Design of an Intelligent Monitoring System for Distribution Transformer Protection Systems for Rural Communities

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Abstract

This paper presents an intelligent distribution transformer protective device monitoring system for rural power networks to improve the reliability of power supply. The aim is to design a cost-effective remote transformer protective device monitoring system for a low-voltage transformer in a rural distribution network. Analyzing the effect of protective device dropout, MATLAB was used to design a protective system. Proteus was used for data acquisition and transmission systems design. The code was written using Arduino programing language. Global System of Mobile Communication technology was used for fault reporting through SMS and call alerts. Reliability indexes such as the system average interruption duration index, and system average interruption frequency index was calculated. Results revealed that manual monitoring expenditures can be lowered by 15%, and production failure due to undiscovered protection device dropout can be decreased by 10%. Results show that manual monitoring is 70% more expensive than remote monitoring. The system will reduce downtime when implemented in real-time.

Keywords: Cost-Effective, GSM, Intelligent System, Reliability, Power System, Transformer.

1. Introduction

Power system which comprises the interconnection of electrical equipment in a generation, transmission, and distribution network has in recent years experienced instability in the delivery of electrical power to customers which is a major challenge in developing countries. Besides inadequate power generation, other issues affect the availability of stable power supply in developing countries, ranging from transmission line faults to even faults in the distribution system (Epemu & Enalume, 2017; Somkuwar & Panjwani, 2015). A transformer is one of the important pieces of electrical equipment that is used everywhere in a power network system. Its operation and control are important aspects that determine the reliability and quality of power supply, hence the monitoring of such transformer's parameters and its protective devices has become a fiery task (Sarsamba et al., 2013). In the electrical power distribution system, several types of faults reduce the performance of the equipment and supply delivery in the distribution network. However, some of the major problems resulting from the instability of power supply in a distribution network are the faults associated with the distribution network such as single-phase ground (L-G) faults, two phases ground (L-L-G) faults, phase-to-phase (L-L) faults, three-phase (L-L-L) faults, and protective devices dropouts are a major source of downtime in power supply (Singh et al., 2019; Tran et al., 2020). Research conducted by Al-Issa et al., (2022), Gokula Krishnan et al., (2008), and Parvez, (2021) revealed that the protection of distribution transformers is a subject of growing interest in recent years where many systems are controlled using wireless. It's also argued that abnormality in distribution transformer is accompanied by a variation in different parameters like oil temperature, load current, over-voltage, and rise in oil level, which can cause a transformer to burn would result in putting a community or even a Region off. It was further stated that such problems retard the development of a country (Rout et al., 2021). The electricity supply challenges can be attributed to several factors, including a high level of losses in the distribution system, and faulty transformers which are mainly due to the obsolete nature of distribution equipment (Development, 2017). Solving electricity challenges would require measures including proper maintenance practice, and monitoring of equipment manually or wirelessly to enhance the operation of power equipment as stated by some researchers Ahadu, (2019), Braimah and Amponsah, (2012), Nduhuura et al., (2021). With the assurance of a stable power supply, the distribution transformer should be monitored continuously to take the data of its parameters such as load currents, under-voltage, overvoltage, oil level, oil aging, overload, frequency, winding temperature, ambient temperature, and even operation of protective devices (Epemu & Enalume, 2017).

Currently, in most developing countries where transformers are installed in remote areas in rural power distribution network systems, distribution transformer monitoring is done manually for inspection or by the residents in the area reporting a fault to the utility provider (Rahman et al., 2017). Some research has been conducted on some of the various types of technologies used for online transformer diagnoses such as Supervisory control and data acquisition (SCADA) systems, Radiofrequency (RF) based control systems, Internet-based communications, and wireless sensor networks (Umar et al., 2020). The authors' Silva et al., (2021), Srivastava and Tripathi (2018) propose an online transformer health monitoring system based on a global system for mobile communication (GSM). The researchers Shil and Anderson (2019) conducted research and developed a methodology for predicting distribution transformer outages and congestion whereas Nur et al., (2014) suggested and built a detection system based on Bluetooth and an Android application. Dhobale et al., (2018) developed an RF-based distribution transformer monitoring system that monitors and records key distribution transformer parameters. Several works have been done in the area of monitoring distribution transformers to increase the lifespan of the transformer and ensure a stable power supply (Epemu & Enalume, 2017; Umar et al., 2020). Meanwhile, little research has been carried out on distribution transformer protective devices monitoring systems. Therefore, in this article, an intelligent distribution transformer protective device monitoring system for distribution transformers in rural electrification power networks is proposed.

2. *Methodology*

A schematic of the proposed transformer protective device monitoring system is shown in Fig. 1. The schematic is divided into two parts namely, the power distribution system, and the data acquisition and transmission system. The power distribution system consists of a three-phase transformer, a protective device (breaker) connected at both the high and low voltage side, and loads connected to the transformer whereas the data acquisition and transmission system consists of a microcontroller, protective device sensors, and GSM module, power supply unit, and a liquid crystal display (LCD) as shown in Fig. 3.

