An Efficient Model for Low Voltage Distribution Smart Feeder Overcurrent Protection System Using Microcontroller

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Abstract. 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 and 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 and the electricity administration network status have 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) to viable monitoring and control of the Feeder system. The simulation result of this work shows that the system is able to control and monitor the feeder protection system from overcurrent with the help of Microcontroller viable results that have been achieved with this system. In this research work, PhotoMOS relay cut-off time and overcurrent parameters have been calculated. The achieved results show significant results over the traditional EMR circuit protection. The PhotoMOS 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 significantly 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.

1. Introduction
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 the general public and utility staff [1, 2]. The sectional diagram of the smart feeder is shown in figure 1. Microcontroller integration in the relaying circuits improves the accessibility and reliable quality by constant self-monitoring of the overall distribution feeder framework [2-4]. 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 a received practice at present.

There is extensive existing research for microcontroller-based distribution system protection [6-9]. 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. [6] Feeder automation is the quickest developing pattern among utilities to improve distribution systems' dependability. One of the primary uses of feeder automation is programmed fault management. Amare et al. [7], the future smart distribution feeder will comprise new parts and advancements with improved capacity whose fault conduct cannot be resolved with sureness. Srivastava et al. [8] the smart protection system is essential to fulfilling the customer demand. Patel et al. [9] 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. These devices are streamlined for implanted applications that require both preparing usefulness and nimble, responsive cooperation with digital, analog, or electromechanical parts [10, 11]. In the early 70s, a microcontroller was introduced for the first time, including 4 to 8 bit 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 [12]. A microcontroller framework can be utilized for identifying issues in the feeder systems. The continuous observation of the various parameters and equipment types in the feeder framework to recognize electrical faults [13].

The microcontroller in smart grid technology is essential with any electric apparatus that stores, measures, show 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 [14, 15]. Microcontroller additionally gives monitoring and protection to loads.

For the most part, they 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. 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 principal wire increments [14]. 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 the Circuit breaker to open the circuit [16]. As it may, switch all loads off if the overload current exceeds is 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 [17].

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 \( T_{OFF}/T_{ON} \) of 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 [5, 11]. 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 that is associated with a step-down transformer (220/6 V).

![Figure 1. LV distribution smart feeder sectional diagram.](image)

This paper has been organized as follows. Section 2 introduces the Smart Distribution Feeder structure construction. Section 3 presents the SSR interfacing with microcontroller. Section 4 presents
the feeder protection system model using a fast-switching relay, Section 5 shows the protection system results. Finally, Section 6 concludes the work and recommends the future aspects.

2. System Description for LV Distribution Smart Feeder

The Low Voltage (LV) distribution smart feeder framework conveys power from the transmission network and carries it to consumers [18]. 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 to be the end-stage of power distribution to the consumers. 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 [19]. 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 figure 2. Power Reliability Assessment (PRA) to meet the consumer requirement with respect to energy, is the most significant parameter for suitable healing measures to give a continuous and safe power supply to end consumers.

![Image of LV distribution smart feeder](image)

**Figure 2.** Smart feeder layout design.

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. There are four types of LV distribution feeder systems used: Ring main, Meshed system, Radial, Parallel feeders, etc. [20]. 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-closers are also introduced to additionally isolate the feeder in this way, limiting the effect of faults.

3. Proposed Algorithm and Working for Interfacing Solid-State Relay (SSR) With Microcontroller

In this research work, the authors effectively interfaced Solid-State Relay (SSR) with a microcontroller utilizing a transistor. The transistors work as a switching circuit, conveying the necessary current requirements to the relaying circuit operation. Figure 3 shows the basic structure of a PhotoMOS relay device. Detailed working has been provided in the author's previous research work [11].

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 Analog to Digital Converter (ADC) [21]. The transformation procedure of analog to digital sign and microcontrollers working appeared in figure 3. When pin PD7 of the PIC microcontroller goes high, the transistor BC130 turns-ON, and the 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.

Subsequent to getting this data-dependent on the programming given underneath in the relay data memory Read Only Memory / random Access Memory (ROM/RAM), the microcontroller takes the action of the tripping of the solid-state relay [22]. To calculate the relay tripping, the following values have been used.

\[ T = \tau(s)((I \mid I_p)^2-1) - K_d(\partial \theta \mid \partial t) \]  

where \( \tau(s) \) is the torque, \( I \) and \( I_p \) are the applied current and current value when Light Emitting Diode (LED) illuminate, respectively. The constants \( K_d \) and \( \Theta \) are the damping factor and angle, respectively. Therefore, the setting angle will be:

\[ TDS = \tau(s)/K_d((I \mid I_p)^2-1) \]  

Using this equation (2), trip time \( (t) \) can be calculated.

