoMOS relays are used in telecommunication, measurement, security, and industrial control. These characteristics show the operation time and reverse operation time. As described in the PhotoMOS switching characteristics, timings between ON and OFF conditions are reasonably less, making it an optimal choice for use in relays [81]. If the voltage and current value of any electrical/electronic device increase above the threshold limits of the internal system, it can result in overvoltage or overcurrent; consequently, the fast response of the relay becomes critical.

The proposed model and simulation results of the PhotoMOS Relay based LV feeder protection system has been shown in Fig. 4.6 and Fig. 4.7. These relay switching results have been used in overvoltage and overcurrent protection for the smart feeder system. The NO and NC operation circuit characteristics have been shown in Fig. 3.8, which is very fast results as compare to Electromechanical and Triac based relays.



(a) Normally open-circuit characteristics.



(b) Normally closed-circuit characteristics

Fig. 3. 8. Switching characteristics of the relay (a) NO, and (b) NC operation.

3.8 Advantages and Applications of PhotoMOS Relay

Other than the incorporated protection system, PhotoMOS relay circuits offer further preferences over other electrical & electro-mechanical switching components or other Solid-State relays:

- A galvanic detachment of the information and O/P part (up to 5000 V AC)
- No balance voltage and little signal switching (DC and AC) conceivable
- Controlled with low info current flows
- Small leakage current (< 1 μA)
- Stable on-resistance over the lifetime (a few mΩ to 60 Ω)
- Small size, no preferred position, No contact bounces
- Vibration and shock-resistant
- No switching noises, Fast switching speed, Low power consumption
- High reliability with extremely long life
- High vibration and shock resistance

The huge device assortment permits various applications for PhotoMOS relay circuits: they can be utilized for switching little motor or energy supply, for signal input and output in mechanical applications, or multiplexing estimation esteems or signals on transport frameworks.

3.9 Conclusion

In this Chapter, a novel model for PhotoMOS relay protection systems has been proposed incorporating the enhanced switching characteristics, construction. Working and applications of PhotoMOS solid-state relay. The significant switching time for the open and closed-circuit operations have been obtained using the PhotoMOS device that resulted in switching time ratios (T_{OFF}/T_{ON}) of 0.03 and 0.06, respectively. The result shows the considerable gain in the operational switching time parameter using the PhotoMOS device over the conventional Electromechanical (EM) relays. The obtained results also assure that the PhotoMOS is a useful relay circuit element and makes it suitable for future Internet of Things (IoT) applications.

Chapter-4

MODELING OF LOW VOLTAGE DISTRIBUTION SMART FEEDER OVERCURRENT PROTECTION SYSTEM

The Low Voltage (LV) distribution smart feeder framework conveys power from the transmission network and carries it to consumers. The smart feeder system, being an intermediary element for the distribution of power to the regional transformer. In the power system, electricity conveyance is considered the end-stage of power distribution to the consumers. Smart feeder system performance and constant electricity distribution to the consumers are some of the significant problems nowadays. Therefore, fast safety and protection plans must be effective enough to conquer issues within a short period. Fault occurrence has to be detected rapidly by the distribution framework and promptly separated the forestall risks to overall public and utility staff [82, 83]. The sectional diagram of the smart feeder is shown in Fig. 4.1.

4.1 Smart Feeders and Types

With the power stations, it is necessary to decrease the transmission losses in overhead lines. That produced electricity has to be stepped up to a higher level, so the power losses in produced electricity transmission will be less and make it increasingly productive [84]. To make transmission voltage progressively usable for the consumer's transmitted line voltage has to be stepped down. The transmission electrical cables will enter a dispersion substation where the voltage will be stepped down to low voltage levels then it will be appropriated for use by industries, businesses, and residential consumers, as shown in Fig. 4.1 power reliability assessment is the most significant parameter to take opportune healing measures to give a continuous and safe power supply to end consumers. Residential users regularly get the power from overhead or underground feeders exuding from utility-substations. The LV distribution smart feeder overcurrent protection and monitoring system is a key apparatus for power distribution utility to make the power system sound, solid, sheltered, and effective without contributing a lot [85].

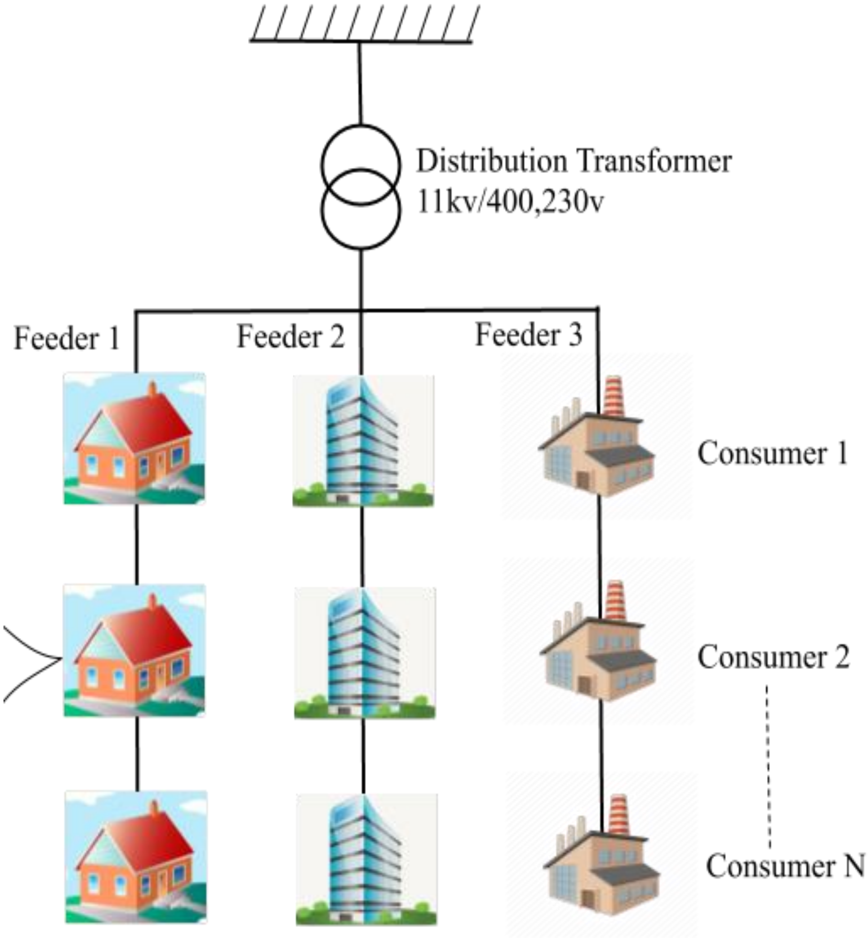


Fig. 4.1 Smart feeder layout design.

In this proposed low voltage feeders exuding from a substation are observed by microcontrollers, relay circuits, and a circuit breaker, which will open when a fault is identified. Programmed microcontroller circuit re-closer are also introduced to isolate the feeder in this way, limiting the effect of faults. Feeders are used to transmit electricity; it is the power line in which electricity is transmitted in power systems. It does the transmission of power from the generating station or substation to the distribution points. There is no intermediate tapping, and by that, the flow of current will be the same for the sending and the receiving section. Feeders are the conducting device used to transmit power to the main load center [86]. The consumers could get constant voltage from the feeder. Types of Feeders are shown in Fig. 4.2:

There are four distribution feeder systems used [87].

• Radial

• Parallel feeders

• Ring main

• interconnected systems

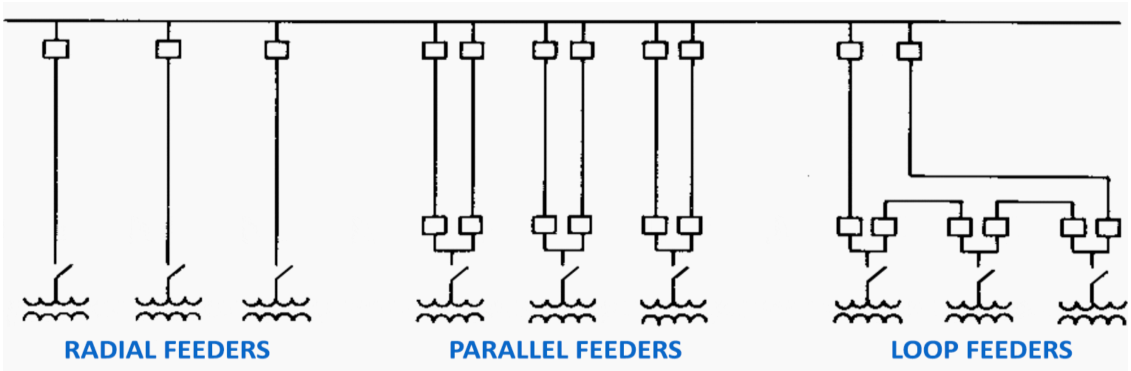


Fig. 4.2. Types of feeder

4.1.1 Radial feeders

These feeders are used for many distribution processes. It is cheap and simple. These feeders are only used when the substation or the generating stations are located at the consumers' center. In this type, the feeder will radiate from the generating stations or substations, and it will reach the distributors at one end. Thus, the power flow is in one direction.

4.1.2 Parallel feeder

There is a disadvantage in radial feeders if there is any fault occur during the transmission, there will be no supply for many customers, so this can be changed by using a parallel feeder. If there is any fault occurs, only one line of the feeder will be affected. The other will do the work the cost is high due to the increase in feeder number it can be used to transfer heavy loads.

4.1.3 Ring main

In this type of feeder system, consumers could get reliability as much as in a parallel system. This type of feeder is used in an urban and industrial environment in this type, the distribution transformers are connected with two feeders cabling has done for many routes starting. Finishing is in the same location the power is delivered to the substations if there is any fault In the ring it will be isolated by a circuit breaker, and the supply will continue by using ring feeder there will be few fluctuations in the customer section there is always an alternative path if any fault occurs.

4.1.4 Interconnected system

The ring feeder is energized by more than one substation or generating station. It is an interconnected distribution in case of transmission failure. The system doesn't stop, it continues, and it does the load transmission.

4.2 Microcontroller Applications in Smart Feeder

The microcontroller in smart feeder technology is essential with any electric device that stores, measures, shows data, or computes a microcontroller chip inside it. The microcontroller device for monitoring and controlling the smart distribution feeder is one of the most utilized ways to provide efficient and reliable electric power to users [88]. Microcontroller additionally gives monitoring and protection to loads. In power distribution, most parts have some critical and non-critical loads. Critical loads ought to never be turned OFF. Non-critical loads can be turned ON or OFF contingent upon power utilization and distribution.

Microcontroller integration in the relaying circuits improves the accessibility and reliable quality by constant self-monitoring of the overall distribution feeder framework [89]. Other than improving the presentation, microcontroller-based transfers likewise offer more noteworthy adaptability and the chance of including new capacities while simultaneously lessening the standard arrangement of hardware. Numerous favorable circumstances are conceivable, and the use of a microcontroller-based PhotoMOS relay is very fast and worldwide received practice at present. There is extensive existing research for microcontroller-based distribution system protection.