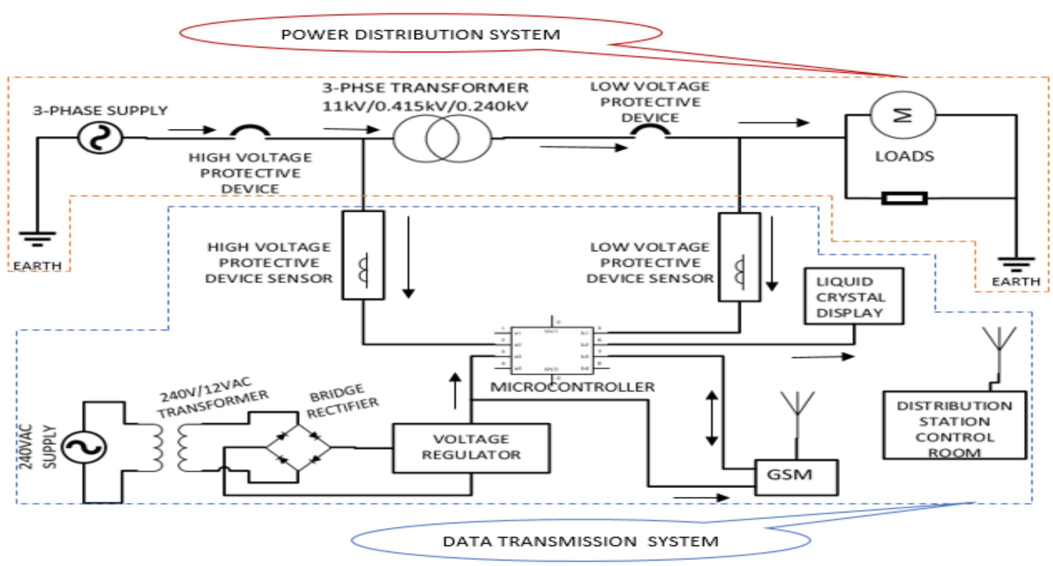

Fig. 1. Block diagram of the proposed protective device monitoring system of a distribution transformer.

The protective devices that are mostly used in power distribution networks are fuses. This is due to its low cost when compared to other protection devices and its satisfactory operation for one of the major problems of the distribution networks which refers to the overcurrent from short circuits. This protective device can perform three main functions namely (a) Safeguarding the entire system to maintain continuity of supply, (b) Minimizing damage and repair costs when faults occur, and (c) Ensuring the safety of personnel. Table 1 shows the technical standards specification of the Compaq drop-out fuse that is mostly used in the distribution grid network.

Table 1. Technical Standards Specification of Compaq Drop-Out Fuse

S/N	Properties	Value
1	System Voltage	11kV
2	Rated Voltage	12kV
3	Impulse withstand voltage to earth Across the Terminal	75kV- 75kV(minimum)
4	Power Frequency volt to earth Across the Terminal	28kV -35kV
5	Rated Short time current for 1 Sec.	10KA
6	Material for Insulator	Polymeric
7	Governing specification	IS 9921-1985, IEC 61109
8	Colour available	Red & Gray

2.1. Calculation of Dropout Fuse Element

Conductors such as aluminum and copper are mainly used as fuse elements. The temperature rise of this conduct depends on the I^2t factor. This factor can be calculated using the empirical formula as in equation 1 for a copper conductor and equation 2 for an Aluminum conductor.

$$I^2t = 11.5x\ 10^4xA^2\log_{10}\frac{273 + \theta_m}{273 + \theta_0} \qquad (1)$$

$$I^2t = 5.2x\ 10^4xA^2\log_{10}\frac{273 + \theta_m}{273 + \theta_0} \qquad (2)$$

where I = Short circuit current (A), t = Duration of the short circuit (s), A = Net cross-sectional area of the conductor (mm^2), θ^o = Initial temperature of the conductor (C^0), and θ_m = Final temperature of the conductor. Table 2 shows the values that were used to calculate the time taken for a fuse element of 0.0507 mm^2 to melt when different rated currents at different voltage levels flow through it with I^2t maintained constant.

Table 2. Estimated time taken for a fuse element to blow.

Parameter	Values	I^2t	Time (T)
Primary voltage (Vp),	11000V		
Secondary voltage (V_L-V_L)	415V		
Rated Power	100kVA		
Secondary voltage (Vs)	240V		
Calculated primary current (Ip)	10A	184.178A^2s	1.84sec
Calculated secondary current (Is) at 415V	241A	184.178A^2s	3.17ms
	362A	184.178A^2s	1.4ms
Calculated secondary current (Is) at 240V	417A	184.178A^2s	1.06ms
	1110A	184.178A^2s	0.149ms
Fuse Element	30 AWG = 0.0507 mm^2		

2.2. Reliability Analysis of the Medium Voltage (MV) Feeders

The distribution reliability criteria, the power grid should be dependable in supplying power to clients connected to such feeders. There are various measures for measuring power grid system reliability, and six important metrics were chosen. These matrices of customer power supply satisfaction considered in this paper are the system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), and average system availability index (ASAI), energy not supplied index (ENS), and average energy not supplied (AENS) (Hussen & Ibrahim, 2020).

The system's average duration of interruption index (SAIDI), this index in the grid network takes into account the duration of the outages, resulting in an average of the number of hours a certain consumer's energy supply was disrupted during the time *t*. The estimation of how long a customer(s) will be able to receive electricity without interruption is expressed in equation 3.

$$\mathrm{SAIDI} = \frac{\sum_{i=0}^{i=m} N_i T_i}{\sum_{i=0}^{i=m} N_i} \quad (3)$$

where *N*i - number of consumers served by i[th] transformer, T_i - Time in minutes when the i[th] transformer lost power during the selected period with *m* representing the total number of transformers on the selected feeder (De Silva, De Soysa, Bandara, Rathnathilake, & Bogahawatte, 2017). System average interruption frequency index (SAIFI), this matric was used to calculate how often the average consumer or a group of consumers is interrupted for an extended period.

