Enhancing automated domestic electrical fault isolation system: The case of Tanzania

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Abstract

Most of electrical equipment's are more sensitive, and they have to be protected from overvoltage and short circuit occurrence. To ensure protection against overload, slow blow circuit breakers and overload relays are generally used. Thermal magnetic circuit breakers are used to offer protection against both overcurrent and overload. Currently fuse and circuit breakers are employed to safeguard the electrical equipment's. Miniature circuit breaker is based on thermal bimetal lever trip mechanism. Miniature circuit breaker is slow and the trip time varies according to the Percentage of overload and surrounding temperature. This research paper is objected to enhance automated domestic electrical fault isolation system. The designed automated circuit cut off the power supply whenever overload or short circuit occur and reset after the fault cleared using hardware and embedded system software on microcontroller. The experiment is performed three times setting the voltage at 220Vac at 2.7A, 5A and 8A and the findings are pointed positive results.

Keywords: Enhancing, domestic, electrical equipment, system

1. Introduction

The sudden surge of electrical current due to increased load or electric short circuit lead to the control panel damage in homes, companies or other institutions, and may also cause damage of the electric wires which carries the electric current. This has become an issue in Tanzania for the user of electrical domestic appliance. To limit this risk, Automated circuit breaker is developed using sophisticated tools to improve the tripping respond of the circuit breaker [1].

According to [1]. The increase of technological domestic appliances causes a number of problems to increased such as exposure to direct shock due to electric short circuit or over loading and thus damaged the control panel as well as electrical domestic appliances, therefore the more attention is needed on sophisticated electrical equipment's as well as intelligent measures should be taken to limit those risks such the smart and fast response circuit breaker.

The protection of electrical domestic appliance from short circuit or over load current trip time of circuit should be very low and this can be achieved by automated circuit breaker [2] in which they are made from semiconductor materials'. An automated online circuit breaker monitoring system [3] is proposed to monitor condition, operation and status of high and medium voltage circuit breakers

It is vital to monitor the electrical appliance for protection of both human being and the appliance [4]. It will run out quickly if humans cannot use them properly. Therefore, we need to monitor and control the resources we have at home.

The circuit breakers are normally defined as electrical switches that are automatically activated to avoid damage to circuits which happens due to short circuits or overload. [5].

The primary goal is to ensure that the circuit breakers plays a vital role in carefully protecting the electrical appliances. The ratings, performance, features, and testing of circuit breakers and switchgear are governed by electrical standards

The use of fast trip circuit breaker for efficient protection is very important because of the increase number of modern equipment as well as the user of electrical equipment. If the protection circuits do not work properly, it may cause loss of service, under voltage, or overvoltage short circuit transients, and loss of synchronization. However, in a serious case, an extreme surge of power may penetrate the equipment and sequentially cause explosion or fire [6].

2. Problem statement

The users of electrical domestic appliances in Tanzania have experience the challenge on how to protect the electrical appliances from short circuit and overvoltage due to power fluctuation. The power is distributed at single phase for the voltage of 220Vac which is directly applicable for the domestic appliances and is required to be stable to avoid overvoltage and short circuit to the electrical appliances. Measures has been taken to protect the electrical appliances including miniature circuit breaker (MCB) which is commonly used. It is made up by bimetallic strip but possesses the challenge that sometimes fails to detect as a result's damage the domestic appliances due to its nature of the operation, depends on increase of heat on bimetallic strip which take more time to detect the fault. For protection of sensitive load from short circuit or over load current trip time of circuit should be small and this can be achieved by using technological components such as semiconductor [7]. The miniature circuit breaker uses two mechanisms to protect the domestic appliances against over-current, first an electromagnetic plunger trips breaks the current when a large current flows through the circuit, such as in the case of a short circuit fault, secondly a bimetallic strip is used to break the circuit, when the current is small such as when an overload fault occurs. Contrariwise, modern electrical appliances use very complex and sensitive electronic components. These systems are very sensitive and could easily burn out if over-current occurs. Thus modern electrical appliances demand fast tripping speed and high reliability as well as sensitivity in order to protect the appliances. By using an Automated domestic electrical fault isolation system that takes less time to detect and isolate the short circuit and overvoltage could solve the domestic appliance problem.