The microcontroller was introduced in the early 70s, including 4bit to 8bit Micro-Controller Units (MCUs). After advanced developments, most microcontrollers being used today are inserted in other machine devices, for example, the auto sector, phones, machines, grid solutions, and peripherals for PC frameworks [90]. A microcontroller framework can be utilized for identifying issues in the feeder systems. The continuous observation of the various parameters and types of equipment in the feeder framework recognizes electrical faults shown in Fig. 4.3. A microcontroller is an Integrated Circuit (IC) gadget utilized for controlling different parts of an electronic framework, ordinarily through a Micro-Processor Unit (MPU), memory, and a few peripherals. Sabeel *et al*. [91] have analyzed that feeder automation is the quickest developing pattern among utilities to improve distribution systems' dependability. One of the primary uses of feeder automation is programmed by fault management. Amare *et al*. [92] stated that the future smart distribution feeder would comprise new parts and advancements with improved capacity whose fault conduct cannot be resolved with sureness.

Srivastava *et al*. [93] have realized that the smart protection system is important to fulfill customer demand. Amare *et al*. [94] have designed a model whose primary goals are to decrease the line losses, responsive power flows on the line, and to abstain from switching surge overvoltage because of turning ON/OFF the capacitors. These devices are streamlined for implanted applications that require both preparing usefulness and nimble, responsive cooperation with digital, analog, or electro-mechanical parts [95]. In-home, consumers have an unbounded supply by distribution feeder. Be that as it may, power utilization is restricted by current suffering constraints of distribution wiring.

The relay interfacing algorithm works as follows: The applied voltage and current values detected by the phase detector at the input. The detected quantities are converted into an analog signal to a digital signal. Then voltage and current values detected whether the quantities are in the threshold values. These received digital signals will be stored in relay input memory and then given relay logic works. If the detected value of current and voltage is higher than the system's threshold value trip circuit, it works and ends the feeder system's supply. When the consumer turns more loads ON, the current is flowing into principle wire increments [96]. If the consumer keeps on turning an ever-increasing number of loads, at that point, a cut-OFF is arrived at where the current surpasses the wiring limit causing the PhotoMOS relay to send a signal to the circuit breaker to open the circuit [97]. As it may switch all loads OFF if overload current exceeds is not a smart idea. Here is the proposed efficient model of LV distribution smart feeder overcurrent protection system that comes to play a crucial role and save the circuit and equipment from overcurrent.

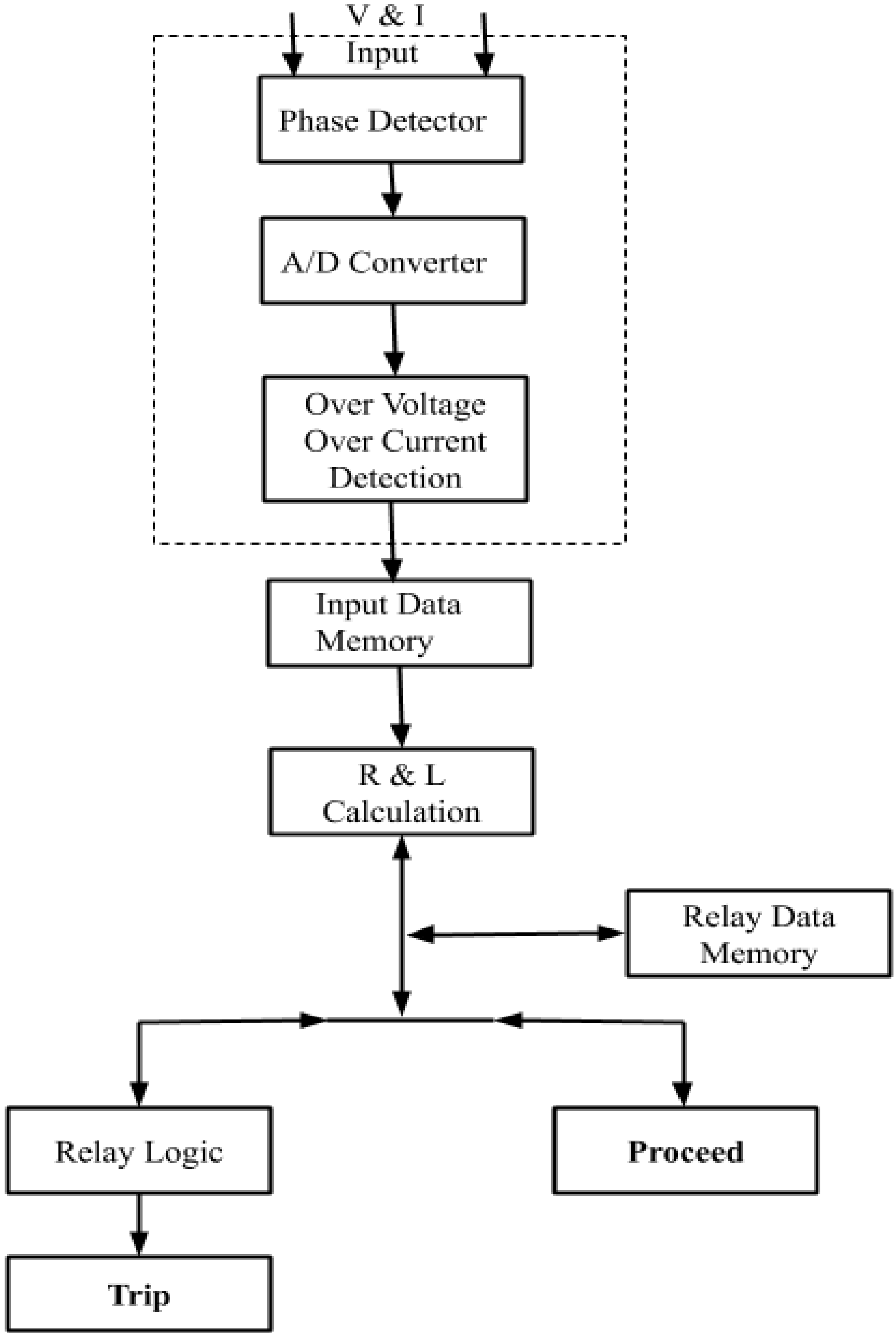


Fig. 4.3 Program for Relay Interfacing and Control

4.3. Proposed Algorithm and Working for Interfacing Solid-State Relay with Microcontroller

A smart feeder is a growing energy distribution framework that is implanted with various types of energy distribution sources, as sustainable power sources, consolidated heat & power, and dispersed energy resources. The advantages of smart feeder arrangement are low transmission and dissemination cost, and, possibly, high dependability, high effectiveness, and low natural effect. Additionally, the administration of the electrical feeder system is getting increasingly problematic. The absence of data at the base feeder, the electricity administration network's status, has been distinguished as the significant obstruction to its successful monitoring and control of the electrical distribution system. This research work presents an advancement of the microcontroller-based smart feeder protection from overcurrent using fast using Solid State relay (SSR) with the goal of viable monitoring and control of the Feeder system.

A microcontroller is a multipurpose, programmable, clock-driven register-based electronic device that peruses double guidelines. Since microcontrollers work on just binary codes, it's important to convert over our analog to digital signal utilizing ADC (Analog to Digital Converter) [98]. The large sparse simulation validation is conducted because the complex system has multiple outputs with different data types. Numerical analyses, such as stability, consistency, convergence, accuracy, error estimation are the indicators to validate the numerical simulation used the numerical indicators to provide validation evidence whether the models are all rightly concerned for predicting the behavior. For example, for a user-friendly interface, the numerical simulation is standardizing into software development. The function is to support embedded systems for specific equipment. Numerical modeling and PC based simulation is normal instruments in most scientific orders. In this manner, scientific projects as executable implementations of models speak to a significant piece of the "output" by concentrating all the scientific software's computational resources. The software's verification is to prove the correctness of scientific software development to support the large sparse simulation. The standardized user interface, User-friendly GUI (Graphical User Interface), HPC (High Performing Computing) based platform, and model testing are the key components for verifying effective tools, checking documents, data aliases, design, code, exclusion of recursion, and program dynamically. The comparison is considered the indicator analysis for benchmarking the superior numerical method, optimum results, and prediction, high resolution of the visualization; thus, the comparison focuses on numerical analysis among different numerical schemes and methods, dimension of the visualization. That provides comparative indicators on the size of sparse simulations and performance behavior across different communication protocols. Fig. 4.5 shows the example of the numerical results for some numerical methods for solving 2D fundamental problems in heat conduction and diffusion process [99]. The proposed algorithm has been developed below:

```
void main()
{
TRISB.F7 = 0;/Makes PD7 a output pin
do
{
PORTB.F7 = 1;//turns on ssr circuit
Delay ms (0.1) ;//0.1 ms delay
PORTB.F7 = 0;//turns off relay
Delay ms (0.1) ;/0.1ms delay
} while (1);
}
```

The transformation procedure of analog to digital sign and microcontrollers working appeared in Fig. 4.4. After getting this data-dependent on the programming given underneath in the relay data memory (ROM/RAM), the microcontroller takes the action of tripping the solid-state relay [22]. To calculate the relay tripping values, Eq. (1), Eq. (2), and Eq. (3) have been used.

$$T = \tau_s\,((I|I_P)^2 - 1) - K_d(\partial\theta|\partial t) \;\ldots\ldots\; (1)$$

where s is Torque, I is applied current, and I is Applied current, I_P is Current value when LED illuminate, K_d is Damping Factor, θ is Angle, TDS is setting angle.

$$\text{TDS} = \frac{\tau_S}{K_D}\ ((I|I_P)^2 - 1)\ \textit{(trip time)}\ \ldots\ldots(2)$$

$$\textit{(trip time)} = \text{TDS}\ \frac{\frac{\tau_S}{K_D}}{\left((I|I_P)^2 - 1\right)} \ldots\ldots (3)$$

When pin PD7 in Fig. 4.7 of the PIC microcontroller goes high, the transistor BC130 turns-ON, and current courses through the relay circuit. One diode D1 associated with an arrangement is used to shield the transistor and the microcontroller during the relay operations. The proposed algorithm and work for interfacing Solid-State Relay (SSR) with microcontroller showed this algorithm. The first step for parallel implementation is rewriting the serial algorithm of numerical methods in single processing executing too concurrently or in parallel algorithms. There are many ways to implement parallel algorithms.

The methodologies of domain or function decomposition and the communication protocol influence the process of parallel programming. Communication protocol for programming the parallel algorithm, PVM (Public View Monitor) used master-slave model, MPI (Multi-Point Injection) used message-passing model, and MDCS (Maintenance Data Collections System) used consumer-generation model, Web technologies and protocols built around the consumer- server model. The system manager is a central part of the MDCS to coordinate the execution of the monitoring system. Moreover, LabVIEW is a model of coordination and operating as a generative communication. Fig. 4.6. shows the flow chart of message passing models among the clients and server. The latest technologies are CUDA (Compute Unified Device Architecture) used a multi-threaded cores model, and LuNA used the data fragmentation model. CPU – GPU with CUDA computing consists of thousands of smaller cores for handling multiple tasks in SIMT (Single Instruction, Multiple Thread) protocols [100], proof that PVM is well suited for solving large sparse numerical simulation compared to MDCS in terms of PPI because of time-consuming on embedded system operations with a high range of rating levels for calling the library.

Figure 4.4 shows the fragmentation model by differentiating the fragmented data and the computation fragments for designing the parallel algorithm. The communication design of the numerical algorithm, concurrent access and synchronization process for sharing the block of simulation, and the load balance feature determine the overall performance and testing for the level of granularity. CUDA is superior programming for CPU-GPU architecture by integrating shared and distributed memory architectures. Based on the generative communication, Gaussian integration with LabVIEW programming language is efficient for predicting chemical properties of benzene on Multicores processor, 2X3TB, WD Black Caviar, 16GB RAM. Dealing with the integrated data and computation fragments, LuNA is highly practical to support a very large numerical simulation up to the terabyte range.