$$\mathrm{SAIFI} = \frac{\sum_{i=0}^{i=m} N_i n_i}{\sum_{i=0}^{i=m} N_i} \quad (4)$$

where; N_i: Number of consumers served by i^{th} transformer, n_i is the number of failures sustained on i^{th} transformer during the selected period, *m* the total number of transformers on the selected feeder. The customer average interruption duration index (CAIDI), was used to calculate the average duration of interruptions per client (customer) who experienced a feeder outage. This interruption is calculated using equation 5.

$$\mathrm{CAIDI} = \frac{\sum_{i=0}^{i=m} N_i T_i}{\sum_{i=0}^{i=m} N_i n_i} = \frac{\mathrm{SAIDI}}{\mathrm{SAIFI}} \quad (5)$$

where; N_i: number of consumers served by i[th] transformer, n_i: number of failures sustained on i[th] transformer during the selected period, m: Total number of transformers on the selected feeder, and Ti: Time in minutes in which the i[th] transformer lost power during the selected period. Average system availability index (ASAI), this power reliability matrix was used to determine the percentage of time a customer had power during the power outage reporting period using equation 6.

$$\mathrm{ASAI} = \frac{\left(T_d \text{ x } \sum_{i=0}^{i=m} N_i\right) - \sum_{i=0}^{i=m} N_i T_i}{Td \text{ x} \sum_{i=0}^{i=m} N_i T_i} \quad (6)$$

where *Ni* is the number of consumers serviced by the i[th] transformer, N_i is the number of failures sustained by the i^{th} transformer over a certain period, *m* is the number of consumers served by the i^{th} transformer, *m* is the total number of transformers on the selected feeder, T_i the time in minutes during which the i^{th} transformer lost power during the given period, and T_d the total period in minutes during which the i^{th} transformer lost power during the selected period (Hussen & Ibrahim, 2020). The energy not supplied index (ENS) in the power delivery to a customer, this index was used to estimate the total of energy not supplied in all groups (various customers) due to interruptions in all the events in a given period. Equation 7 was used to calculate the total energy that was not supplied to all groups (various customers)

$$\text{Energy not supplied (ENS)} = \sum_{i} d_i \text{ x } E_i \quad (7)$$

where d_i is the duration of each interruption; and E_i is the energy not supplied in each interruption (Hussen & Ibrahim, 2020). Average energy not supplied (AENS) was used to evaluate the individual customer reliability of energy supply. Equation 8 was used to estimate the average energy not supplied

$$\mathrm{AENS} = \frac{\sum A_{L(i)} U_i}{\sum N_i} \quad (8)$$

where $A_{L(i)}$ is the average load, U_i is the annual outage time, and *Ni* is the number of customers of load point *I*. Table 3 shows the calculated values of the reliability indices of the distribution system under study.

Table 3. Reliability Indices of Distribution System

Reliability Indices of Distribution System	Calculated values
SAIDI	12 hours/customer/year
SAIFI	20 interruptions/customer/year
CAIDI	1.6hours/customer/interruption
ASAI	0.55 reliability
ENS	500kWh/year
AENS	300 kWh/customer/year

2.3. Fault current (IF) Calculation

The method used for calculation is based on the introduction of an equivalent voltage source at the short-circuit location. The network feeder and the various loads are replaced by their internal impedances. The current of the three-phase short circuit following IEC60909 was calculated by using equation 9 as stated by (Muangchareon et al., 2013).

$$I_F = \frac{V}{(Z_1 + Z_F)} \qquad (9)$$

where V = voltage, Z_1= positive sequence impedance, and Z_F = fault impedance and I_F = Fault current.

3. Proposed distribution transformer protection circuit

3.1. Transformer protection circuit, data acquisition, and transmission (DAT) system

The protection system of a distribution transformer is designed using MATLAB Simulink software as shown in Fig. 2. The transformer is protected by using a three-phase circuit breaker at the high and low voltage sides. The transformer is configured in wye-to-wye connections for the simulation model. The system model consists of a three-phase source, current, and voltage measurements on both sides of the power transformer, and a three-phase circuit breaker on the primary and secondary sides for isolation of the transformer from the source or load in case of fault or for maintenance purposes. RL load, RLC load, and the three-phase dynamic load on the secondary side are used to indicate the loads connected to the transformer in the distribution network. After the design of the model, it was simulated based on the power distribution system faults scenario. The results obtained are presented and discussed taking into consideration factors that cause the tripping of protective devices and how this device tripping or failure can be monitored remotely to help provide a continued supply of power in remote areas to customers.