The proposed algorithm and work for interfacing Solid-State Relay (SSR) with microcontroller showed this algorithm.

========================================================================
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);
}
========================================================================

Figure 3. PhotoMOS relay circuit.
The operation time of microcontroller-based relay circuits is given in the binary code very low so that the relay tripping operation will be fast, and our feeder system will be safe from the faults [23]. Hence the microcontroller based solid-state relay will be very in-line with the LV distribution feeder system.

4. Proposed Model of Microcontroller Based Monitoring and Protection Using SSR

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 administrative control frameworks to distinguish the fault area [24].

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 (SSR) is an electronic switch that works on Photovoltaic impacts to switch High Voltage/Current using low power circuits utilizing. For fast switching, MOS innovation is applied to its control terminals [25]. To associate an SSR with a microcontroller, it needs a driving circuit shown in figure 5.

In figure 4, an effective LV distribution smart feeder protection system has been proposed using a Microcontroller-based solid-state relay circuit in operation [26]. The proposed model embodies the benefits of microcontroller-based solid-state relay circuits inside the general system that comprise other structure squares, such as step-down transformer (6 V), rectification assembly, sensing devices transduction, and an automation microcontroller to enable the operation of the circuit breaker.
Figure 5. Proposed model of feeder protection system.

For example, with the assistance of a rectifying circuit, a bridge rectifier is associated in series to convert the feeder voltage from a 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 [27-31]. Any change in AC voltage can bring a power cut or a weak signal. Thereafter, such changes are logically evaluated.

5. Simulation Results

The simulation of microcontroller-based LV feeder protection system design and results have been shown in figure 6 and figure 7. 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 figure 7. In this research work, relay, cut-off time, and overcurrent parameters have been calculated. The cut-Off time of the relay has been achieved using simulations and equations given above. With the calculation value of equation (1) to equation (3), authors 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 significantly less compared to the EMR protection system.

Figure 6. Microcontroller based feeder protection system simulation.
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. Overall, to protect the LV feeder system, three tests have been conducted based on the results proposed circuit of the microcontroller-based system shows very positive outcomes for future research work. These characteristics show the cut-off time and overcurrent values.

6. Conclusion and Future Recommendation
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. An electric system's safety against overcurrent, under-voltage, and earth fault utilizes a robust 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.

7. References
[1] Jones D and Kumm J J 2014 Future distribution feeder protection using directional overcurrent elements IEEE Transactions on Industry Applications 50(2) 1385-1390.
[2] Eluvathingal A V and Swarup K S 2019 Protection scheme for smart distribution networks with inverter interfaced renewable power generating sources Lecture Notes in Electrical Engineering 580 254-260.
[3] Chen L 2016 Overcurrent protection for distribution feeders with renewable generation,” International Journal of Electrical Power & Energy Systems 84 202-213.
[4] Baran M and El-Markabi I 2004 Adaptive over current protection for distribution feeders with distributed generators IEEE PES Power Systems Conference and Exposition (New York, USA) 715-719.
[5] Zhuang W, Dai J, and Liu Y 2019 Application of solid-state circuit breaker in selective relay protection of marine dc distribution system IEEE Workshop on the Electronic Grid (China) 1-6.

[6] Sabeel N, Alam A and Zaid M 2019 Feeder automation based strategy for reliability enhancement of radial distribution systems International Conference on Power Electronics, Control and Automation (India).

[7] Amare T and Helvik B E 2018 Dependability analysis of smart distribution grid architectures considering various failure modes IEEE PES Innovative Smart Grid Technologies Conference (Sarajevo) 1-6.

[8] Srivastava A and Parida S K 2019 Frequency and voltage data processing based feeder protection in medium voltage microgrid IEEE PES Innovative Smart Grid Technologies Europe, (Romania) 1-5.

[9] Patel Y, Panchal B, Parmar S, Shinde K and Prajapati P 2019 Power factor correction with microcontroller use solid state relay Journal for Research 5(2) 681-685.

