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Design and Implementation of an Automatic Over/Undervoltage Protection System for Single-Phase Low Voltage Power Lines

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Abstract

Today, many industrial and domestic electronic appliances and equipment (devices) are exposed to power disturbances such as voltage variations of the AC mains supply which often lead to damage of the electronic devices. As these devices are quite sensitive to power disturbances, there is a need for a tripping system that can help avoid any damage to devices in use. The objective of this work is to build a system that monitors line voltage and protects appliances from unacceptable voltage variations. The system consists of a tripping mechanism that monitors the input voltage and trips according to the limits provided. An Arduino Uno microcontroller is used to determine the voltage level through a voltage divider circuit. The system's novelty and innovation lie in its flexibility. It offers the user the ability to define different overvoltage and undervoltage threshold values depending on the specific appliances used in the household. In operation, the system displays the voltage state (overvoltage, normal voltage, overvoltage) and alerts the user by sending an SMS via a GSM modem. The system is valuable for industrial and domestic applications, especially in developing economies such as those of Sub-Saharan Africa, where overvoltage and undervoltage are acute problems.

Keywords

Overvoltage, Undervoltage, Simulation, Arduino Microcontroller, Tripping Mechanism, Sub-Saharan Africa

1. Introduction

Electrical energy is considered the most convenient form of energy for its ease of use and conversion. Since the advent of electrical energy, reliable and secured consumption of electrical power has been realized with outstanding importance as an essential ingredient for growth [1]. However, as the demand for electrical energy increases for both domestic and non-domestic use [2], more generating units and transmission lines are added to the power supply system; which in turn increases its complexity, making the system more susceptible to various faults and power disturbances. These disturbances are often responsible for damage to sensitive equipment and electronic devices. In many developing economies such as those of Africa where the electric power supply has been adeptly described as being erratic [3], electricity users, both domestic and industrial are plagued with power disturbances almost on a daily basis not only as a result of poor policies [3] [4] but more especially because of inadequate power generation and transmission infrastructure characterized by grid disruptions and voltage variations outside nominal values. For example, in zones with fewer transmission lines, undervoltage is a frequent issue; and in zones where improper connections are made, overvoltage is an issue. Voltage variation has been termed the "physiology" of network functioning in that no voltage characteristics (e.g. magnitude) can always and continuously stay within its exact nominal value and with an ideal sine waveform [5]. The implication is that voltage variations are unavoidable, and efforts must be made to maintain them as small as possible (by the utility company) or avoid them completely if such variations are detrimental as in cases of overvoltage and undervoltage (by the utility company and electricity end users).

Today, modern industrial and home electrical equipment and devices designed for developed economies, where the power supply is stable and of high quality are used in developing economies, where they are exposed to conditions of huge voltage variations. But huge voltage variations outside predefined limits may lead to severe problems and consequences for electricity users [5]. One consequence is that electrical equipment and devices in these developing economies either do not function well or are often damaged and forced to retire before the end of their life span; leading to financial burdens on electricity end users in these economies. In some cases, the occurrence of huge voltage variations may not only cause malfunction of, and damage to electrical equipment and devices; but also the loss of human life.

Against this state of affairs, many people in developing economies tend to use voltage stabilizers to cope with voltage variations. However, because these stabilizers operate within specified voltage ranges; in cases where the variation in input voltage is out of the specified voltage, the stabilizers themselves malfunction or become damaged. Quite often, one stabilizer is unable to sustain the electrical appliances of an entire household in terms of power rating. Consequently, people in these developing economies then tend to need two or more voltage stabilizer; which becomes very costly. One may think of circuit breakers used in homes to protect the appliances from voltage variations; but these devices are not automatic with respect to the high sensitivity of modern electrical appliances used in homes and cannot resist certain voltages due to their limited range of operation. For these reasons, the objective of this work is to design and implement a low-cost, reliable, and automatic system that will be able to protect household electrical appliances from voltage variations in low-income developing economies such as those of Sub-Saharan Africa (SSA). This system will be used not only to protect household appliances from voltage abnormalities but also other protection devices such as voltage stabilizers, using a tripping mechanism that automatically disconnects the protected device(s) from the AC mains whenever there is a voltage abnormality, and informs the electricity end user through an alert subsystem based on a Global System for Mobiles (GSM) communication module. The system's novelty and innovation lie in its flexibility. The system offers the user the ability to define the required overvoltage and undervoltage threshold values depending on the specific appliances used in the household.

2. Background and Related Works

2.1. Background

Voltage-related power disturbances which are reflected by the increase (rise) or decrease (fall) of RMS voltage are the major issues faced by industrial and home users of electrical energy. Depending on the magnitude of the increase or decrease and its duration, voltage variations are broadly classified in two groups as either short duration or long duration. Within the short duration category, variations are sub-classified as instantaneous, momentary, and temporary; and within each of these sub-groups, variations are specifically distinguished as either sag, swell, or interruption; except for the instantaneous variations that do not have interruptions. Within the long duration category, variations are simply distinguished as either undervoltage, overvoltage, or sustained interruptions. The characterizations of the various voltage variations are summarized in **Table 1** and briefly analyzed [5]-[11].

The characterization of power disturbances as per **Table 1** is important in the design and implementation of systems that can help protect appliances from the power disturbances. Specifically, in order to protect against equipment damage (due to overvoltage) or failure (due to under voltage), the system design goal may be obtained by considering a shorter time interval to average measured values [5].

The classification reveals that the effect on the RMS voltage of the pair-wise disturbances (swell and sag; long and short interruption; and overvoltage and undervoltage) is generally the opposite of each other; and while the causes of each disturbance are not the opposite of each other, their effects, in the general sense are the same: they are harmful and cause destruction of various types and designation. For example, on the one hand, swells are caused by switching off of large loads, energizing capacitor banks, voltage increase of un-faulted phases

Table 1. Characterization of voltage variations.