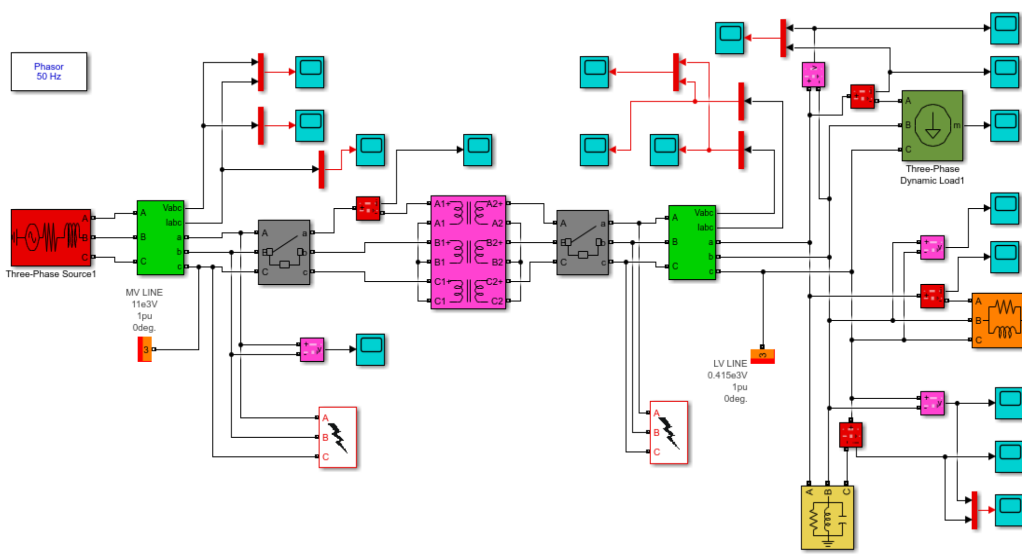

Fig. 2. Distribution transformer protection system circuit diagram

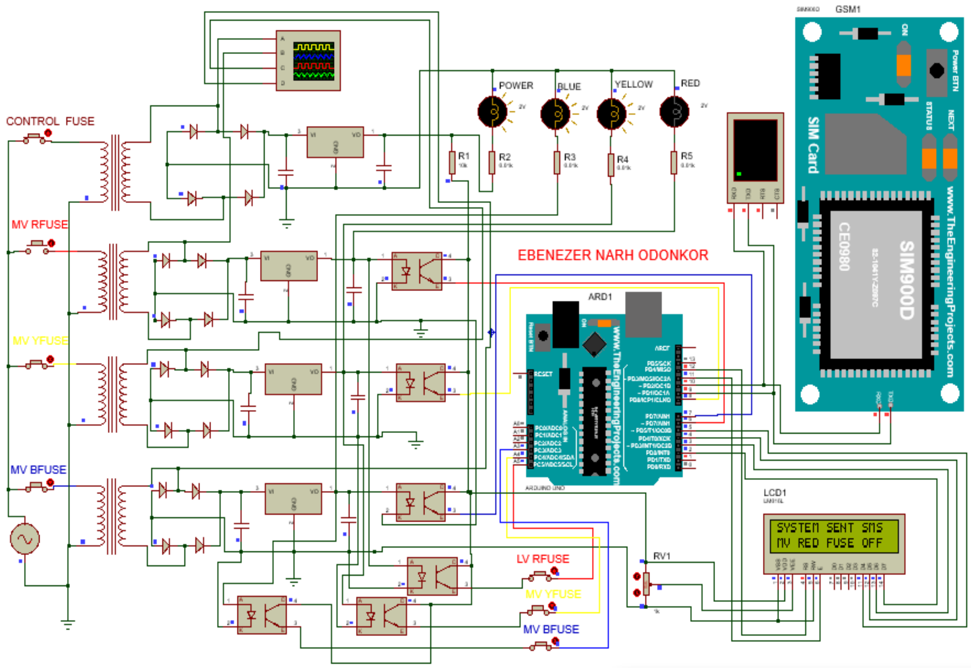

Fig. 3. Data acquisition and transmission (DAT) circuit diagram

Fig. 3 shows the design of the data acquisition and transmission system using the Proteus 8.6 SP2 professional software. The liquid crystal display (LCD) was used as a visual communication device to display any information the microcontroller would send out to indicate the status of the transformer protective device. The digital pins 5, 4, 3, and 2 (PD4, PD5, PD6, and PD7) of the microcontroller are connected to the data pins D11, D12, D13, and D14 of the LCD to receive information from the microcontroller to display the status of the fuse. The PB3 and PB4 pins of the microcontroller are connected to the enable (E) and reset (RS) pins of the LCD to enable its functionality to help display any information received from the microcontroller. Digital pin 8 (PD8) and pin 9 (PD9) which are the receiver (RX) and transmitter (TX) pins of the microcontroller are connected to the RX and TX terminals of the GSM module to receive and transmit information (data) wirelessly from the transformer protective device to a substation designated mobile phone.

3.2. Display and Information Unit of Data Acquisition and Transmission Circuit.

This unit gives the output information by displaying it and sending it to a predefined phone number. It displays the state of the various detector circuit. It comprises a liquid display (LCD) which is interfaced with the microcontroller. Three Pilot lights were also used to indicate the phases available. A variable voltage regulator was connected across pins 2 and 7 to control the brightness of the LCD. Employing the SIM900A GSM module interfaced with the microcontroller. The GSM module requires a SIM card to operate. Some of the features of the SIM-900A GSM module which made it necessary in this paper were its tiny configuration of 24mm x 24mm x 3mm, a complete Quad-band GSM/GPRS, it delivers GSM/GPRS 900/1800MHz performance for voice, SMS, Data, and Fax with low power consumption. A programmed SMS and call alert is sent to the utility providers indicating the location of the transformer and the faulty protective device(s). Table 4 shows the specification of components used in designing the data acquisition and transmission circuit.

Table 4. Specification of data acquisition and transmission circuit components

Component Symbol	Component Name	Quantity	Component Specification
TRAN-2P2S	Transformer	4	240VAC/12VAC, 50Hz
F	fuse	6	5A
D	Diode	16	1N4001
PC817	Optocoupler	6	
RG1	Voltage Regulator	4	78L05
SW1	Push Button Switch	6	Push to Make Switch
GSM	GSM module	1	Sim 900D
IC	Microcontroller (Arduino UNO)	1	ATMEGA328
LM016L	Liquid Crystal Display	1	LM16x2
R	Fixed Resistor	5	0.5W 0.01k
POT-HG	Variable Resistor	1	0.5W 1k
Cap	Electrolytic Capacitor	8	166.86uF
LAP	Indicating Lamp	4	2VDC