The finer granularity, the greater potential HPC architecture for emerging big data communication between processors. An increase in the simulation can be categorized as a shared, distributed number of processors and the size of the memory and hybrid computing system. Shared memory increases proportionately. Rapid memory access contains multiple processors that can operate for each processor. Granularity is the ratio of independently but shares the same memory computation and communication.

The finest resources of data sharing between tasks are both fast granularity, the greater the potential for parallelism and uniform due to the proximity of memory to CPUs and speed-up, but the greater the overheads of distributed memory consists of several units of synchronization and communication. Some example of the HPC under consideration; NVIDIA, multicore on the open operating system, the familiar communication software PVM, MPI, LuNA, MDCS, OpenMP, CUDA, COMSOL, LINDA and integrated with C++, C, Fortran, 6154 embedded system, the hardware DPCS computational tools MDCS R2011. The operation time of microcontroller-based relay circuits is given in the binary code very low, so the relay tripping operation will be fast, and our feeder system will be safe from the faults [101]. Hence the microcontroller-based solid-state relay will be very in line with the LV distribution feeder system.

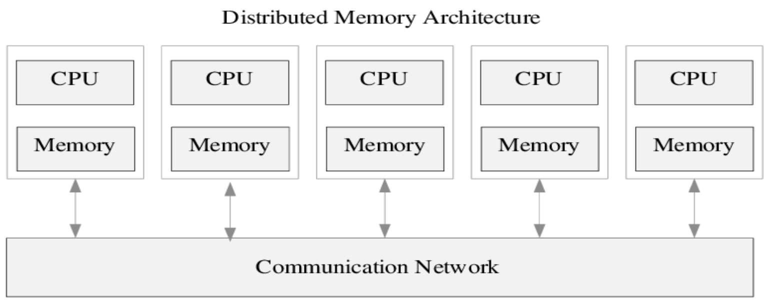


Fig. 4.4 Memory architecture.

4.4 Proposed Model of Microcontroller based Smart Feeder Protection

In power systems, it is usual for the feeders to encounter operational distortion or faults due to exposure to several surrounding conditions. In a feeder system, the relays are responsible for detecting the over-values (voltage, current, resistance, or reactance), enumerate the fault parameters, and further deliver the fault information to supervisory control systems to identify the troubleshooting location [102]. In that situation, incorporating a solid-state relay that provides many desirable benefits such as accurate tripping, less disturbance, and enhanced fault parameters to the subsequent system seems appropriate [103].

In Fig. 4.6, an efficient feeder protection system has been proposed utilizing a PhotoMOS device in relay operation. The proposed model encapsulates the advantages of the PhotoMOS relay circuit within the overall system that consists of other building blocks such as a step-down transformer (6 V), rectification assembly, sensing devices for transduction, and an automation microcontroller to enable the circuit breaker's operation. In this model, the authors have proposed a protection system consisting of an inlet with an AC 220 V transmission line as the source connected to a step-down transformer (220/6 V). With the help of a rectifying circuit, i.e. a bridge rectifier is connected in series to convert the feeder voltage from a 220-Volt AC supply to a 6-Volt DC. This DC supply connected with sensing devices to observe the circuit's abnormalities and provide information to microcontroller circuit units. Any change in AC voltage can bring a power cut or a weak signal to affect the DC voltage that a microcontroller experiences changes. Thereafter, such changes are logically evaluated if the feeder still can supply electricity without electrical distortions [104]. When the distorted values rise above the system's

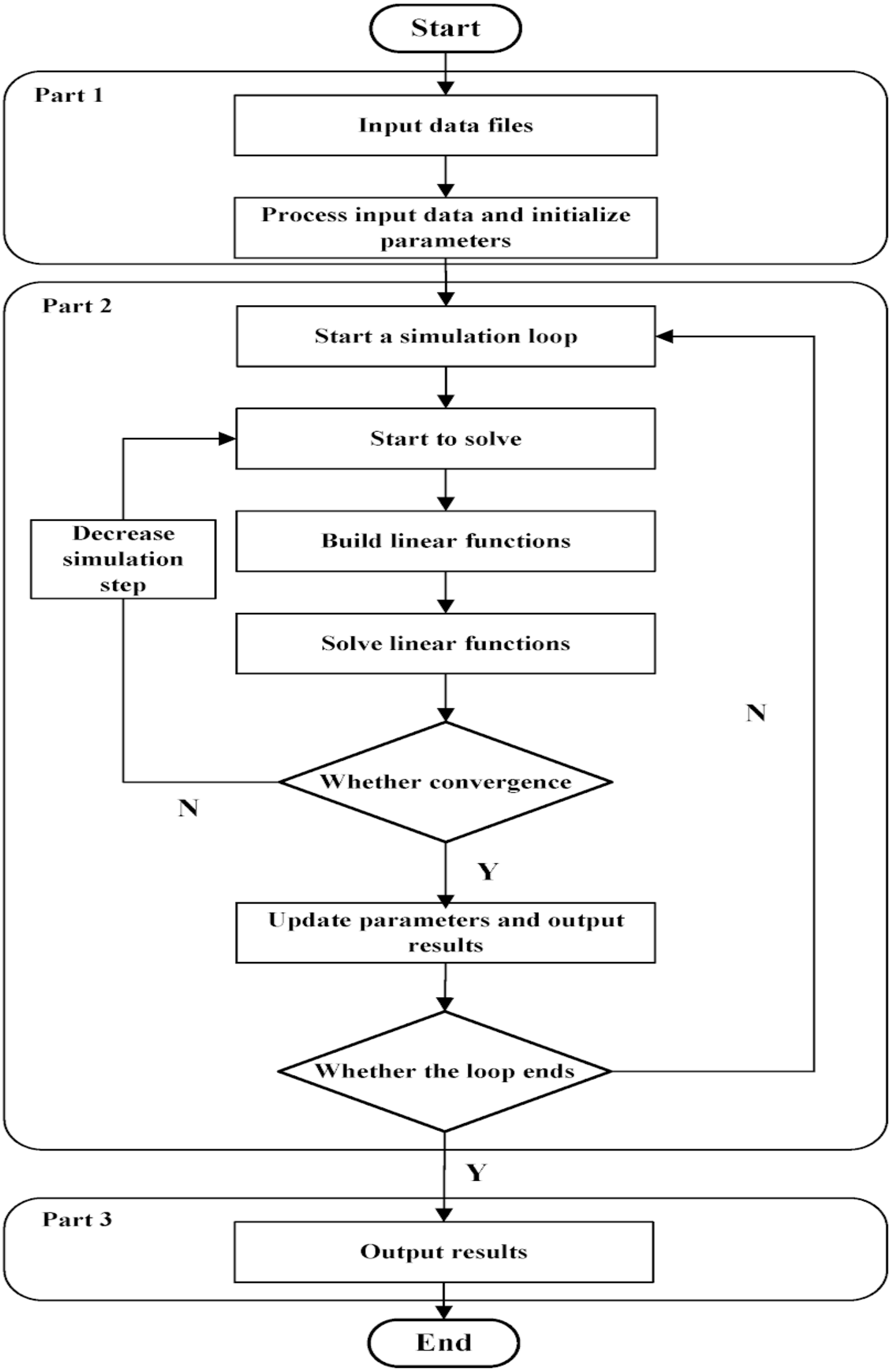


Fig. 4.5 Microcontroller software algorithm structure.

predetermined threshold values, the microcontroller sends an immediate signal to the PhotoMOS relay protection system connected with microcontrollers pins through MOSFET's driver switching [105].

The PhotoMOS relay protection system sends an immediate signal to the circuit breaker to break the system so no current and voltage can flow through the circuit and assures electrical equipment remains safe. The microcontroller circuit is connected with the IoT cloud services to send an immediate alert signal to the live monitoring system, then the PhotoMOS relay protection system sends an immediate signal to the circuit breaker to break the system so no current and voltage can flow through the circuit and assures electrical equipment remains safe.

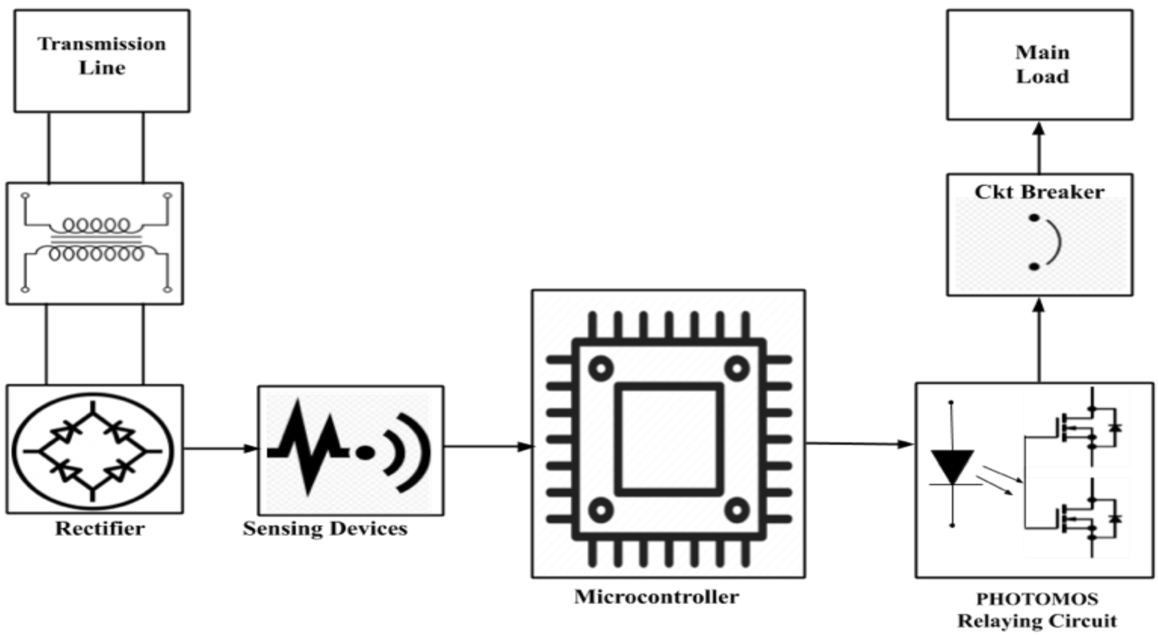


Fig. 4.6 Proposed feeder protection system using PhotoMOS relay [52].

4.5 Results of the System

The simulation of microcontroller-based LV feeder protection system design and results have been shown in Fig. 4.7 and Fig. 4.8. The results of the overcurrent analysis of dynamic LV feeders utilizing microcontroller show that if the overcurrent value increases, the cut-off value of the SSR inversely decreases, as shown in Fig. 4.8.

