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Development of a Remote Transformer Switching System for Smart Distribution Networks

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Abstract

In this work, analysis and development of a GSM based transformer switching system for deployment in a smart distribution network was carried out. This system was implemented by the use of discrete electrical components with the PIC16F876A microcontroller programmed in mikro basic language serving as the main control unit. In the design, each transformer in the network is assigned a unique phone number. Thus when this number is dialled, the ring tone from the GSM phone attached to the transformer is converted into an electrical signal, this signal is harnessed, and it is used to control the stepper motors connected between the 11kV supply to the transformer and the J&P fuses. The steppers motors are connected across each phase in such a way that their movement either disconnects or connects the transformer to the 11kV supply. Thus each transformer in the network can be remotely switched by simply dialling a unique GSM number assigned to it. A prototype of the system designed in this work was constructed and it worked satisfactorily on test.

Keywords: Stepper Motor, Distribution Network, Microcontroller, GSM

1.0 Introduction

Electricity is the most versatile and easily controlled form of energy [1]. At the point of use it is practically loss-free and essentially non-polluting. At the point of generation it can be produced clean with entirely renewable methods, such as wind, water and sunlight. Its availability, reliability and affordability are some of the key parameter indicators of a country's industrial growth. This is so because the running of modern industrial structure depends on the low cost and uninterrupted supply of electricity. In fact a country is said to be developed if the per capital consumption of electricity is high, and a lack of electricity breeds and sustains poverty [2]. The truthfulness of the above statement can be seen by comparing the economies of a country like the United Kingdom (UK) that has 1340 watts of electricity per person to that of Nigeria that has 32 watt per person [3].

One of the objectives of electricity distribution companies is to ensure reliability and availability of supply among other things.

In this respect, Nigeria's electric power distribution systems perform relatively poor: blackouts are common and electricity bills are hardly manageable even in the face of actual lack of the product. Furthermore, technical constraints including voltage control, frequency control and grid management limitations are listed as part of the nine major problems militating against the performance of PHCN by the Central Bank of Nigeria. For a country with a population of over 150 million persons that generates less than 5000MW of electric power [4], our power system could be described as everything but stable. There is a good reason to ponder whether we might be better served if our distribution system is automated. Again the power grid is aging and congested and faces new challenges and stresses that put at risk its ability to reliably deliver power to an economy that is increasingly dependent on electricity. A growing recognition of the need to modernize the grid to meet tomorrow's challenges has found articulation in the vision of a Smart Grid.

The concept of a smart grid emerges from the integration of the power systems of the electricity grid with its corresponding information technology systems. The combined concept that uses the information network to enhance the functioning of the electricity grid is generally what is called the smart grid [5].

There is an urgent need to establish protocols and standards for the Smart Grid, thus development and deployment of various Smart Grid elements, including smart sensors on distribution lines is crucial to achieving this noble objective.

In Nigeria for instance, the absence of switches at different points in the distribution network, makes it impossible to isolate

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certain loads for load shedding or for the purpose of maintenance as at when required. The only option available in the present Nigerian distribution network is the circuit breaker (one each for every main 11 kV feeder) at the 33/11 kV injection substation. However, these circuit breakers are actually provided as a means of protection to completely isolate the downstream network in the event of a fault. Using this as a tool for load management is not desirable, as it disconnects the power supply to a very large segment of consumers. Extended outage resulting from poor resolution in load management could result in significant economic loss. Clearly, there is a need to put in place a system that can achieve a finer resolution in load management in line with the vision of the smart grid. In the sections that follows, the design and implementation of such a system is presented.

2.0 Remote Transformer switching System

The remote transformer switching system for deployment in a smart distribution network developed in this work, consists of several subunits as shown in the block diagram of Figure 1