3. Related work

In this part of the study presents literature review, deals with an Automated domestic electrical fault isolation system that concerned with protection of domestic appliance.

3.1 Concept and theory

Fuse is one of the most popular protection devices to protect electrical circuits against the negative effects of overload and short-circuit currents. The diagram below shows the internal components of a cartridge fuse. The main component of the fuse is a metal wire. In the case of overload and short-circuit faults, this wire melts and breaks the path of current. However, the fuse is not a fast tripping protection device in the case of high currents like the short-circuit fault.

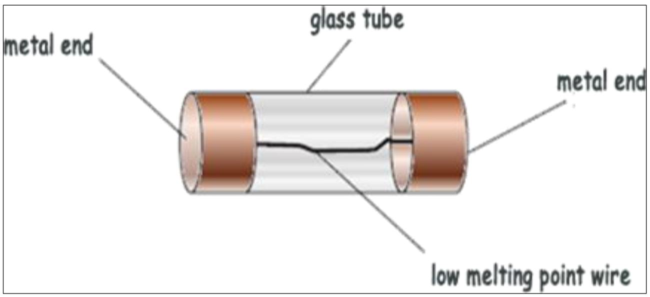

Fig 1: Internal components of cartridge fuse

The most used protective device is Miniature circuit breaker which take longer time to trip especially for sensitive domestic equipment such as Television, fridge, computer and microwave. For home appliances it is important to activate the tripping mechanism for short time.

In different operating conditions, electrical devices sometimes start to draw more current than their overall capacity, this fail to predict event and may leads damage the domestic electrical appliances. To avoid overvoltage, the installation of sensitive protective devices is required where will automatically shut down the extra amount of voltage flowing in the circuit [8].

Short-circuit current occurs under specific conditions when there is a short connection between phase and null wires. This means that the current finds a short way to bypass the electrical loads. The amount of short-circuit current is order of magnitude higher than the nominal current and can cause critical damages in electrical circuits. The short-circuit current can produce extreme heating that can damage the insulation of electrical devices and cause an electrical fire [9].

4. The development of an automated fault isolation system prototype for short circuit and overcurrent.

Since its invention, electricity has played a vital role in our everyday life. The appearance of the first power production facilities in the late nineteenth century paved the way for the electrical power system and its subsystems; generation, transmission and distribution. Consumers of electrical power demand dependable services in terms of power grid stability and safety [10]. Automated domestic electrical fault isolation system makes possible to track the circuit breaker switching sequences and make conclusions about their performance and final outcome [3]. Despite of the small size and light weight automated domestic electrical fault isolation system is capable of detecting the fault at minimum time than miniature circuit breaker.

5. Validation of the automated domestic electrical fault isolation system prototype for short circuit and overcurrent

Protection and control of electrical equipment is very important. To avoid electrical failure, we use fast responding circuit breakers because of its considerable accuracy in fault detection and cut off- time, and also its smooth operation compared to conventional type. Comprehensive experiments conducted by constructing the necessary circuit yielded successful results. It was proved that electronic circuit breaker is very useful circuit for sensitive loads. The main advantage of this circuit is that over all tripping time is less as compare to conventional [11].

5.1 Tripping respond for automated domestic electrical fault isolation system

The automatic system is designed for domestic electrical system to detect if any short circuit or overvoltage occur. The AC supply to the load is thus cut off from the load and the load is tripped. The microcontroller is programmed so as to show the status of the output on the LCD interfaced to it. In case of normal operation microcontroller will pin will receive 5v dc from regulator and accordingly displays the status on the LCD. In case of any abnormalities, the microcontroller pin doesn't receive the 5V input signal and the related status is accordingly displayed on the LCD [12]. According to [13] shows the tripping action of automated domestic electrical fault isolation system

Testing is done under different loading conditions and overloading is detected and the relay tends to trip. The LCD shows the overload status to the user through message and later supply has been cutoff. Supply is restored back after clearing the fault. With switching action, a short circuit condition was simulated and seems to be tripping time of around 0.022 seconds [14]. Thus, the system can be used to replaced miniature circuit breaker devices since tripping respond is faster

5.2 Validate the automated domestic electrical fault isolation system

To validate the system, a scenario is defined to control short circuit and overvoltage. Microcontroller is the main component for control the process. According to [15], testing is done under the assumption that one lamp constitutes the rated load of the system. So when the second lamp is turned on, an overloaded condition is detected and the relay trips instantaneously. The LCD shows the overloaded status and an SMS was received stating that the system has been overloaded and that supply has been cut off.