[10] Kacar S 2016 Analog circuit and microcontroller based rng application of a new easy realizable 4d chaotic system Elsevier Optik 127(20) 9551-9561.

[11] Kumar A and Srivastava V M 2020 A novel feeder protection system using fast switching photomos relay International Conference on Computing, Communication and Networking Technologies (India) 1-6.

[12] Metering A S, Visalatchi S and Sandeep K K 2017 Smart energy metering and power theft control using Arduino & GSM International Conference for Convergence in Technology (India) 858-961.

[13] Marie T F B, Han, H and An B 2019 Microcontroller design for security system: implementation of a microcontroller based on STM32F103 microchip International Journal of Embedded Systems 11(5) 541-550.

[14] Suteerawatananon S, Chompusiri, Y, Charbkaew N and Bunyagul T 2018 Design of a low-cost microcontroller-based high impedance fault detector International Conference on Electrical Engineering/Electronics, Computer, Telecommunications, and Information Technology (Thailand) 552-555.

[15] Ali M A and Bendary F M 2013 Design of prototype non-directional overcurrent relay microcontroller-based International Conference and Exhibition on Electricity Distribution, (Stockholm) 1-4.

[16] Jhunjhunwala S, Pandey K and Kumar R 2018 A microcontroller based embedded system to provide complete self-protection (CSP) to any distribution transformer International Conference on Power Energy, Environment and Intelligent Control (India) 307-310.

[17] Chen C, Ku T and Lin C 2012 Design of phase identification system to support three-phase loading balance of distribution feeders IEEE Transactions on Industry Applications 48(1) 191-198.

[18] Khadar A A, Hayath T M and Nagraj M S 2017 Design and implementation of ZigBee based smart grid system for power management International Conference on Smart Technologies For Smart Nation (India) 1339-1343.

[19] Rodriguez D F C, Osorio J D P and Ramos G 2018 Virtual relay design for feeder protection testing with online simulation IEEE Transactions on Industry Applications 54(1) 143-149.

[20] Manditereza P T and Bansal R C 2018 Introducing a new type of protection zone for the smart grid incorporating distributed generation IEEE Innovative Smart Grid Technologies (Singapore) 86-90.

[21] The panasonic electric works Europe website 2020 Available: https://www.panasonic-electric-works.com/eu/photomos-relays.

[22] An W, Ma J J, Zhou H Y, Chen H S, Jun X and Jian X 2019 Application of an integrated protection and control system for smart distribution grid based on PTN and 4G LTE communication International Conference on Smart Grid and Smart Cities, (USA) 70-75.
[23] Mbunwe M J, Ogbuefi U C, Anyaka B O and Ayogu C C 2018 Protection of a disturbed electric network using solid state protection devices World Congress on Engineering and Computer Science (USA) 76-82.

[24] Mehta P and Makwana V H 2018 Radial feeder protection by definite time overcurrent relay International Conference on Intelligent Systems and Signal Processing (Singapore) 185-198.

[25] Hameed A A, Sultan A J and Bonneya M F 2020 Design and implementation of a new real-time overcurrent relay based on Arduino International Conference on Materials Science and Engineering 012005.

[26] Swathika O G and Hemamalini S 2015 Adaptive and intelligent controller for protection in radial distribution systems Advanced Computer and Communication Engineering Technology 362(4) 195-209.

[27] Leeuw S and Srivastava V M 2021 Realization with fabrication of double-gate MOSFET based buck regulator International Journal of Electrical and Electronic Engineering & Telecommunications 10(1) 66-75.

[28] Srivastava V M 2016 Schematic of boost regulator with DG MOSFET: A device modeling for energy transmission 13th Int. Conf. on Industrial and Commercial Use of Energy (South Africa) 256-261.

[29] Shabani A and Mazlumi K 2020 Evaluation of a communication-assisted overcurrent protection scheme for photovoltaic-based dc microgrid IEEE Transactions on Smart Grid 11(1) 429-439.

[30] Kavi M, Mishra Y and Vilathgamuwa M 2018 Morphological fault detector for adaptive overcurrent protection in distribution networks with increasing photovoltaic penetration IEEE Transactions on Sustainable Energy 9(3) 1021-1029.

[31] Kumar A and Srivastava V M 2020 Proficient model of monitoring and controlling of low voltage distribution smart feeder protection system using IoT International Journal of Advances Trends in Computer Science and Engineering 9(5) 9131-9137.