4. Results and Discussion

A protective device is one of the important equipment of for power distribution lines, high-voltage drop-out fuses often have poor contact which affects power delivery to customers. Protective device drop-out which could be a result of a short circuit between phases can cause a fire outbreak, which could also cause a serious shutdown of connected loads causing great losses to production and livelihood. For the internal fault scenario, a three-phase fault is introduced between the primary side (Medium Voltage Side) and the secondary side (Low voltage Side) of a power transformer which shows performance as in (Abd-Elaziz et al., 2007; Lakkaraju, 2016). This fault creates a magnitude current of 1000A and above. For this study, a time duration of one second was considered during the simulation. The red, yellow, and blue phase faults were all within 0-0.1 seconds of faults occurring time in the circuit during the simulation of the distribution network. The relay gives a logic value of '1' before the fault and '0' after the fault. The protective device is closed in normal conditions and opens under fault conditions, in which no further current passes through the circuit under abnormal conditions. During the internal fault scenario simulation, when faults were introduced between respective phases internally of the transformer, spikes of current flow through the system caused system disturbances. It was found that within the simulated sample-based period of one second (1sec), the fault current in the three phases occurred between 0-0.1sec, with a current magnitude of about 1000A and above were recorded at both the high and low voltage side of the transformer. These currents of the individual phases are represented in Figs. 4. and 5.

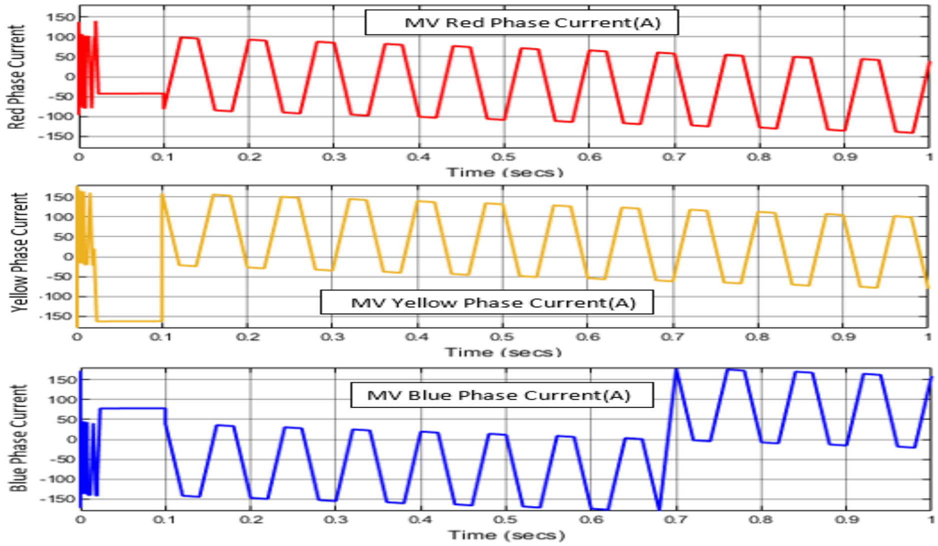

Fig. 4. MV breaker tripping current during an internal fault condition

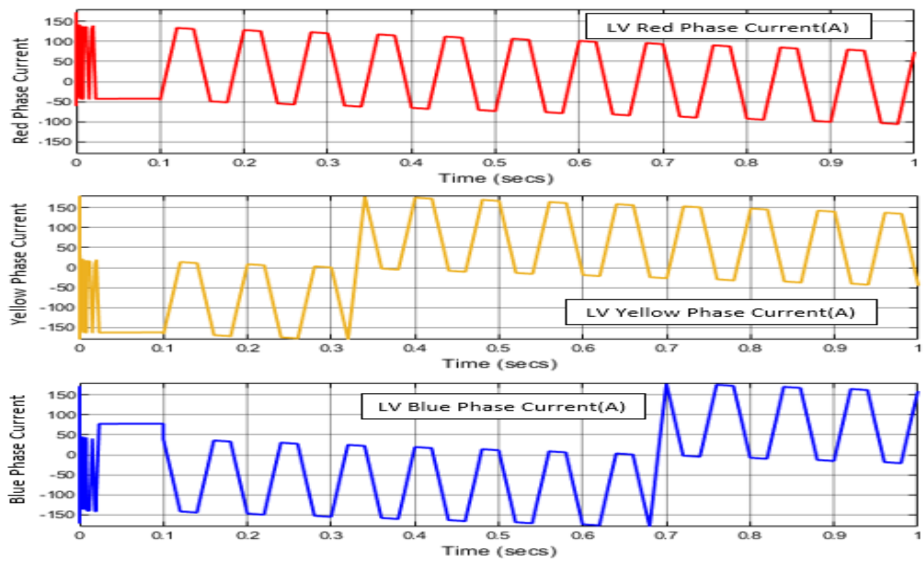

Fig. 5. LV breaker tripping current during an internal fault condition

The internal fault of a transformer could cause the opening of all protective devices on both sides of a transformer. This scenario is simulated to demonstrate the occurrence of this fault on a real-time basis, the effect on various loads connected in a distribution network, and the cost that would be incurred by the utility provider. The results of such cases are presented in Figs. 6, 7, and 8. The connected loads are the resistive and inductive (RL) load, resistive, inductive, and capacitive (RLC), and the three-phase dynamic load, and the current and voltage that flows through the loads connected in the network are shown in Figs. 6, 7, and 8 respectively. The current and voltage in a given circuit connected to a load have a specific wave characteristic depending on the fault current. In Fig. 6, the voltage and current waveform were disturbed at the occurrence of a fault within 0-0.2 seconds with the current wave recorded above 10000A and magnitude of 0A after the fault has occurred. The fault current of the resistive-inductive (RL) load occurred between 0.2 seconds and currents flows almost uniformly in the circuit. With the dynamic load, the fault occurred between 0-0.1 seconds continuously. Comparing the current and voltage waveform of Figs. 6, 7, and 8. The fault current was twice as high as that of the dynamic load. A fault in an electrical circuit can cause current and voltage to be out of phase. This happens because of the changes in loads in the circuit. When different loads are connected in a circuit, there will be different levels of current drawn by such loads to operate correctly.