The simulation result of this work shows that the system can control and monitor the feeder protection system from overcurrent with Microcontroller viable results achieved

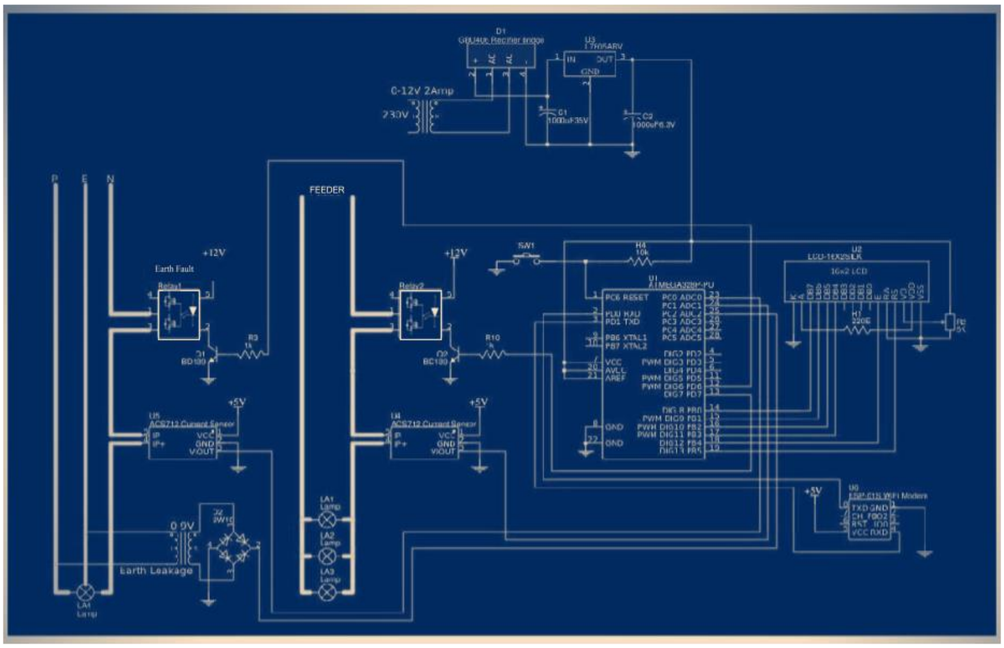


Fig. 4.7. Microcontroller based feeder protection system simulation.

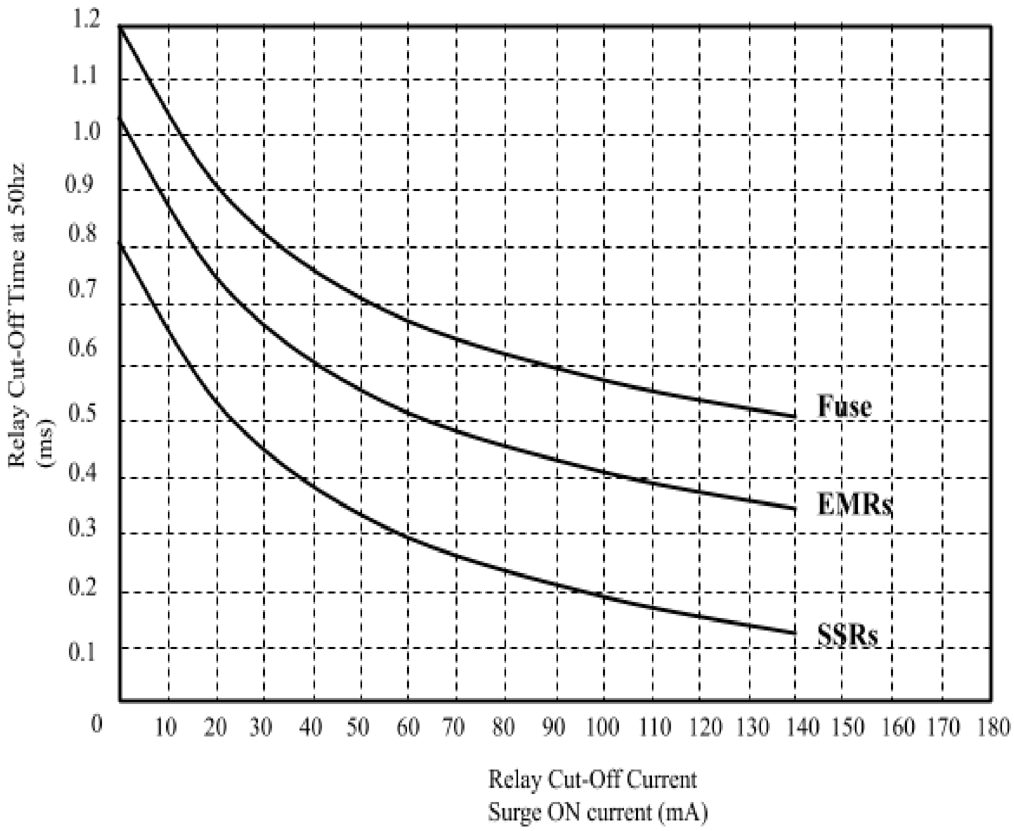


Fig. 4.8. Relay cut-off time characteristics.

with this system. In this research work, PhotoMOS relay cut-off time and overcurrent parameters have been calculated. The achieved results show the significant results over the traditional EMR circuit protection. The PhotoMOS relay operating cut-off time 1.2ms, 1.3ms, and 1.4ms with respect to the overcurrent values 0.8, 1.0, and 1.2 mA, which is very less than the EMR protection system. A 220 V electricity network was utilized to test the reliability and quality of the microcontroller-based PhotoMOS circuit. The proposed approach is demonstrated to be compelling in both grids associated and islanded modes. The cut-off time of the relay has been achieved using simulations and equations given above.

With the calculation value of Eq. (1), Eq. (2) and Eq. (3), we have successfully calculated the relay trip circuit values. The achieved results show significant results over the traditional EMR circuit protection relay operating cut-off time 1.2, 1.3, and 1.4 ms with respect to the overcurrent values 0.8, 1.0, and 1.2 mA, which is very less compared to the EMR protection system. It is commonly a decent practice to adjust down to the closest incentive to give extra headroom. Using a graph, for example, the one underneath will also help choose a cut-off value of our proposed model. To protect the LV feeder system; overall, three tests have been conducted based on the results proposed circuit of a microcontroller-based system shows very positive results for future research work. These characteristics show the cut-off time and overcurrent values.

4.6 Conclusion

This work furnishes that microcontroller-based LV feeders' performance using a solid-state relay is very significant for the electrical distribution system. Microcontroller and PhotoMOS relay play a crucial role in present-day power system security to detect and segregate various sorts of electric circuit faults. The choice of SSR and Microcontroller relies upon power rating, voltage, current rating, the impact of outside elements, etc. The design and implementation of the security of a disturbed electric system utilizing a microcontroller-based defensive system given. Because of the utilization of semiconductor, arc less fast switching of the system is conceivable with which the effectiveness, unwavering quality, and lifetime of the insurance unit increments. The achieved results show significant results over the traditional EMR circuit protection relay operating cut-off time 1.2, 1.3, and 1.4 ms with respect to the overcurrent values 0.8, 1.0, and 1.2 mA, which is very less compared to the EMR protection system. The significant switching time of the system for the open and closed-circuit operations have been obtained using the Solid-State Relay device that resulted in switching time ratios (T_{OFF}/T_{ON}) 0.03 and 0.06, respectively. The result shows the considerable gain in the operational switching time parameter using the solid-state relay device over the conventional Electromechanical (EM) relays. The obtained results also assure that the SSR is a useful relay circuit element. In this present model, the authors have proposed a protection framework consisting of an inlet with an AC 220 V transmission line as the source associated with a step-down transformer (220/6 V).

With an electric system against overcurrent, under-voltage, and earth fault utilizing a strong microcontroller presently unveiled. However, it is suggested that different methodologies ought to be utilized to supplement this methodology. The assurance of the power network framework is a fundamental and unavoidable procedure to guarantee the LV feeder's security since the faults are inescapable. The proposed model can further be utilized to monitor and control relaying circuits pertaining to the Internet of Thing (IoT) based smart feeder protection circuits for system performance analysis. The compatibility of available SSRs with the IoT system and real comparison in all the aspects would be a challenge and a field of further research in this area.

Chapter-5

PROPOSED MODEL FOR FEEDER PROTECTION AND ITS IMPLEMENTATION WITH IoT APPLICATIONS

A Smart feeder is a developing power distribution network embedded with a blend of different kinds of energy distribution sources, as sustainable energy sources, united heat and power, and scattered energy assets. The smart feeder system, being an intermediary component for the distribution of energy to the local transformer, protects against the event of any fault, turns into a necessity in the power systems. This research work presents an advancement of the Internet of Thing (IoT) based monitoring and controlling (Voltage, Current, and Temperature) of the LV Smart feeder system. The absence of data at the base feeder, the electricity administration network's status, has been distinguished as the significant obstruction to its successful monitoring and control of the electrical distribution system. To tackle the issues in the current smart feeder controlling and monitoring, utilizing the IoT innovations, present-day communication, data handling, authors planned and achieved a smart feeder controlling and monitoring framework dependent on energy IoT [106]. The framework acknowledged continuous observation of feeder system devices and working conditions, information knowledge examination, alert linkage, and visual showcase. It gave help backing to feeder operation, and maintenance improved the activity and the intelligent smart feeder's management level.

5.1 IoT in Smart Feeder

The arrangement of IoT technologies in a smart feeder system would revive the smart feeder improvement and redesign the power movement organizations getting progressively lively, engaging, responsive, and open. In this research work, a smart feeder protection system has been proposed with the IoT based monitoring and controlling of Voltage, Current, and Temperature (V, I, and T) of the system. The Internet of Thing (IoT) technologies provides two-way communication systems between the electricity provider and consumer shown in Fig. 5.1.

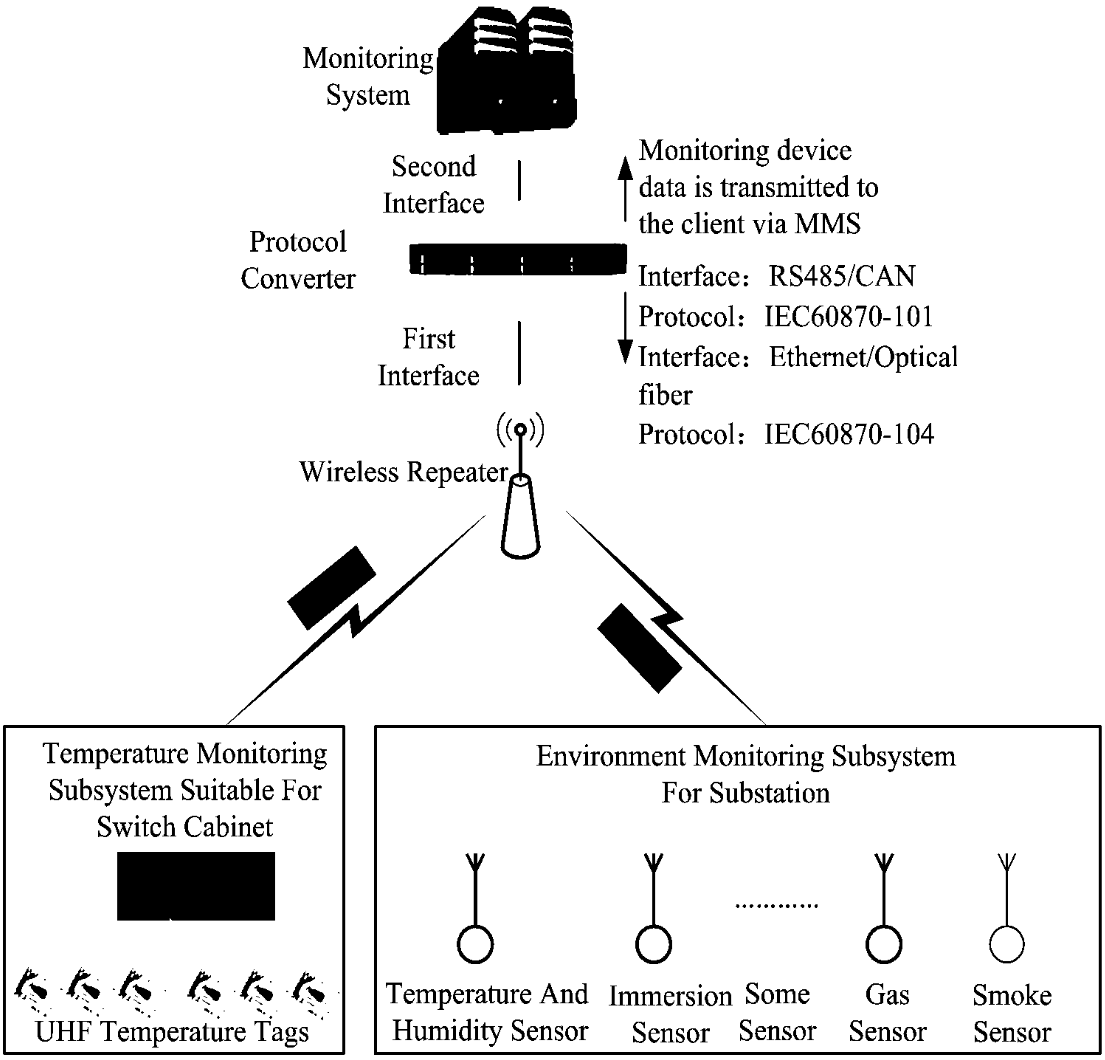


Fig. 5.1 Feeder monitoring architecture [107].

