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Open-Source Automatic Circuit Recloser with Remote Control and Monitoring

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***Abstract*— According to statistics, a large amount of faults in transmission and distribution networks are temporary faults that disappear a certain time after de-energization of the faulted sections of the network and then power is restored manually after the fault has cleared. Most recently, technology advancement has made available Automatic Circuit Recloser (ACR). This device makes it possible to recover the original status of the network without any human interaction. Unfortunately, for Africa and Zambia in particular the ACR system is proprietary, expensive and need "experts" to install, maintain and repair it. This study uses an open source embedded prototype single-line-to-ground (SLG) system that uses fixed dead time to discriminate transient from permanent faults. Simultaneously, an SMS is sent to the technician or the control center. A program generated dead time it will attempt to switch ON for a number of given times beyond which the system is locked out until reset. The prototype was successfully simulated and implemented.**

***Keywords*— Recloser, Transient and permanent fault, dead time.**

I. INTRODUCTION

Transmission and distribution lines cover long distances are prone to climate battering and environmental damages such as falling trees, lightening and vehicles ramming, etc. The results are live line touching the ground, the neutral line or worse more another live line. Such create high currents called faults currents in the system capable of causing damaging high mechanical and thermal stress. Universally and particularly in Zambia, utility companies have put different protection schemes to mitigate, monitor and control the flow of these currents.

Protective relays are installed at various places in the power system to detect faults and isolate the faulted part from the remaining transmission line system [1]. On the other hand, the continuity of supply is another key issue that has to be taken into consideration in power systems. To meet this condition, it is required that a .transmission line, isolated following a fault occurrence, be reclosed within possible short duration of time. This in turn improves not only the continuity of supply but also the maintenance of the power system stability and synchronism, particularly to HV systems in Zambia. It is then advantageous to attempt closing the circuit automatically, hoping the fault has disappeared. Such a system is called an Automatic Circuit Recloser(ACR) and is used to recover the original status of the network without any human interaction [1] [2] [3] [4]. This reduces operating costs and improves the reliability of service of the network in places such Luapula and Muchinga provinces of Zambia.

Previous studies have shown that single-line-to-ground (SLG) failures make up the majority of transient faults in overhead transmission lines, accounting for 80–90% of the faults [5] [6] [7] [8] [9]. Temporary and permanent defects on overhead transmission lines are the two categories that they fall under. By isolating the flawed phase from healthy phases, temporary faults that are intermittent and transient can be easily removed. Permanent flaws can only be identified after they have been manually patched. Automatic circuit reclosers (ACRs) are utilized to do this. They are a form of switchgear used in electric power distribution, and are intended for use on overhead electrical distribution networks to identify and interrupt transient faults. Generally, the existing AC auto-reclosing schemes are divided into three main categories: conventional auto-reclosing schemes, adaptive auto-reclosing schemes, and intelligent auto-reclosing schemes [10] [5] [7] [2] [11]. Several simulations have been achieved in [7] [3] [12] [10] [13]. This paper aims to achieve a fully functional Open Source ACR starting with its simulation.

II. METHODOLOGY

To achieve the level of protection performance achieved by proprietary ACR manufacturers or nearly so, this open source need to have able to:

- *Cut off the load in case of overcurrent*. A current transformer (CT) is used for data collection and a pickup value is set in the algorithm of the microcontroller.
- *Distinguished between transient and permanent fault.* If the fault duration is, a fault condition is detected. A fixed dead time is programmed to allow time for the fault to disappear before attempting to close the circuit breaker. The dead time value will depend on the environment of the transmission line and standards set by the energy

corporation. Fig. 1 shows the system block diagram.

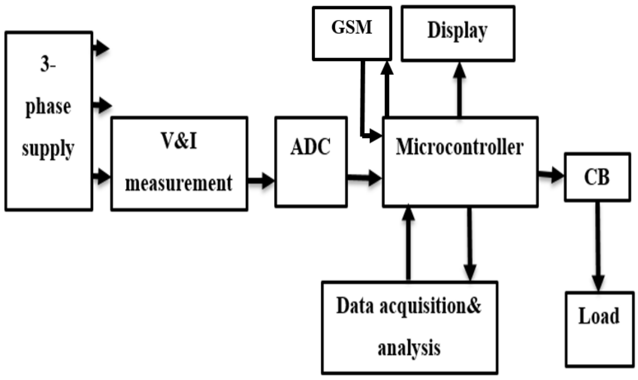

Fig. 1 Smart ACR block diagram.