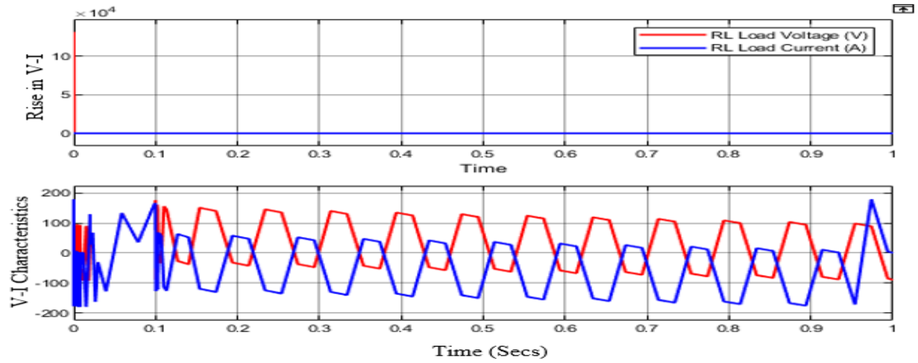

Fig. 6. Voltage and Current flow signal at the RL load

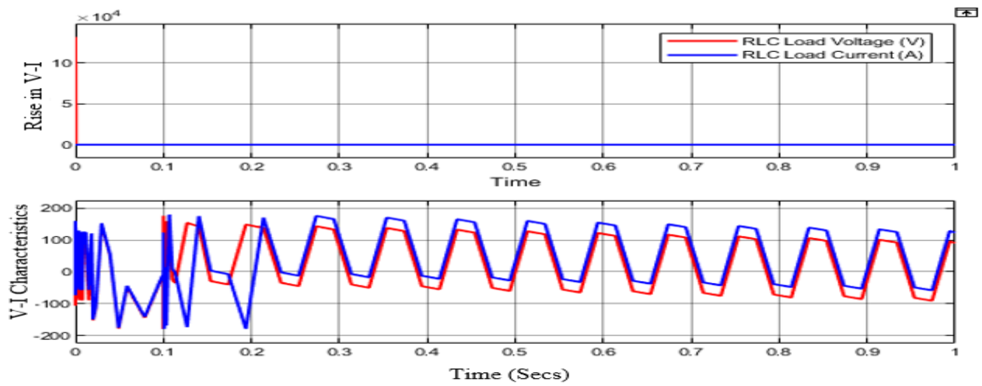

Fig. 7. Voltage and Current flow signal at the RLC load

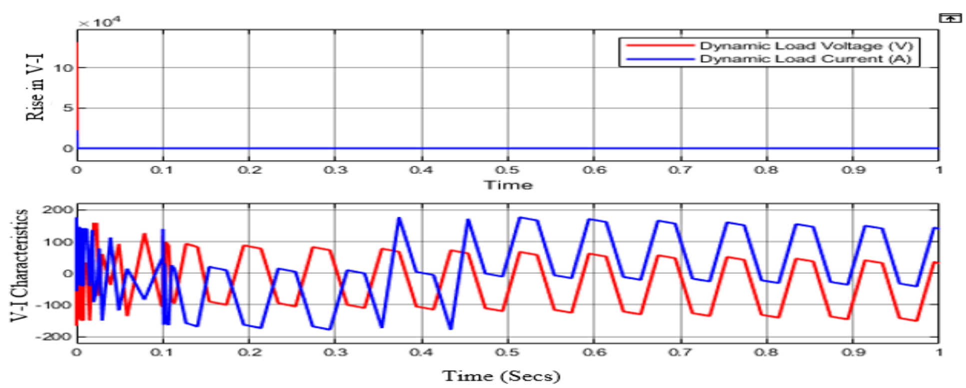

Fig. 8. Voltage and Current flow signal at the Dynamic load

4.1. External Fault Analysis

A simulation scenario of an external fault was introduced between the load and the secondary side of the transformer. Current waveforms and protective device restrain signal are shown in Fig. 9. When a faulty current flows through the circuit, the significant difference in current on both sides of the transformer is seen by the protective device. The breaker then operates and avoids damages that may occur by such fault currents. At the occurrence of this fault, SMS and call alerts are placed to alert the power distribution authorities for prompt action to be taken to restore power to consumers. It is also noticed that external faults of a distribution transformer could also be caused due to abnormalities in the network (Pawar & Deosarkar, 2018; Rahman et al., 2017; Srivastava & Tripathi, 2018). Such abnormalities are over-frequency, over-fluxing of power transformers, under-excitation of synchronous machines, power frequency overvoltage or under-voltage, power swings, overloading of the power network, asynchronous operation of synchronous machines, and mechanical faults that affect the performance and life span of the transformer. The result presented in Fig. 9 shows the un-uniform flow of current in the vent of the external fault in a distribution network.

The non-uniform flow of the current flow distribution network through the transformer can have a negative effect on the transform performance. A fault within a time frame of 0-0.1 seconds has a magnitude of fault current above 150A through each phase of the system network.