5.3 Features of automated domestic electrical fault isolation system

Features like nearly unlimited short circuit capability by current limitation, programmable rated current, programmable trip time curve, wire break indication, remote controllability and monitoring functions for current and voltage [16]. Online monitoring can be implemented with the help of the GSM module with the network connectivity. Protective device nearest to the fault will open when an over current occurs. Tripping characteristics of the circuit breaker can be represented by a tripping curve which plots tripping time and current level. The curve represents the time required for a breaker to trip at a given excess current level. The proposed methodology protects the sensible equipment's when fault occurs by cutting the supply in fraction of seconds. It is done by means of Wi-Fi technology [2].

6. Design of circuit diagram operation of the circuit

The main power supply is given directly to load through step down transformer of 220 AC voltage at the input and is Step down to 12 AC voltage then the output is given to bridge rectifier for convention of voltage from AC to DC voltage and then passed through 7805 regulator to get 5v supply for working of microcontroller, in the microcontroller, when there is short circuit or overvoltage the microcontroller generate the signal to trip through the current sensor.

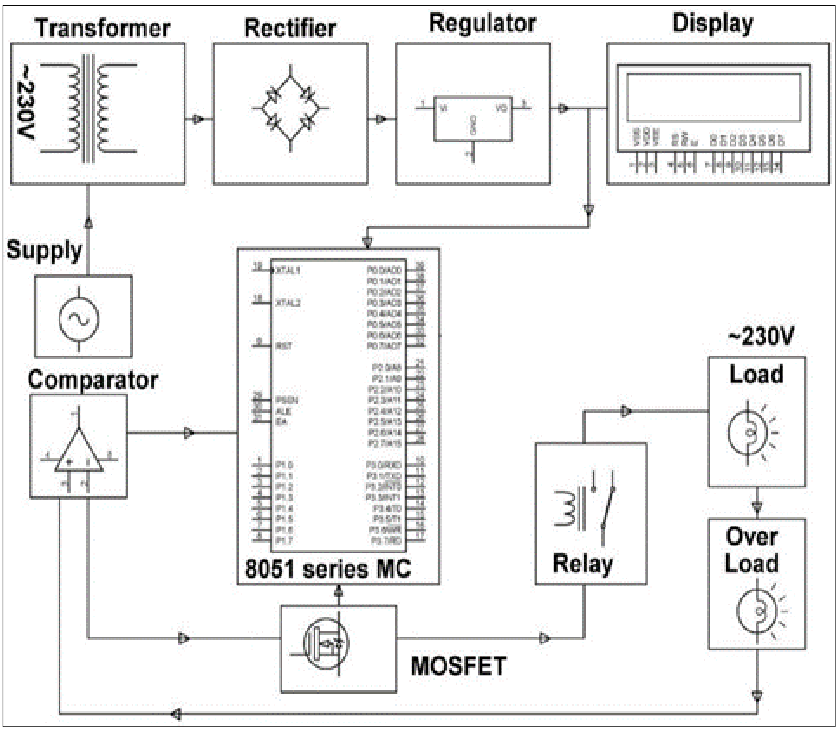

Fig 2: Complete circuit diagram

6.1 Hardware testing results at 220Vac

In order to developing a prototype, the hardware is tested with a 220Vac supply and a load resistor having a small inductance. Instead of putting a real fault at the load terminals, the load resistance is varied from 60 ohms to 6.4 ohm so that final steady state value of load current is beyond overcurrent threshold set in micro-controller.