As an idea, the smart grid is a combination of power generation, transmission, and distribution network improved by advanced digital control, monitoring, and broadcast communications abilities [107]. IoT allows effective data execution and working at all stages. IoT is the update of mobile, home, and implanted applications to be essential for a system of associated physical devices with sensors that both import and export information. Smart feeder system performance and constant electricity distribution to the consumers are some of the significant problems nowadays. Therefore, fast safety and protection plans must be effective enough to conquer issues within a short period [108]. Thereafter, the smart grid technologies have grown, and the Internet of Things (IoT) innovation has been broadly utilized in the grid distribution network. It is naturally incorporated with the power innovation, which significantly improves the intelligence degree of the grid distribution. In any case, at the current stage in the smart grid network, the degree of setting up intelligent feeder data monitoring in joins smart feeder and understanding the general controlling, monitoring, and the understanding of feeder hardware and operation status should be improved [109].

The devices, utilizing embedded sensors, assemble information about the nature in which they are working and how they are being utilized. The sensors are incorporated into each physical device, from electrical machines to lights to cell phones and tablets to scanner tags on non-electrical things. At that point, the devices share the information progressively about their operational state through the cloud to an IoT stage where there is an all-inclusive language by which all IoT gadgets impart. The accumulated information is then dumped or coordinated, and an informal investigation is performed.

In the early 80s, the IoT was introduced to refrigerator appliances to check if their drink is available. Constantly 2013, the IoT had developed into a system utilizing different technology, extending from the Internet to wireless communication and from Micro-Electromechanical Systems (MEMS) to embedded systems. The customary automation (counting the computerization of structures and homes), wireless sensor systems, GPS, control frameworks, and others all help the IoT, as shown in Fig. 5.2. The IoT systems can be interconnected with any other devices, privacy and security are the main advantages [110].

Residential users regularly get the power from overhead or underground feeders exuding from utility-substations. The LV distribution smart feeder overcurrent protection and monitoring system is a key apparatus for power distribution utility to make the power system sound solid, sheltered, and effective without contributing a lot [111]. In this proposed low voltage feeders exuding from a substation are observed by microcontrollers, relay circuits, and a circuit breaker, which will open when a fault is identified. Programmed microcontroller circuit recloses also introduced to isolate the feeder in this way, limiting the effect of faults.

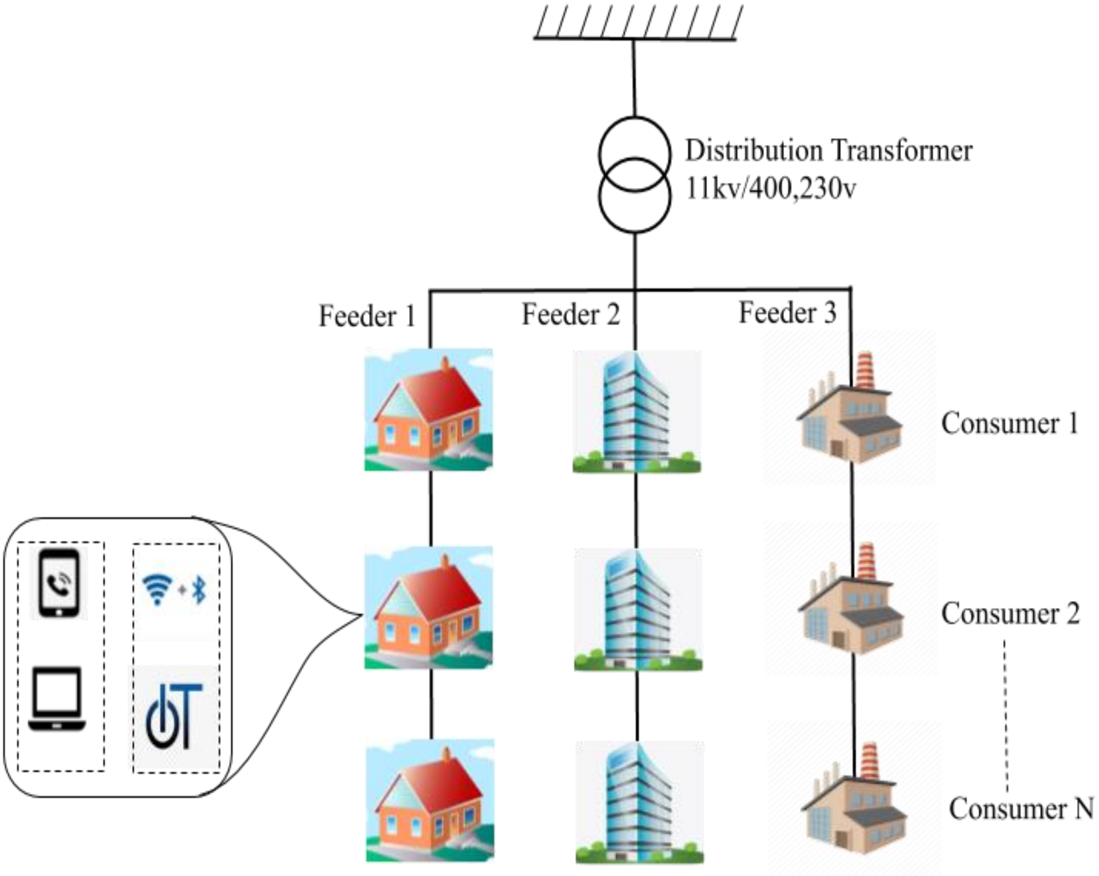


Fig. 5.2 LV smart feeder with IoT block design.

5.2. Microcontroller and IoT Aspect in Low Voltage (LV) Smart Feeder System

The Low Voltage(LV) distribution smart feeder framework conveys power from the transmission network and carries it to consumers. The smart feeder system, being an intermediary element for the distribution of power to the regional transformer.

In the power system, electricity conveyance is considered the end-stage power distribution to the consumers [112]. IoT applications for smart feeder systems allow for more accurate and precise ways of monitoring and controlling the smart grid systems. In smart feeders, IoT systems are programmed using microcontrollers; these programming systems are designed to process automatically [113]. The enormous part of introduced limits in the Medium Voltage (MV) and Low Voltage (LV) dissemination network stayed without legitimate monitoring, control, and outside the typical Supervisory Control and Data

Acquisition (SCADA) utility frameworks, as shown in Fig. 5.2 and Fig. 5.3. But these days, all-electric systems are moving towards automation. These automation systems are a combination of the power system, control system, and mechanical system controlled by an IoT based microcontroller system. Microcontroller systems are more efficient and flexible. Using microcontroller and IoT systems, authors can get live data of feeder lines voltage, current, and temperature to monitor and control them accordingly [114]. If the feeder line voltage and current increase above or lower to the threshold value, the IoT system sends an immediate signal of alert in this research work.

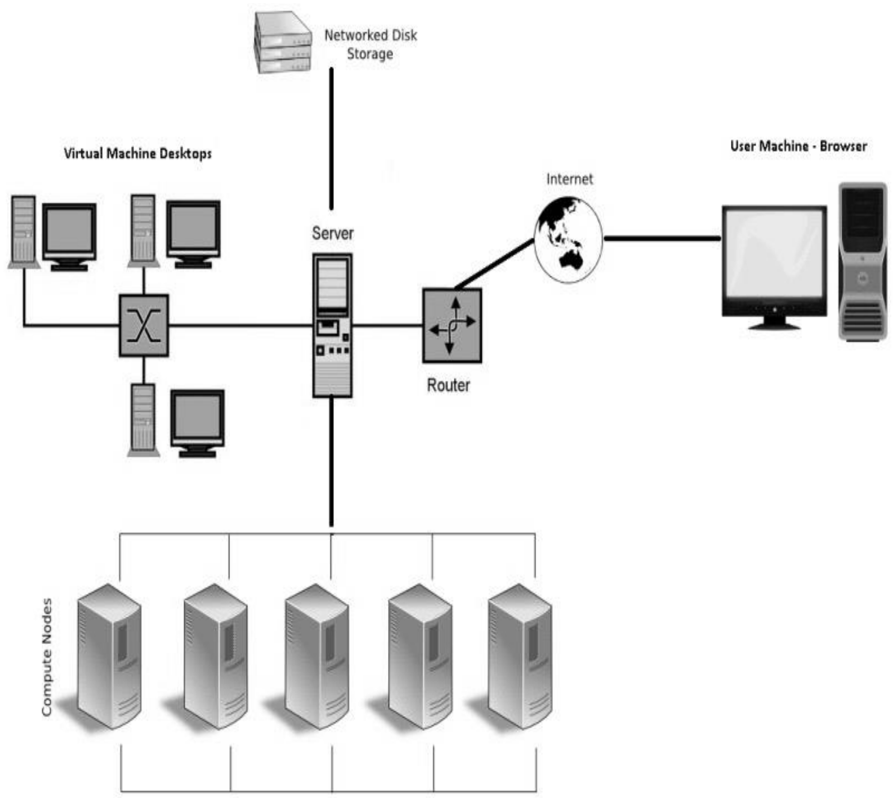


Fig. 5.3 IoT monitoring systems [95].

With the power stations, it is necessary to decrease the transmission losses in overhead lines for that produced electricity has to be stepped up to a higher level so the power losses in produced electricity transmission will be less and make it increasingly productive [115]. To make transmission voltage progressively usable for the consumer's transmitted line voltage has to be stepped down. The transmission electrical cables will enter a dispersion substation where the voltage will be stepped down to low voltage levels; then, it will be appropriated for use by industries, businesses, and residential consumers, as shown in Fig. 3. Power reliability assessment is the most significant parameter for opportune healing measures to give continuous and safe power supply to end consumers.

5.3 Proposed Model of Smart Feeder Protection System with IoT

In the power system, it is common for the feeders to experience operational contortion or faults inferable from the presentation to a few encompassing conditions. In a Smart feeder system, the microcontroller-based PhotoMOS relay circuits are liable for detecting the over-values (voltage, current, resistance, or reactance), list the fault parameters, and further, convey the fault data to IoT based developed administrative control frameworks to distinguish the fault area.