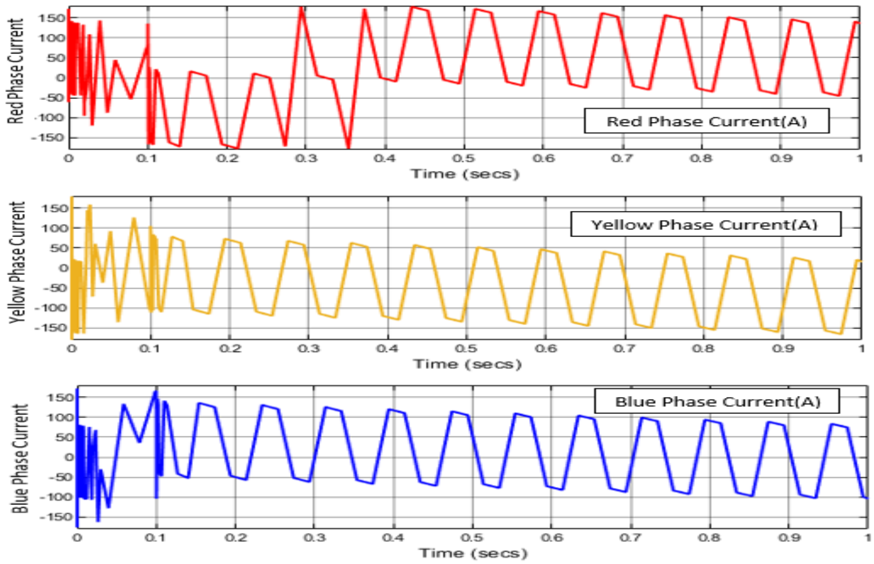

Fig. 9: Current Waveform During External Fault

4.2. Overload analysis on distribution transformer

Overloading of a transformer can occur when at least one of the phase currents exceeds its rated value. In a distribution network, overloading is one of the major problems that will result in fuse blowing or breaker tripping. Therefore, there is a need to understand the overall load behaviors in a given network, effective parameters in transformers, and environmental conditions that affect the performance of the transformer. Whereas the load variation in the distribution system is so much that, one phase could be in an overloading condition for a long period. Longtime overloading beyond standard duration causes disturbances in the power network thereby resulting in serious damage to the transformer and as well reduce its life span. Considering the effects and duration of transformer overloading, the following standards, such as, system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) were used to determine the reliability of a distribution system. Figs. 10 and 11 show the current rise and fall when a transformer in a distribution network is overloaded. The protective devices at both the medium and low voltage sides of the transformer are tripped under overloading conditions to safeguard the transformer. Under the condition of three-phase and three-phase-to-ground faults, a similar current flow phenomenon was obtained during the simulation of the distribution network. This highlighted the results of Dharanya et al., (2013), Gokula Krishnan et al., (2008), Hussen and Ibrahim (2020), Srivastava and Tripathi, (2018). Figs. 10 and 11 are the result of the three phases' current waveforms when the system was overloaded. It could be seen that disturbance of current flow occurs between a simulated period of 0-0.18 seconds for the medium voltage system and 0-0.35 seconds for the low voltage system. In both figures, a maximum rise in the current of the blue and the yellow phases on both the medium and low voltage side of the transformer was recorded to be about 500MA, 180A respectively, but that of the red phase was lower than 150A rise in current within a short time at fault insertion which indicates that there is a disturbance in terms of current flows due to overloading of system circuit. This abnormal current flow through connected loads in the distribution can result in the damage of equipment due to the flow of faulty current. In the case where the protective devices are opened to safeguard equipment(s), there will be an outage of power supply to customers thereby creating a reduction in production and uncomfortable living conditions for customers connected to the grid in rural areas.

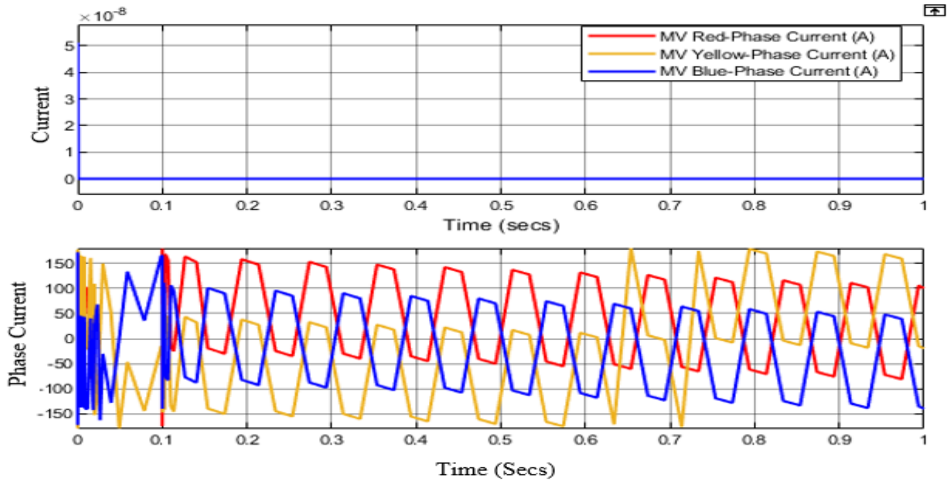

Fig. 10: Current flow at the medium voltage side of the transformer when overloaded.

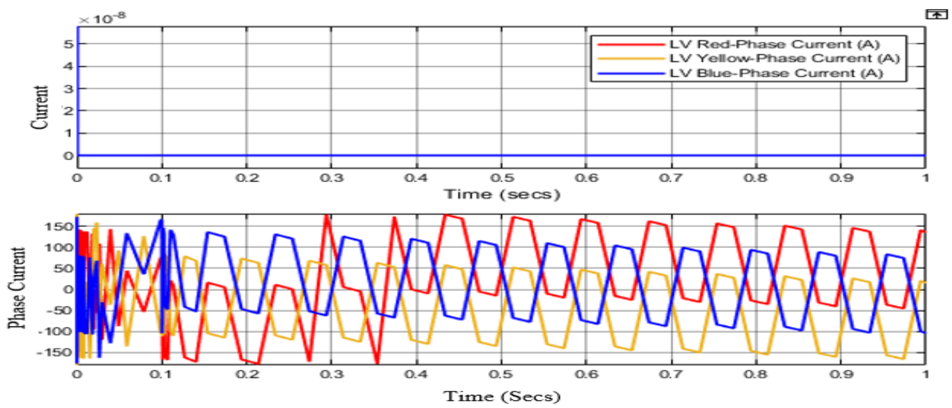

Fig. 11: Current flow at the low voltage side of the transformer when overloaded.