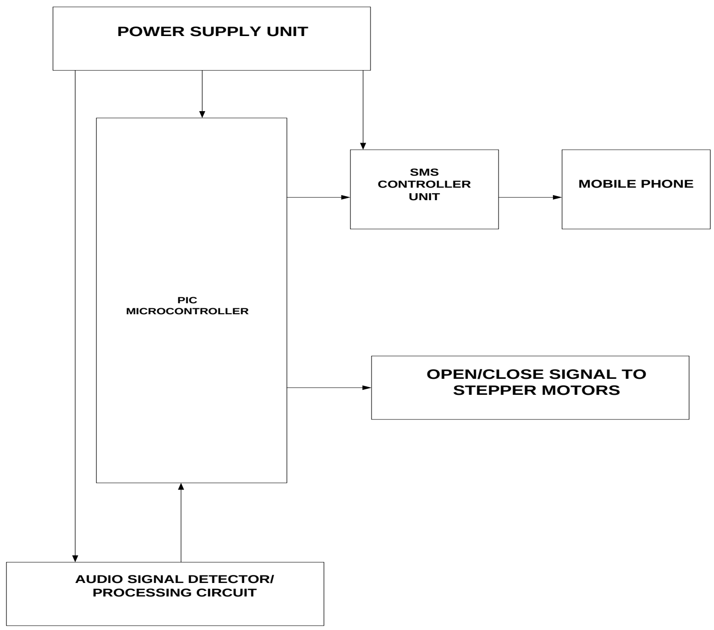

Figure 1: Block Diagram of Remote Transformer switching System

Figure 1 consists of power supply unit, audio signal detector/processing unit, systems controller unit (microcontroller), an SMS controller unit and a mobile phone. The systems controller unit processes inputs from all its peripherals, and sends a signal to the SMS controller unit which in turn sends a programmed SMS to the system operators to confirm that a particular switching operation was successful.

Next, the design of each component of the block diagram is presented.

2.1 Power Supply Unit

The circuit diagram for the power supply unit is shown in Figure 2.

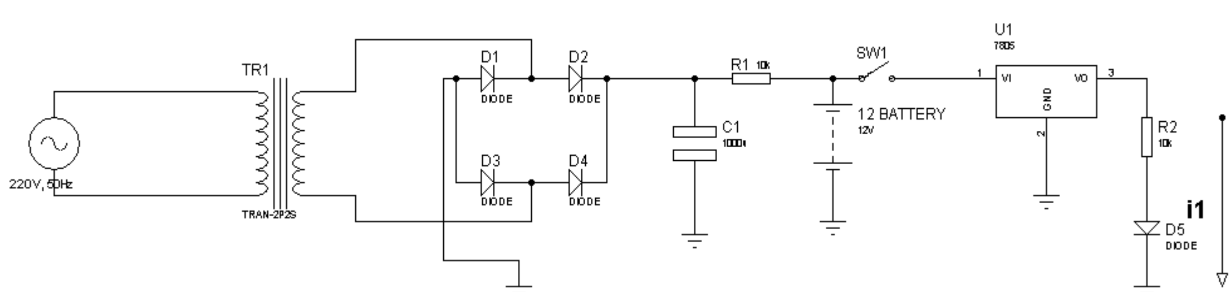

Figure 2: Power Supply Unit

DC power supply to the entire circuit is from the rechargeable 12V, 4.7AH lead acid battery. This battery is charged from the rectified output voltage from the mains. The rectifier circuit is implemented with a combination of 220/15V transformer (TR1), full wave bridge rectifier and an RC filter circuit as shown in Figure 2. U1 is a 7805 IC voltage regulator; this maintains part of the battery output at 5v required as V_{cc} for the microcontroller circuits.

2.2 Audio Signal Detector/Processing Unit

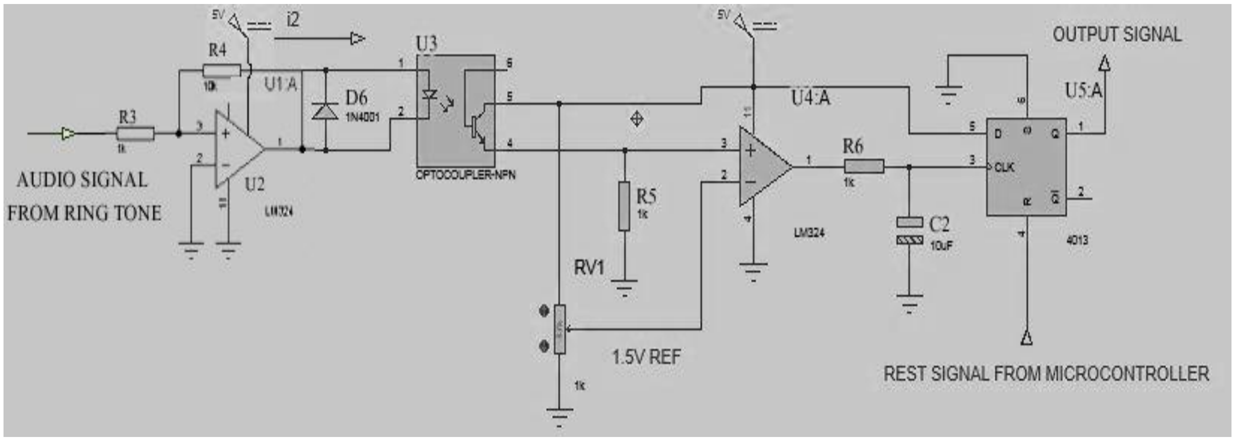

Figure 3: Audio Signal Detector/Processing Circuit

As shown in Figure 3, the circuit consist of a PC123 optocoupler (U_3), two (2) LM324 operational amplifiers (U_2 and U_4) and a D flip flop (U_5) among other components.