In that circumstance, fusing a microcontroller-based PhotoMOS relay that gives numerous desirable advantages, for example, accurate tripping, less disturbance, and enhanced fault parameter to the resulting framework appear to be proper. A PhotoMOS Solid State Relay (SSR) is an electronic switch that works on 'photo-voltaic' impacts to switch high voltage/current using low power circuits utilizing. For fast switching, MOS innovation is applied to its control terminals. To associate an SSR with a microcontroller, it needs a driving circuit shown in Fig. 5.4.

In Fig. 5.4, an effective LV distribution smart feeder protection system has been proposed using an IoT-based microcontroller & solid-state relay circuit in operation. The proposed model embodies the benefits of a microcontroller-based solid-state relay circuit inside the general system that comprises of other structure squares, for example, step-down transformer (6 V), rectification assembly, sensing devices for transduction, and an automation microcontroller to enable the operation of the circuit breaker.

With the assistance of a rectifying circuit, for example, a bridge rectifier is associated in series to convert the feeder voltage from 220-V AC supply to a 6-V DC. This DC supply connected with sensing devices to observe the circuit's abnormalities and provide information to microcontroller circuit units. Any change in AC voltage can bring a power cut or a weak signal to affect the DC voltage that a microcontroller experiences changes. Thereafter, such changes are logically evaluated if the feeder still can supply electricity without electrical distortions.

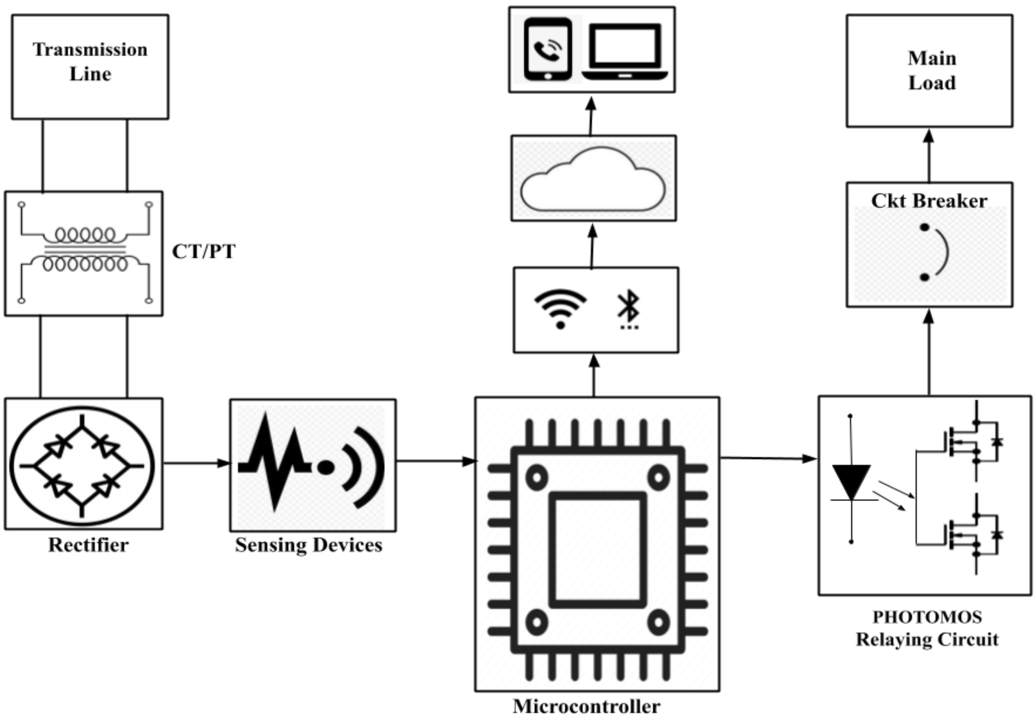


Fig. 5.4 Proposed model of the Feeder Protection system with IoT [111].

When the distorted values rise above the system's predetermined threshold values, the microcontroller sends an immediate signal to the PhotoMOS relay protection system connected with microcontrollers pins through MOSFET's driver switching. The microcontroller circuit connected with the IoT cloud services to send an immediate alert signal to the live monitoring system, then the PhotoMOS relay protection system sends an immediate signal to the circuit breaker to break the system so no current and voltage can flow through the circuit and assures electrical equipment remains safe.

5.4 Hardware and Software Implementation of the Protection System

The architecture of the smart feeder monitoring and controlling system is shown in Fig. 5.5. The general architecture of the framework comprises two interfaces:

- The primary interface is the interface between the observing device (wireless repeater) and the protocol converter. The subsequent interface is the interface between the convention converter and the brought together access passage. This part incorporates the transmission method of the energy network and the open system. The power network embraces the standard interface convention of the energy framework, and the open system adheres to the norm of the open system [116]. The primary interface: the correspondence protocol indicates the interface between the monitoring and the convention converter to meet the correspondence necessities between the monitoring device and the convention converter.

- The secondary interface: The correspondence protocol indicates the interface between the convention converter and the system level brought together the access door, as shown in Fig. 5.5 and Fig. 5.6. This part briefly keeps the force business-standard IEC 61850 and IEC 60870-1-104. The relay interfacing algorithm works as follows: The applied voltage, temperature, and current values detected by the phase detector at the input. The detected quantities are converted into an analog signal to a digital signal. Then voltage, temperature, and current values detected whether the quantities are in the threshold values. These received digital signals will be stored in relay input memory and then given relay logic works. If the detected value of current, temperature, and voltage is higher than the threshold value trip circuit of the system works and ends the feeder system's supply.

The open system's transmission receives the open system's correspondence convention, which can get to the common information base through the protected admittance stage. The software implementation of this system shown in Fig 5.7.
Every subsystem can screen every application scene autonomously and can likewise cooperate. Smart feeder condition observing subsystem is chiefly made out of sensors of different capacities, for example, voltage, current, and temperature sensors for checking the voltage, current, and live temperature values of the protection system. UHF temperature checking subsystem comprises UHF temperature labels and UHF per user. UHF temperature labels incorporate RFID and detecting capacities, sensors, and their estimation circuits utilize wireless energy transmission to provide power and afterward measure temperature and store information [117]. With the help of all the sensors, connected authors can have all the data to control the system. The microcontroller circuit handles the gathered system information, and the protocol converter receives the direct command from the microcontroller circuit. This research work aims to implement the software design for a feeder system to monitor and control (V, I, and T).

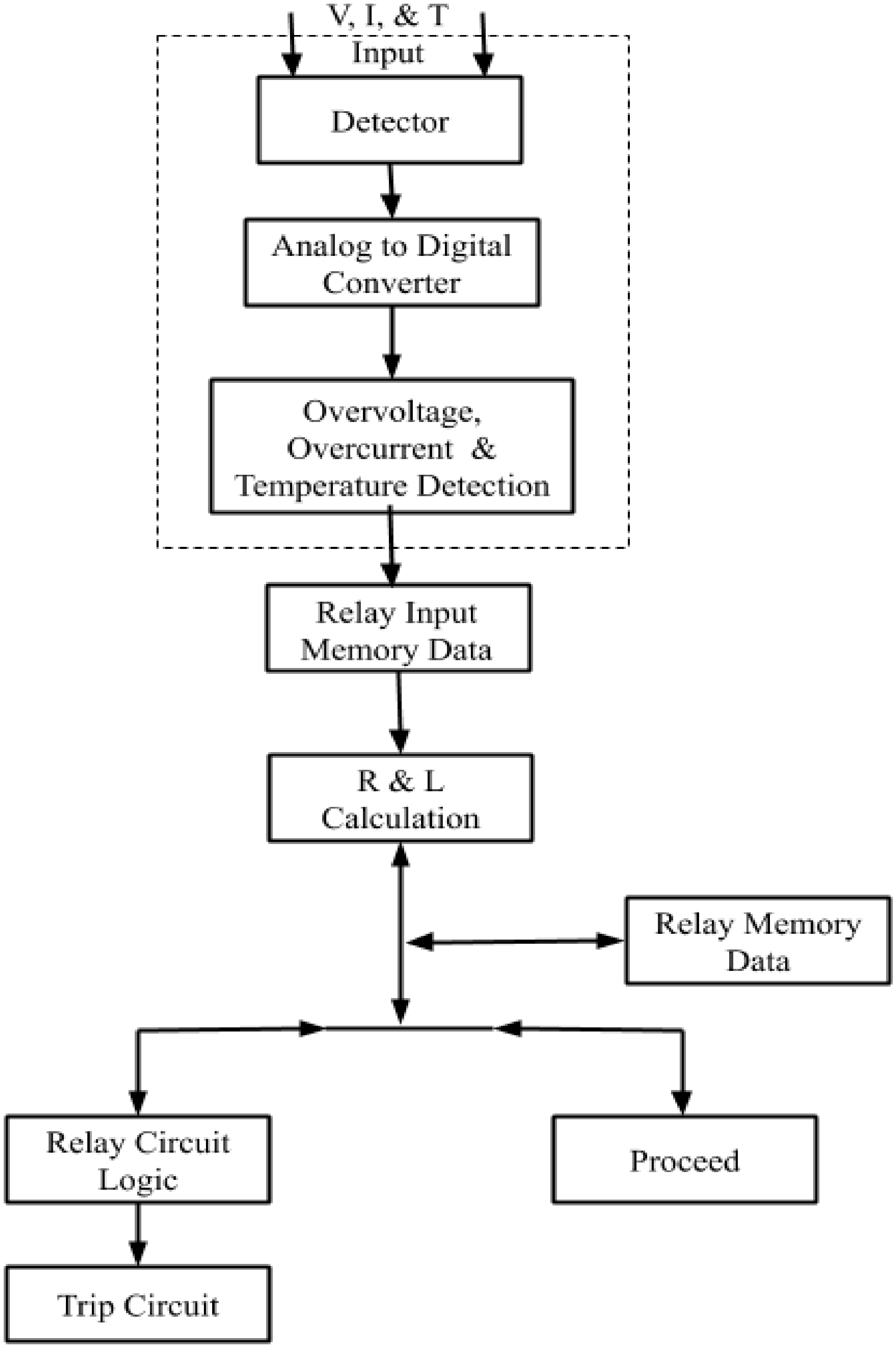


Fig. 5.5 Microcontroller with Relay Working Block Diagram.