4.3. Economic benefits of remote monitoring

A cost-effective analysis for a monitoring system requires a hypothesis of many individual parameters which are difficult to assess. For a general approach, not all of these items can be calculated exactly. In any case, the prevention of major failures can be counted. In effect, the method of savings has to be taken into account dependent on the specific situation.

4.4. Equivalent annual investment costs

The equivalent annual investment costs C_{spare} of the n*th* spare transformer were calculated using equations 10 and 11.

$$C_{spare} = S_{Unit} x \frac{r(1+r)^l}{r(1+r)^l - 1} \qquad (10)$$

$$S_{Unit} = S_{procurement} + S_{replacement} \qquad (11)$$

where S*unit* is the actual total investment costs of one spare transformer, *r* is the discount rate, and *l* is the average economic life of one transformer. $S_{procurement}$ is the procurement costs due to one spare transformer, and $S_{replacement}$ is the replacement costs including installation, labor, and transportation costs. The transformer monitoring, maintenance, and acquisition of protective device strategies and cost-benefit analysis are presented in Table 5.

Table 5: Transformer monitoring, maintenance, and acquisition of protective device strategies and cost-benefit analysis.

Cases	Transformer monitoring, maintenance and acquisition of Protective device	The total number of spare transformer Protective device	Present value of total investment costs (M$)	Present value of total economic benefits (M$)	Present value of total net benefits (M$)	Total cost-benefit ratios
Case1	2018-2019	40	1.52	6.52	5.00	4.29
Case2	2019-2020	35	1.24	3.43	2.19	2.77
Case3	2020-2021	39	1.42	5.75	4.33	4.05
Case4	2021-2022	36	1.24	3.43	2.19	2.77

The merits of the proposed system of transformer monitoring strategy, the annual investment costs, annual transportation cost, and annual net benefits are converted into the present values. The cost-benefit ratio indices under the four cases are derived and shown in Table 5. Although all four-transformer monitoring, maintenance, and acquisition of protective device spare strategies are financially justified, there are still big differences between the net benefits and cost-benefit ratios. The spare transformer strategy under Case 1 has the biggest economic benefits and the cost-benefit ratio. It means that the proposed strategy outperforms the strategies under Cases 2–4. The manual monitoring process of each transformer is not accurately captured under Cases 2–4, which results in significantly underestimated reliability indices and less economical spare protective devices for transformer monitoring strategy which was highlighted in the study by (Puri et al., 2020). The income loss caused by the undiscovered failure of protection devices in the power network for urgent maintenance operations raises production costs due to worse performance and this is in line with the research conducted by (Puri et al., 2020; Umar et al., 2020). Given a connected load on a distribution feeder with a capacity of 20 MW, and an electricity price of 0.046 USD/kWh, availability and income loss are determined using equation 12.

$$S_r = (1 - R_{devices})\ x Hours\ in\ a\ year(8760)\ x\ load\ on\ a\ distribution\ feeder\ x\ Price\ of\ Electricity\left(\frac{USD}{kWh}\right) \tag{12}$$

where Sr = loss in income capacity, and R = reliability of devices. Due to significant income loss as a result of the poor performance of maintenance and monitoring technologies, which has a stronger economic impact on power delivery. Therefore, by implementing the aforementioned approach to the maintenance and monitoring technology issue, it is possible to reduce the number of unnoticed dropouts of protective devices in a rural distribution network by 50%, while increasing the reliability of the power supply and lowering costs by 15%, and decreasing production downfalls caused by prolonged downtime by 10%. The study results also show that the costs of manual monitoring of distribution protective devices are up to 70% greater than those of a preventive method based on remote monitoring of distribution protective devices. It must be emphasized that the manual process of monitoring each transformer significantly influences the reliability of the power supply, hence the remote monitoring system of transformers will help reduce the cost and downtime period of a distribution network in rural areas.

5. Conclusion

This article presents a study on distribution transformer protective device monitoring systems to monitor protective device operations. The proposed system of distribution transformer protection system and data acquisition and transmission system was designed and simulated using MATLAB and Proteus software respectively. With the proposed system, a dropout of protective devices of a transformer sent an operating signal to a power distribution substation control center to notify linesmen of the dropout of a protective device of a given transformer using the internet as a transmission medium. This system will help in monitoring the operation, restoration of the power supply, and maintenance of the protective device. Comparing the proposed system with the manual way of the linesmen monitoring system of inspection the operations of protective devices incur a lot of costs and prolonged downtime as a result of the manual method of monitoring. Again, the proposed system will help the potential functions of failure identification, and that will bring a series of advantages to utility companies, reducing maintenance costs, lengthening the transformer's life span, enhancing the safety of operators, minimizing power outages based on a failure of protective devices, minimizing accidents and the severity of destruction as well as improving power delivery in rural distribution networks. Implementing this technology in the power distribution sector will help the power utility companies to minimize costs in terms of monitoring, restoration of power to customers will also be prompt, and aid in energy dispatch. The proposed technology will help policymakers and the government at large in decision-making in the power sector.

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