Fig. 2 below shows the flowchart of the system where I_l is load current, I_p the pickup current, t the time, D_t the predetermine dead time and N the predetermined number of shot or attempted reclosures.

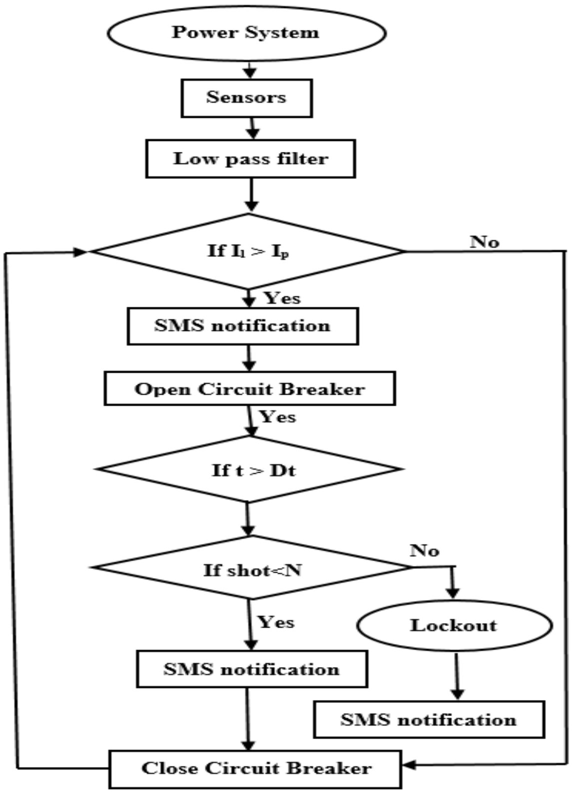

Fig. 2 Flowchart of proposed method for diagnosis of fault type.

A GSM module in this case is used to notify the control the center of the change of the circuit breaker status. The control center will be able to remotely switch ON or OFF by means of SMS, emails or SCADA. This economical and helps avoid travelling long distances in terrible conditions by sending a simple SMS to close or open the ACR.

A good understanding of protection system, including analog relay is paramount to a successful implementation on this project. The collection and conditioning of data, the processing of the data taking in consideration the main important feature of protection such as overcurrent, zonal protection will be paramount to the successful implementation of the project. Simulation in this case cannot be over emphasized as it will reduce on down time and components wastages. Features of remote monitoring and controlling via SMS will make this model very useful in our power distribution system.

The system is simulated in both Matlab and Proteus. Table I shows parameters and settings used in the model and simulation. The parameters are for three phase sources which represent Zambia Electricity Supply Corporation Limited(Zesco) 60km Lwasombe line along Ndola-Kabwe road, three phase transmission line and three phase fault while the settings are for over-current and auto-reclose relays. Figure 1 shows power source, circuit breakers on each line, transmission line equivalent resistances and inductances, load and measurements system. Transmission line is separated into two parts to simulate single phase-to-ground fault at red phase conductor, 12.77 km from local substation. The following table gives the modelling parameters and relay setting.

TABLE I

MODELLING PARAMETERS AND RELAY SETTING

Source parameters	**Values**
Three phase sending voltage	33 kV
Base voltage	33 kV
Frequency	50Hz
Internal resistance	0.8929 Ω
Internal inductance	16.58 mH
Internal capacitance	0 uF
Transmission Line Parameters (Short)	**Values**
Line resistance	0.0663 Ω/km
Line inductance	0.00025 H/km
Line length	60 km
Over-current Relay Setting	**Values**
Rated Current	200 A
Pick up current (Ipickup)	228 A
Operation time	0.1 s
Auto-reclose Relay Setting	**Values**
Dead time	0.2 s
Load Parameters	**Values**
Active power	7.5 MW
Inductive Reactive Power Ql	4 MVar
Capacitive Reactive Power Qc	0
Fault Parameters	**Values/Types**
Type of fault	***Single line-to-ground fault,*** *if 0.2< k<=0.9 => transient If k>0.9 => permanent, k is the fault duration.*