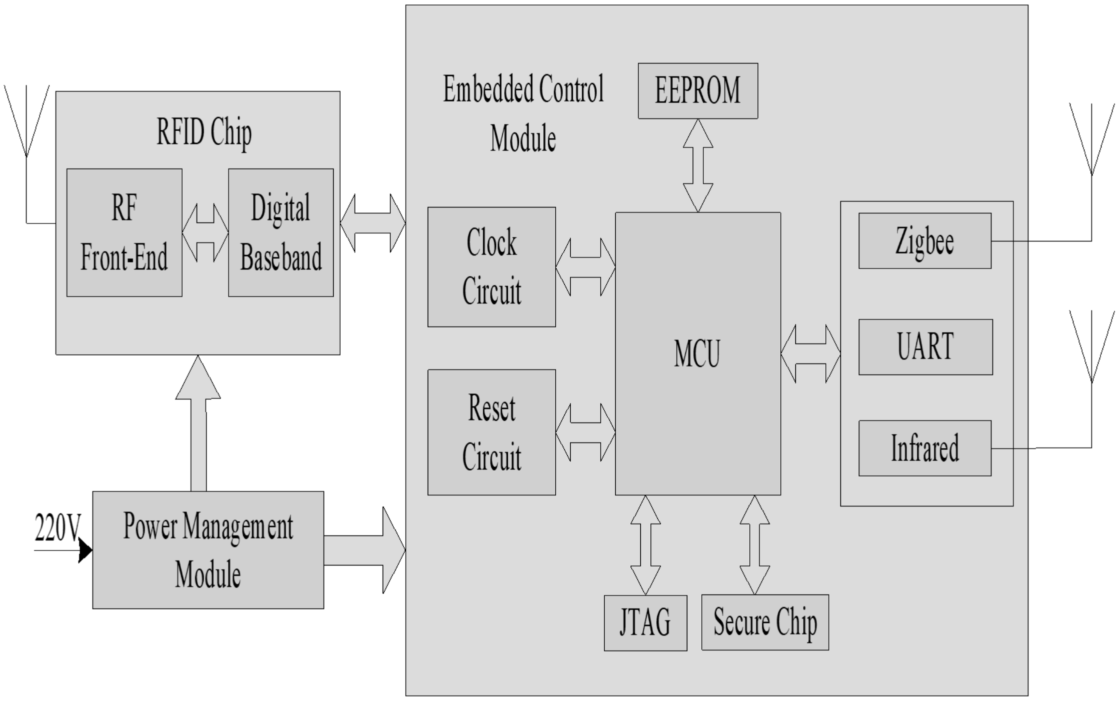


Fig. 5.6 Hardware for Sensor Devices

```
function _class(name){
  return document.getElementsByClassName(name);
}

let tabPanes = _class("tab-header")[0].getElementsByTagName("div");

for(let i=0;i<tabPanes.length;i++){
  tabPanes[i].addEventListener("click",function(){
    _class("tab-header")[0].getElementsByClassName("active")[0].classList.remove("active");
    tabPanes[i].classList.add("active");

    _class("tab-indicator")[0].style.top = `calc(80px + ${i*50}px)`;

    _class("tab-content")[0].getElementsByClassName("active")[0].classList.remove("active");
    _class("tab-content")[0].getElementsByTagName("div")[i].classList.add("active");

  });
}
```

(a)

```
$('form.form-voltage').submit(function(e){
    e.preventDefault();
    var voltage = Math.floor(Math.random() * 250) + 1;
    var current = Math.floor(Math.random() * 10) + 1;
    var temperature = Math.floor(Math.random() * 150) + 1;
    console.log(voltage, current, temperature);
    if(voltage > 230 || current > 5 || temperature > 100){
        $('span.voltage-message').addClass('error').remove('success').html('<br>Alert! Feeder is in
            Danger! <br><br>Voltage = '+voltage+' V ; <br><br>Current = '+current+' A ; <br><br>
            Temperature = '+temperature+' C');
    }
    else{
        if(voltage < 230 || current < 5 || temperature < 100){
            $('span.voltage-message').addClass('error').remove('success').html('<br>Alert! Feeder is in
                Danger! <br><br>Coltage = '+voltage+' V ; <br><br>Current = '+current+' A ; <br><br>
                Temperature = '+temperature+' C');
        }
        else{
            $('span.voltage-message').addClass('success').remove('error').html('<br>Alert! Feeder is in
                Safe! <br><br>Voltage = '+voltage+' V ; <br><br>Current = '+current+' A ; <br><br>
                Temperature = '+temperature+' C');
        }
    }
});
```

(b)

```
<!DOCTYPE html>
<html>
<head>
    <title></title>
  <meta name="viewport" content="width=device-width, initial-scale=1">
    <link rel="stylesheet" type="text/css" href="style.css">
</head>
<body>
    <div class="tabs">
        <div class="tab-header">
            <div class="active">
                <i class="fa fa-code"></i> Feeder Live Data
            </div>
        </div>
        <div class="tab-indicator"></div>
        <div class="tab-content">
            <div class="active" style="padding-left: 50px; margin-top: -20px;">
                <h4>Voltage (current value : 230V) <br><br> Current (current value : 5 A) <br><br> Temperature (current value : 100
                C)</h4>
                <p>
                    <form class="form-voltage">
                        <input type="submit" name="voltage-button" value="Feeder Performance">
                    </form>
                    <span class="voltage-message" style="padding-top: 20px;"></span>
                </p>
            </div>
        </div>
    </div>
    <script src="https://ajax.googleapis.com/ajax/libs/jquery/3.5.1/jquery.min.js"></script>
    <script type="text/javascript" src="script.js"></script>
</body>
</html>
```

(c)

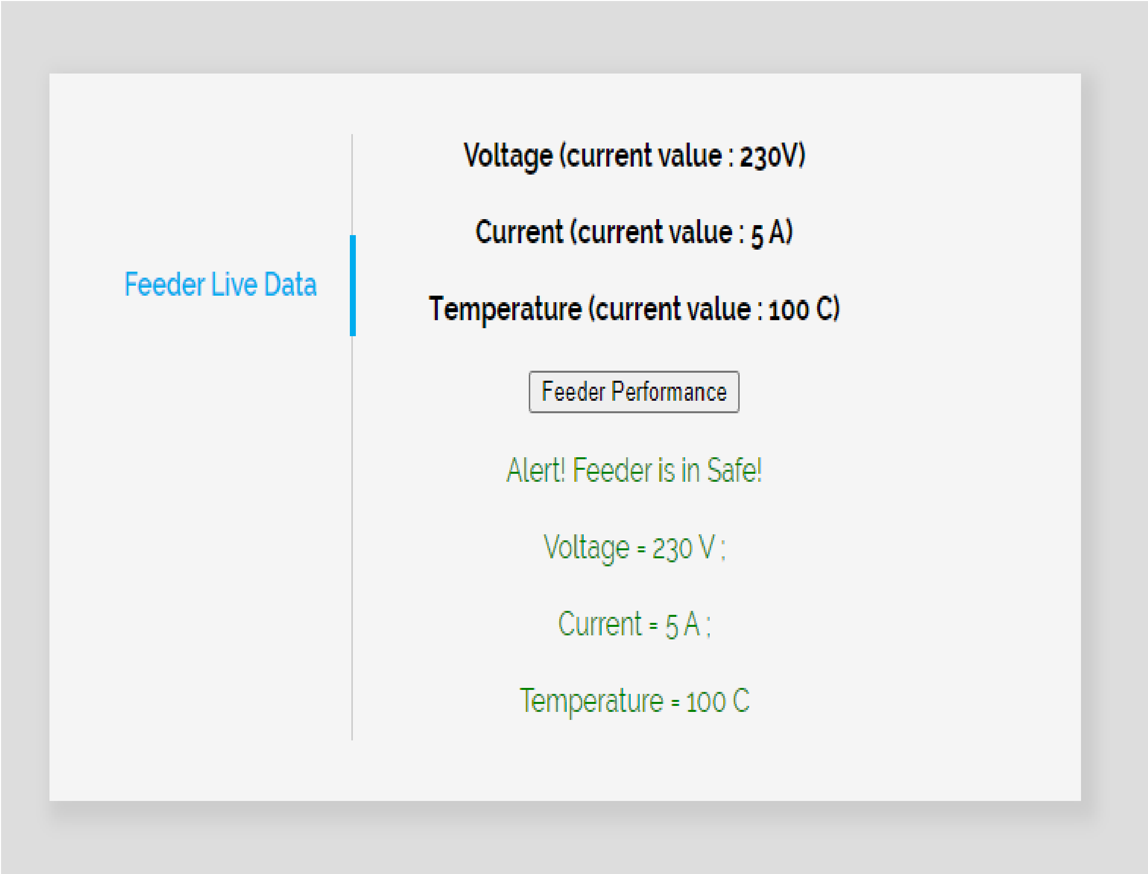
Fig. 5.7 (a) NC (b) FC and (c) FC Software Implementation of IoT Protection System.

To implement a protection system, software should have the following functions: System should receive the data from wireless receiver, the monitoring data of the system is communicated by SMS and the users, and the convention converter alludes to the IEC61850 standard, Sending the downlink orders of the SMS users to monitor, information gathering with microcontroller capacities, sensor demonstration, Setting up the threshold value of the system (V, I, and T). In this system, the alarm function has been set up with the help of software of the system. In the case of overvaluing the quantity, an immediate alarm system can be activated, and to manage all the device equipment management system has been set up.

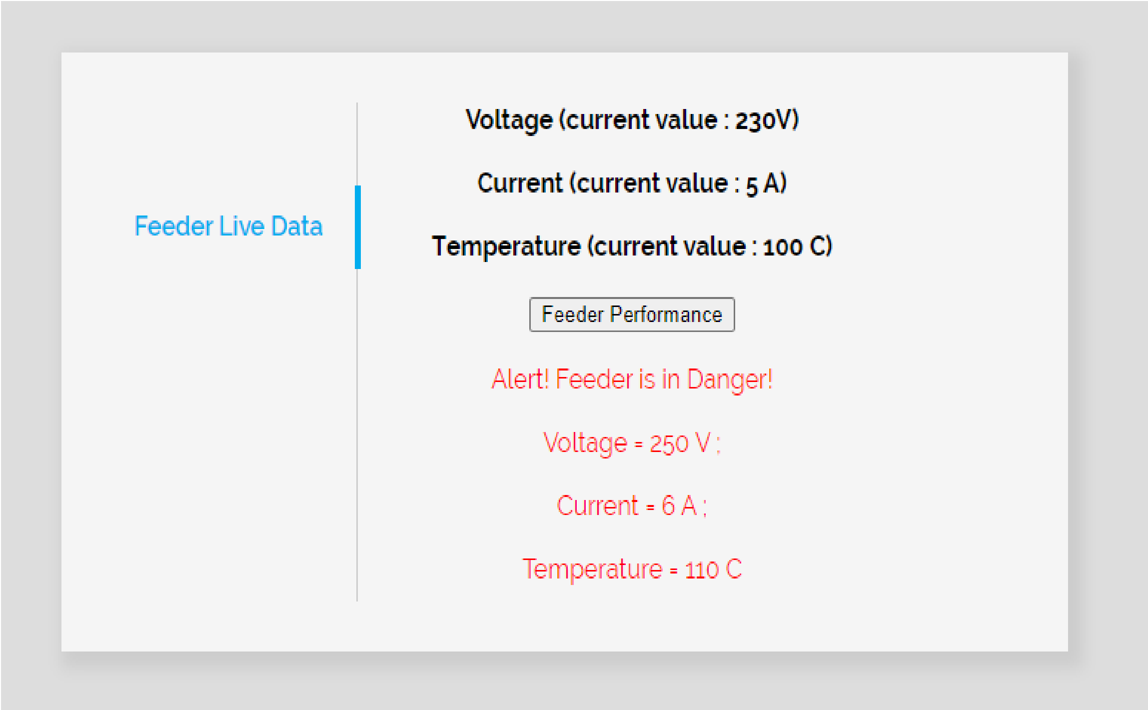
5.5 Results and Discussion

The developed software system for LV smart feeder systems have been shown in Fig. 5.7 and Fig. 5.8. The results of the monitoring and analysis of dynamic LV feeders utilizing IoT and microcontroller is shown in Fig. 5.8 that if the overcurrent value increases or decreases from the cut-off value in the developed IoT system sends the immediate signal as shown in Fig. 5.8. In this research work, relay, cut-off time, and overcurrent parameters have been calculated with IoT-based developed software, as shown in Fig. 5.5 and Fig 5.6. The achieved results show the significant monitoring and controlling results over the traditional circuit protection. The authors have recorded and shown that the IoT system can capture the slightest fault or value change in the system, and an alert signal will be sent immediately to resolve the system's fault. It is commonly a decent practice to adjust down to the closest incentive to give extra headroom.