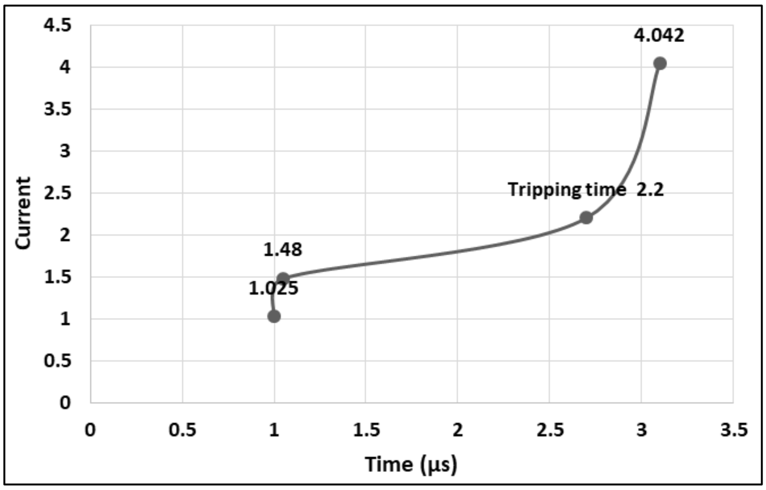

Fig 3: Graph shows when current is 2.7 A

When current threshold is set at 2.7 A, micro-controller output command to opt couple and gate driver. The system makes auto-re closure attempts and if the fault is still persistent, the main switch remains off until micro-controller is reset manually. The time taken by micro-controller can vary up to a maximum of 2.2µs depending on which instruction the micro-controller is executing when a fault occurs.

Before fault occurred, load current was 1 A. When fault occurs, current starts to rise and as a result, current sensor circuitry output (sensor and OPAMP buffer) begins to rise. When feedback to micro- controller increases beyond programmed threshold, the micro-controller sends OFF command to opto-coupler and gate driver circuitry. Gate driver and opto-coupler take finite amount of time to send OFF command to main switch and finally main switch takes some time to turn OFF and then load current begins to commutate to freewheeling diode decaying exponentially as stored energy in inductor dissipates

After micro-controller sends OFF command to opto-coupler and gate driver, it waits for 50S (auto-reclosure time) and sends command to turn ON main switch again.

With switching action, a short circuit condition was simulated and seems to be tripping time of around 2.2µs

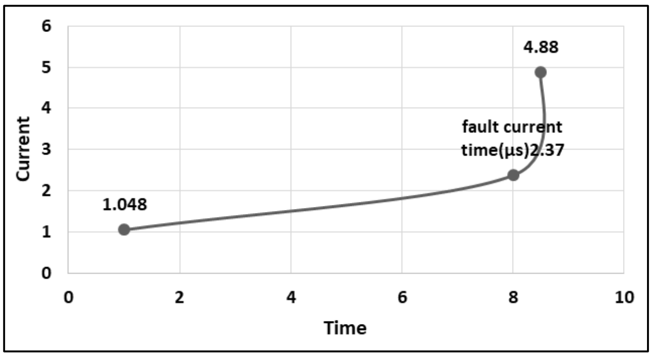

Fig 4: Graph show when current is 8A

The prototype performs an auto-reclosure attempts and if the fault is still persistent, main switch remains off until micro-controller is reset manually. The time taken by micro-controller can vary up to a maximum of 2.2uS then the micro-controller is executing when a fault occurs. The figure above shows that the microcontroller trip at 2.37µs and reset again after the fault is cleared.

Prediction of sensor operation time

This expression enables us to calculate expected sensor operating time for a given system, given current sensor and a given threshold.

Mathematical derivation for sensor response time

Let V be the source voltage, L be the total inductance in power circuit and R be total resistance of power circuit. Time constant of power circuit is given by ʈ s = L / R. Let the bandwidth of sensor be ωBW. Applying KVL to power circuit we get.

$$V = R*i + L* di/dt$$

Taking Laplace transform,

$$V/s = R* i(s) + LS*s*i(s)$$

Taking inverse Laplace transform

$$i(t)=\frac{V}{R}*(1-e^{-t/\tau})$$

$i(s)=\frac{V}{R}(1-\frac{\tau}{\tau+\tau B\omega}e^{-}+\frac{\tau B\omega}{\tau+\tau B\omega}e^{-1/\tau B\omega}$ this equation can be used to find time taken by the load current to reach threshold and calculating sensor response time.