Fault location from local substation	12.77 km
Fault initiation time	0.2 s
Fault disappearance time	0.25 s
Fault resistance	*p* Ω *(0.1<p<10)*

III. Results

The circuit in Fig. 3 shows the complete simulation in Matlab. The protection system includes the current measuring unit, breaker control unit and the lockout system. The results for a single line fault operation are gotten from the three input oscilloscope and are shown in Fig. 4 where line I is the line current, V_r the receiving end voltage and V_s the sending end voltage. The top figure shows the behavior of the sending end voltage during the fault within a period of one second. The middle figure shows the behavior of the receiving end voltage while the last one shows the line current. It can be clearly seen that the sending voltage deeps during the fault while the receiving voltage at the fault point falls to a fraction of the normal voltage when the load current increases beyond the pickup value of 228A. Since the number of reclosures (also known as number of shots) is set to 4, for attempts are made to reclose. Since the fault still persist the circuit breaker will be locked out.

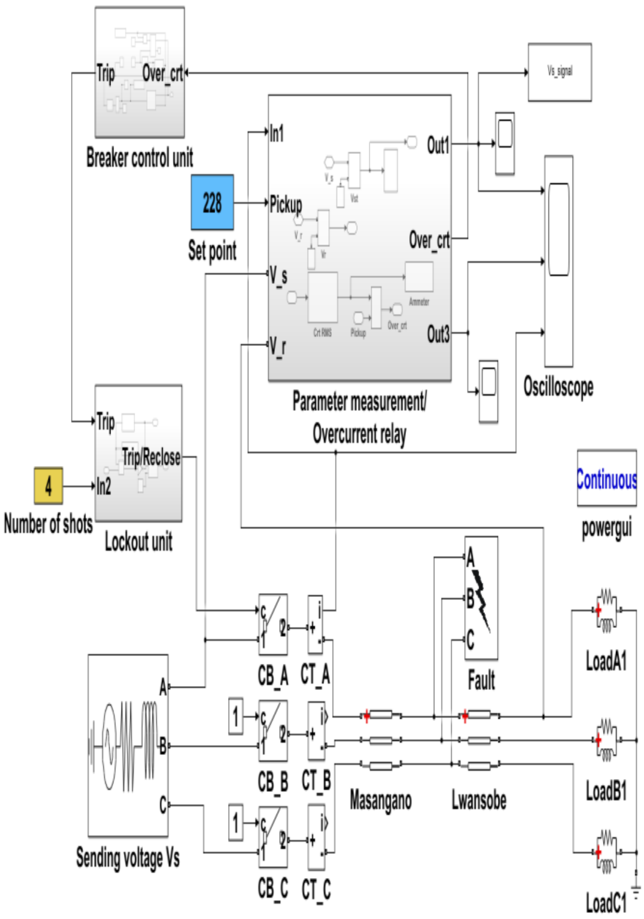

Fig. 3 Autoreclosure simulation circuit diagram.

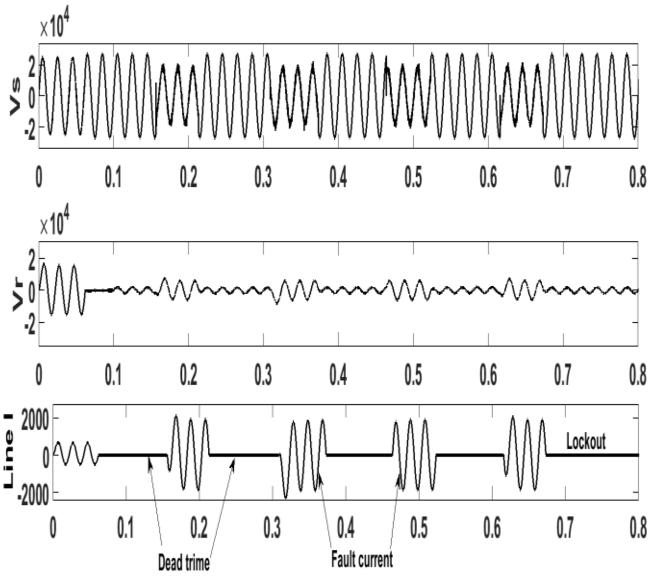

Fig. 4 Graphs output obtained in Simulink.