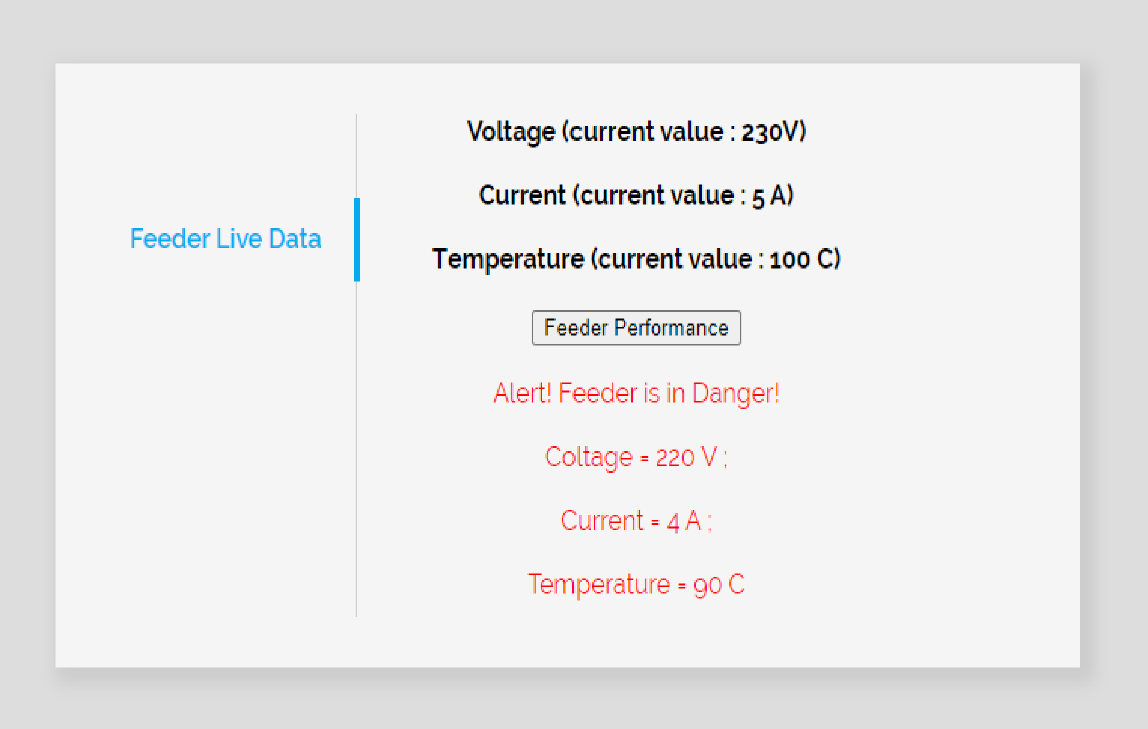
To protect the LV feeder system, overall, three IoT system tests have been conducted based on the results proposed circuit of IoT and microcontroller-based system shows very positive results for future research work. These results show the alert signal time and overcurrent values.



(a) Normal Operation



(b) Fault Condition



(c) Fault Condition

Fig. 5.8 IoT Based Live Monitoring and Alert System for LV Smart Feeder.

5.5 Conclusion

In this research work, a unique IoT based monitoring and controlling framework has been created by utilizing open source programming, measured, simulations, and ease parts. With this framework, system data can be gained from various sensors and observed in different conditions, such as LCD, PC, cell phones, and tablets persistently. This work also furnishes that microcontroller-based LV feeders' performance using a solid-state relay is very significant for the electrical distribution system.

The created system has been tested on a model LV smart feeder. It was seen that the information collection, count operations, and output signals as per the cut-off esteems, administration life, the executives, recording tasks, and warning frameworks were working without an error. Subsequently, this framework gives a minimal effort option compared to significant expense proficient checking frameworks. The design and implementation of the IoT based system of a disturbed electric system utilizing a microcontroller and software-based defensive system given. Because of the utilization of semiconductor devices in the protection system, arc less fast switching of the system is conceivable. The effectiveness, unwavering quality, and lifetime of the insurance unit increments. In conclusion, the conceptual framework performs a more comprehensive perspective based on future software system design dealing with the next- generation of HPC architecture system and assessing the environmental and societal implications of this big data emerging technology and enabling decision support for data science.

With an electric system's safety against overcurrent, under-voltage, earth fault, and temperature, a strong IoT-based system is presently unveiled. However, it is suggested that different methodologies ought to be utilized to supplement this methodology. The assurance of the power network framework is a fundamental and unavoidable procedure to guarantee the LV Feeder's security since the faults are inescapable. This developed IoT system is capable of performing in any difficult condition for LV smart feeder protection.

The proposed model can further monitor and control relaying circuits about the IoT based smart feeder protection circuits for system performance analysis. The compatibility of available SSRs with the IoT system and real comparison in all the aspects would be a challenge and a field of further research in this area.

Chapter-6

CONCLUSIONS AND FUTURE WORK

A novel model of feeder protection system using enhanced PhotoMOS relay circuits has been proposed. The switching performance has been derived from the transfer characteristics of the PhotoMOS device. In this research work (thesis), a novel model for feeder protection systems has been proposed to monitor, control, and incorporate the enhanced switching characteristics of PhotoMOS solid-state relay.

6.1 Conclusions

The used PhotoMOS relay is operating at cut-off time 1.2 ms, 1.3 ms, and 1.4 ms concerning the overcurrent values of 0.8 mA, 1.0 mA, and 1.2 mA, respectively is significantly less than the EMR protection system. The significant switching time for the open-circuit and closed-circuit operations was obtained using the PhotoMOS device, which resulted in switching time ratios (T_{OFF}/T_{ON}) 0.03 and 0.06, respectively. A 220 V electricity network was utilized to test the reliability and quality of the microcontroller-based PhotoMOS circuit. The result shows the considerable gain in the operational switching time parameter using the PhotoMOS device over the conventional Electro-Mechanical (EM) relays. The obtained results also assure that the PhotoMOS is a useful relay circuit element and makes it suitable for the Internet of Things (IoT) applications. The large sparse simulation for emerging big data assessed by the HPC (High-Performance Computing) platform and configured by communication software with a specific message-passing protocol. The big data analytic solves the grand challenge application involving huge data and large sparse matrix of the complex system modeling and nano-scale computation and large sparse simulation. Thus, parallel computing and methodology is the tool to support the big data emerging on nanotechnology theory, model, and simulation. Parallel performance analysis and numerical results are significant indicators for big data analytic in terms of time execution, speed-up, efficiency, effectiveness, temporal performance, and granularity. In addition, model validation, scientific software verification and performance comparison in numerical schemes and methods, the architecture of HPC, size of matrices, number of processors, cores or multi-thread, and its communication software for solving multi-dimension models are analyzed.

This work furnishes that microcontroller-based LV feeders' performance using a solid-state relay is very significant for the electrical distribution system. Microcontroller and PhotoMOS relay play a crucial role in present-day power system security to detect and segregate various sorts of electric circuit faults. The choice of SSR and Microcontroller relies upon power rating, voltage, current rating, the impact of outside elements, etc. The design and implementation of the security of a disturbed electric system utilizing a microcontroller-based defensive system given. Because of the utilization of semiconductor, arc less fast switching of the system is conceivable with which the effectiveness, unwavering quality, and lifetime of the insurance unit increments. With an electric system against overcurrent, under-voltage, and earth fault utilizing a strong microcontroller presently unveiled. However, it is suggested that different methodologies ought to be utilized to supplement this methodology. The assurance of the power network framework is a fundamental and unavoidable procedure to guarantee the LV Feeder's security since the faults are inescapable.

In this research work (Thesis), a unique IoT based monitoring and controlling framework have been created by utilizing open source programming, measured, simulations, and ease parts. With this framework, system data can be gained from various sensors and can be observed in different conditions, for example, LCD, PC, cell phones, and tablets persistently. This work also furnishes that microcontroller-based LV feeders' performance using a solid-state relay is very significant for the electrical distribution system. The created system has been tested on a model LV smart feeder. It was seen that the information collection, count operations, and output signals as per the cut-off esteems, administration life, the executives, recording tasks, and warning frameworks were working without an error. Subsequently, this framework gives a minimal effort option in contrast to significant expense proficient checking frameworks. The design and implementation of the IoT based system of a disturbed electric system utilizing a microcontroller and software-based defensive system are given. Because of the utilization of semiconductor devices in the protection system, arc less fast switching of the system is conceivable with which the effectiveness, unwavering quality, and lifetime of the insurance unit increments. With an electric system against overcurrent, under-voltage, earth fault, and temperature, a strong IOT based system is presently unveiled. However, it is suggested that different methodologies ought to be utilized to supplement this methodology. The assurance of the power network framework is a fundamental and unavoidable procedure to guarantee the LV feeder's security since the faults are inescapable. This developed IoT system is capable of performing in any difficult condition for LV smart feeder protection.

At the later stage, this research work also presents an advancement of the IoT based monitoring and controlling of various parameters (as Voltage, Current, and Temperature) of the Low Voltage (LV) smart feeder system. The framework acknowledged continuous observation of feeder system operational devices and working conditions, information knowledge examination, alert linkage, and visual showcase. It helps in backing to feeder operation, and maintenance improves the activity and the intelligent smart feeder's management level. The arrangement of IoT technologies in a smart feeder system would revive the smart feeder improvement and redesign the power movement organizations getting progressively lively, engaging, responsive, and open.

Finally, a software system has been developed to show the feeder system's live monitoring and in any fault (overcurrent, overvoltage, and temperature rise). The developed system can send an alert signal if any fault condition occurs in the developed system. Overall, in this research work, a smart feeder protection system has been proposed with the IoT based monitoring and controlling of Voltage, Current, and Temperature (V, I, and T) of the system.

6.2 Future Works

Smart feeder innovation enables the suitable administration and conveyance of manageable energy sources like sun, wind, and hydrogen. Smart electric feeder configuration keeps up the green-life here on Earth while giving capable energy grid conveyance. Smart feeder offers two-route correspondence between the individual consumer and energy providers with the help of IoT applications. Along these lines, consumers can decide their energy utilization and deal with their financial plan likewise. Moreover, it encourages every consumer to check out energy grid exercises to diminish their capacity bills. This system can be utilized from slanted housetop foundations to level roof tilt-up bunches and building composed models, possible results for business sunlight based force age are moved and different. Associations taking an interest in the sun-oriented influence-based example have the uncommon prize of offering bounty impact to the energy for cash as credits and reserve funds. With the help of real-time monitoring and the

PhotoMOS relay protection system, smart feeders can recognize certain frameworks overloads and rerouting the energy grid to limit expected power outages or stay away from potential energy unsettling influence in the areas. Smart feeders can fundamentally recognize manageable force sources from sun and wind sources, just as joining other energy stockpiling Technologies.

The proposed model can further be utilized to monitor and control relaying circuits pertaining to the Internet of Thing (IoT) based smart feeder protection circuits for system performance analysis. The compatibility of available SSRs with the IoT system and real comparison in all the aspects would be a challenge and a field of further research in this area.

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