Calculation of sensor response time

For all cases, V=220V,
R=6.45ohm, L=16uH,

$\tau=\frac{L}{R}$ = 2.48u and for sensor τBω is given by

$$\tau B\omega = \frac{1}{2\pi*200000}=0.79$$

For the Current =2.7A

$$2.7=9.3023*(1- e^{-t/2.48u})$$

Solving for t, we get $t = t_1 = 0.85uS$

This means that current will take 0.85uS to reach 2.7A threshold if it starts at t=0. Now putting same values in equation 4.2, $2.7=9.3023*(1-1.4725*e^{-t/2.48u}+0.4725*e^{-t/0.7958u})$

Solving for t, we get $t = t_2 = 1.599Us$
This means that sensor response will reach 2.7A at $t_2 = 1.599uS$. Therefore, sensor response time = $t_2 - t_1 = 1.599uS - 0.85uS = 0.749uS$

For the current 5.5A

$$5.5=9.3023*(1- e^{-t/2.48u})$$

Solving for t, we get t = t1= 2.219uS
This means that current will take 2.219uS to reach 5.5A threshold if it starts at t=0.
5.5=9.3023*(1-1.4725*e-t/2.48u+0.4725*e-t/0.7958u)
Solving for t, we get t = t2= 3.124Us
This means that sensor response will reach 5.5A at t2= 3.124uS. Therefore, sensor response time = t2- t1 =3.124uS-2.219uS= 0.905uS,

For Current threshold=8A

$$8.1=9.3023*(1- e-t/2.48u)$$

Solving for t, we get t = t1= 5.074uS
This means that current will take 5.074uS to reach 8.1A threshold if it starts at t=0
8.1=9.3023*(1-1.4725*e-t/2.48u+0.4725*e-t/0.7958u)
Solving for t, we get t = t2= 6.03uS
This means that sensor response will reach 8.1A at t2= 6.03uS. Therefore, sensor response time = t2- t1 =6.03uS-5.074uS= 0.956uS

7. Findings and Discussion

It is seen from comparison of the miniature circuit breaker and the developed circuit that, the MCB tripping time respond is much longer in which the maximum is about five second in order to detect the fault, and it has observed that for a modern electronics equipment's has less effect on provision of protection and hence the risk of damaged is quite higher. On using the use of automated fault isolation system has shown some improvement in which the detection of fault is around 0.002s. During the experiment the noise is negligible, less voltage is used which is around five volts.
The prototype can handle protection even to modern domestic electrical appliances.
Despite of benefit there are some challenges arise which are the sensor operating time should be set to less than 1uS for all current for the current to trip when detecting the fault. This should be treated as an important factor while choosing current thresholds. For a given system, steady state fault current at a given location can be calculated provided all loads connected to system are known. During programming to the microcontroller, care should be taken to select a current threshold of final steady state fault current. This will help to predict sensor response time.

8. Conclusion and future research

Comprehensive experiments conducted by constructing the necessary circuit yielded successful results. Automated fault isolation system is very useful circuit for sensitive loads. The main advantage of this circuit is that over all tripping time is less as compare to miniature circuit breaker. The experiment is successful and energy saving. Further research on improving the load capacity and tripping time is being undertaken. This study of enhancing the performance of automated domestic fault isolation system shows that the tripping of load takes place in case of short circuit or overload condition is less compared to MCB. This system has very fast tripping mechanisms compared to the miniature circuit breakers. Fast clearing of electrical failure like overload or short circuit is very necessary. Automated domestic fault isolation system is very efficiently for fault clearing and the operating time of circuit is approximately 2.2µ second. I recommend the use of automated switch to the society due to its safety and economic growth increment of the country. More research is required on developing the automated domestic fault isolation system that can fit at all environment despite of the changes of temperature.

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