To be able to come up with an electronic circuit, the circuit was simulated in Proteus successfully, proving that auto reclosing can be achieved with open source. Fig. 5 shows the simulation circuit. One Arduino is used to receive data and control the circuit breaker represented by a relay. The normal load is shown by one lamp and the other lamp represents an overload. Switches represent faults. The other Arduino is dedicated to sending and receiving SMS commands shown as a virtual terminal. Two pushbuttons, CLOSE and OPEN, allow local control of the ACR. A liquid crystal display (LCD20x4) is added to display parameters.

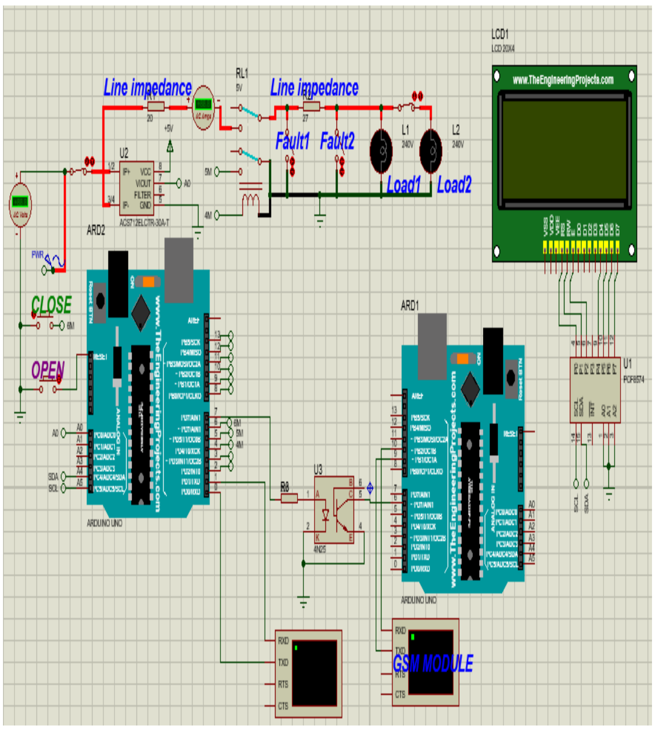

Fig. 5 Simulation of Autorecloser in Proteus8.6.

IV. DISCUSION

Technology advancement has made the use of Automatic Circuit Recloser (ACR) vital in power system management and control. This device makes it possible to recover the original status of the network without any human interaction. Unfortunately, for Africa and Zambia in particular the ACR system being proprietary is expensive and need supplier registered “experts” to install, train maintenance team and repair it. Given that most rural area roads in Zambia are gravel and in bad state, this makes it difficult and expensive to simply attempt a reclose, let alone know in good time that a fault has occurred. Since the reset, Open and Close buttons are usually in substations near the end user, it is economical and effective to have a remote control system that is able to both monitor the circuit breaker status and control it. Moreover, most of the damaged controllers have their tanks redundant. Coming up with a local and cheap solution will reduce the downtime, transportation and cost of maintenance. An algorithm to achieve this was successfully done in Matlab with the view to see the wave forms and RMS of sending and receiving voltages as well as load current. Based on the Matlab simulation, a C/C++ code was generated and used in a Proteus8.6 software. Arduino Uno microcontroller model which is an open source microcontroller and readily available on the market was used in the simulation. To achieve control in real time a second microcontroller is dedicated to sending messages. These simulations show that it is possible to achieve the key functionalities of the ACR, namely ON/OFF control and status monitoring both in local and remote mode. Another important functionality that needs to be added in future to this study in data logging. This feature is essential for history keeping for good system management. Fault location estimation also will make this system very useful. It is recommendable to implement such a system which has the potential to greatly improve the reliability of transmission lines in Zambia in particular and Africa in general’

V. CONCLUSION

Both simulations and prototype have shown that it possible in Zambia to use locally designed and constructed technology to improve the power distribution reliability, protection cost effectiveness as well as easy maintenance using locally available knowledge and expertise. An investment in mass production, absolute trust and confidence in local talent to solve industries challenge will encourage more researcher and engineers to bring up new bright ideas.

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