The gain of the op amp (U_2) [6, 7] is

$$A = {}^{R_4}/_{R_3} \qquad (1)$$

Thus, Resistors R_3 and R_4 were chosen to set the gain of the op-amp at 10; this is to ensure that the audio signal from the mobile phone is able to drive the optocoupler.

Thus R_3= 1kΩ, R_4=10kΩ.

When light from the LED falls on the base of the transistor in the optocoupler, the transistor saturates and voltage is dropped across pull down resistor R_5. This drop is compared with V_{ref} (1.5V) in the comparator circuit of U4 (LM324). For U4 to saturate, V_{R5} must be greater or equal to V_{ref};Setting V_{R5} at 3V,

$$R_5 = \frac{V_{R5}}{I_3} = \frac{3}{I_3} \qquad (2)$$

Where I_3 is the emitter current of the transistor at saturation I_{sat} = 2 mA [8].

Therefore $R_5 = 3/\ 2X10^{-3} = 1500\ \Omega$

A standard resistor of 1kΩ is chosen as R_5 so as to adequately limit the current flowing through the OP-amp and ensure U4 saturates whenever current flows through the optocoupler. Hence when V_{R5} is greater than V_{ref}, voltage comparator U4 switches to positive saturation. R_{V1} is a potentiometer used to set V_{ref} at 1.5 V. The output of the voltage comparator is fed to the clock of the D flip flop through a low pass filter (R_6 and C_2). A high clock input in the flip flop is interpreted by the microcontroller as request to switch ON or switch OFF the transformer.

2.3 Systems Controller Unit

The system is built on the PIC16F876A microcontroller programmed in mikrobasic language. This unit interprets the signal from the audio signal detector/processing unit. It sends a high logic signal (5v) to the SMS controller unit when it receives a signal from the detector circuits. The signal from the microcontroller also drives the LED indicators D7, D8 and D9 which indicates the positions of the stepper motors connected to each phase of the 11kv supply. Figure 4 shows the circuit diagram of the system control unit.

The P1C16F876A microcontroller has three Input/output (I/O) ports [9]. These are port A, B and port C. In Figure 4, port A and B is configured as output ports, while port C is configured input port. The output of the detector circuit is used as signal input to the microcontroller at port C. The PIC16F876A microcontroller is operated with a 4MHz crystal oscillator. Resistors R_8, R_9, and R_{10} are pull down resistors of the same rating to drive the LEDs by limiting the current flow. Port A.0 (pin 2) is used as reset signal for the flip flops in the detector circuit. The output signal at Port B (output port), is used as driver for the SMS controller unit.

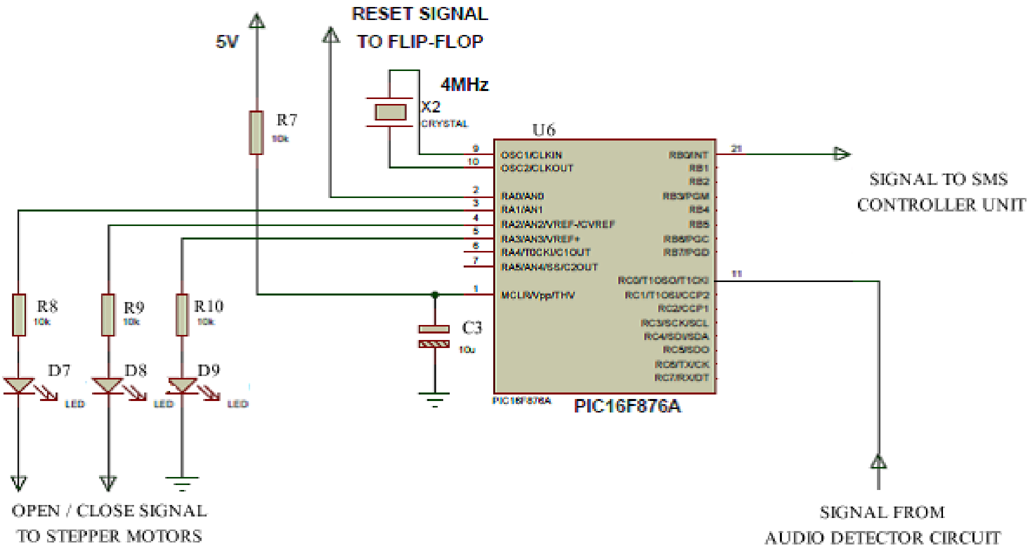

Figure 4: Systems Controller Unit

2.4 SMS Controller Unit

Shown in Figure 5 is the SMS controller unit. This unit receives signal from the systems controller and send the appropriate dialling codes to the mobile phone. This code enables the mobile phone to automatically send programmed SMS to alert managers of the system that a switching operation was successful.

The circuit is implemented with an ATMEL89C52 microcontroller. Input to the microcontroller is at port 0 [10][11]. Its output is interfaced with the mobile phone at port 3. Communication between the microcontroller and the mobile phone is enhanced through AT- commands. (Attention command) at port 3.2 and port 3.3 which utilizes the serial port module of the microcontroller [12]. The signals at port 0 correspond to a programmed SMS. When a 1 appears at any of the inputs at port 0, the microcontroller sends a signal to the mobile phone and a text message is sent.

The entire circuit was simulated on lab center proteus 8.0 and it was found to have worked satisfactorily.

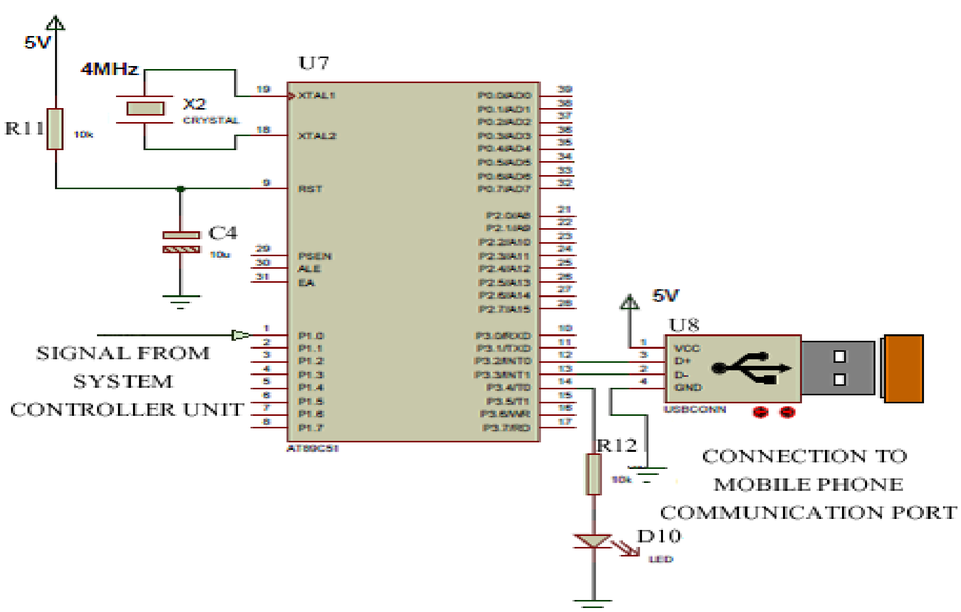

Figure 5: SMS controller Unit.

2.5 Principle of Operation of the Designed Circuit

DC power supply to the entire circuit is from the rechargeable 12V, 4.7AH lead acid battery. This battery is charged from the rectified output voltage from the mains. The rectifier circuit is implemented with a combination of 220/15V transformer (TR_1), full wave bridge rectifier (G25B20 IC), and an RC filter circuit. The 7805 IC voltage regulator maintains part of the battery output at 5V required as V_{cc} for the microcontroller circuits.
To switch a transformer, the unique phone number assigned to the particular transformer is dialled. This will initiate a ring tone (audio signal) in the mobile unit attached to the transformer. This audio signal current is amplified, and flows through the LED in the optocoupler, causing it to glow and in essence switches on the phototransistor also present in the optocoupler.
For U_4 to saturate, V_{R5} must be greater or equal to $V_{ref,}$ hence when V_{R5} is greater than Vre_f, voltage comparator U_5 switches to positive saturation and outputs 5V. The output of the voltage comparator is fed to the clock input of the D flip flop through a low pass filter (R_6 and C2). A high clock input in the flip flop is interpreted by the PIC16F876A microcontroller as a switching signal.

The systems controller unit built on the PIC16F876A microcontroller continuously analyzes signals from the audio signal detector circuit. It sends a high logic signal to the SMS controller when it receives a high signal from the detector circuit.
The SMS controller unit built on the ATMEL89C52 microcontroller receives signal from the systems controller and send the appropriate stored SMS AT commands to the mobile phone. This command enables the mobile phone to automatically send programmed SMS to alert managers of the system that the switching operation was successful.

3.0 Conclusion

In this paper a remote transformer switching system for smart distribution networks, to facilitate switching of distribution transformer was developed. The system was built around PIC16F867A as the main system control unit, and an audio signal detector/processing unit was also implemented alongside an SMS control unit.
Utility providers should adopt this method for seamless switching of distribution transformers. This system would help to achieve finer resolution in load management, thus reducing outages resulting from poor resolution in load management.The prototype smart grid network constructed will be a useful teaching/demonstration tool for students in the laboratory.

4.0 References

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