Type	Effect on RMS voltage	Final Magnitude	Duration of effect on RMS voltage
	(a): Short duration voltage variation		
Instantaneous			
Sag	decrease	0.1 - 0.9 pu	0.5 - 30 cycles
Swell	increase	0.1 - 1.8 pu	0.5 - 30 cycles
Momentary			
Sag	decrease	0.1 - 0.9 pu	0.5 cycle to 1 minute
Swell	increase	1.1 - 1.8 pu	0.5 cycle to 1 minute
Interruption (v. short)	decrease	<0.1 pu	0.5 cycles - 3 s
Temporary			
Sag	decrease	0.1 - 0.9 pu	3 s - 1 minute
Swell	increase	1.1 - 1.2 pu	3 s - 1 minute
Interruption (Short)	decrease	<0.1 pu	≤3 minutes
	(b): Long duration voltage variation		
Over Voltage	increase	1.1 - 1.2 pu	>1 minute
Under Voltage	decrease	0.8 - 0.9 pu	>1 minute
Interruption (Long)	decrease	0.0 pu	>3 minute

during single line-to-ground faults, and momentary overvoltage; while on the other hand, sags are caused by energization of heavy loads, starting of large induction motors, single line-to-ground faults, line-line and symmetrical faults, and transferring of load from one power source to another. But the effects of swells or sags are generally the same; and include malfunctions of electrical low-voltage devices, malfunctions of uninterruptible power supply, and malfunction of measuring and control equipment [12]. An interesting positive effect of both swells and sags is voltage stability due to the reduction of bus voltage for short durations. **Figure 1** and **Figure 2** respectively depict instantaneous sags and instantaneous swells in power systems [7].

For their part, interruptions are caused by power supply equipment failures, control malfunction, blown fuse, and opening of circuit breakers; and their effects include little or complete loss of voltage (**Figure 3**).

Finally, while undervoltages are caused by overload, short circuits, and less supply capability; and their presence may lead to voltage instability, drawl of high current by motors, high reactive power demand, burnout, distortion, and equipment failure and malfunction; overvoltages are caused be insulation faults, overcompensation, and lightning; and manifested in the form of spikes and surges and cause distortion, burn-out, melt-down, fire, electro-pulsing and permanent damage. **Figure 4** and **Figure 5** respectively depict overvoltage and undervoltages in power systems [13].

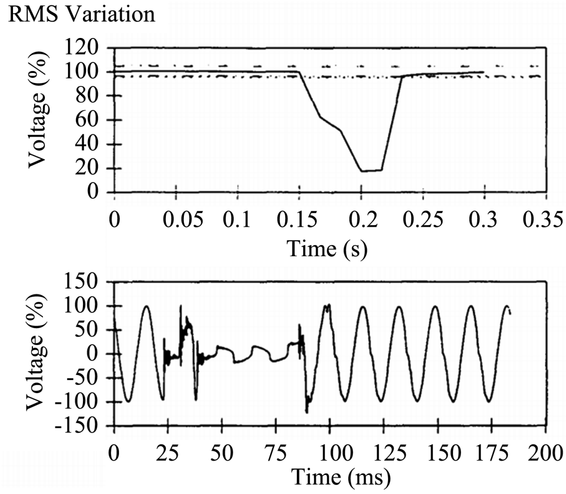


Figure 1. Instantaneous sag [11].

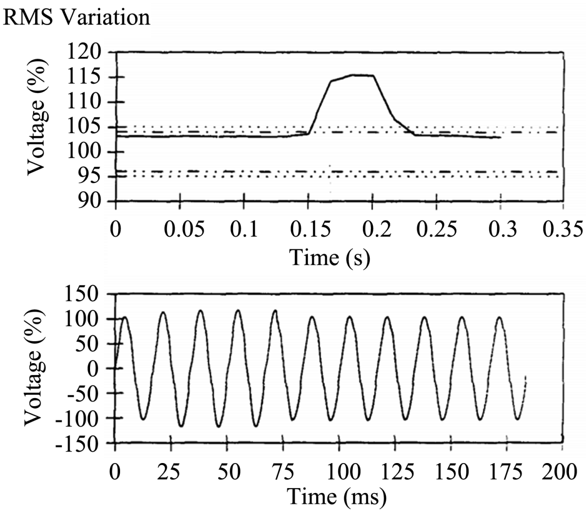


Figure 2. Instantaneous swell [11].

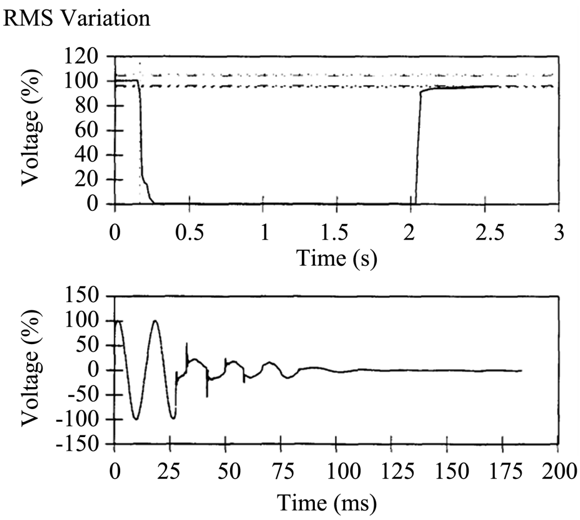


Figure 3. Momentary interruption [11].

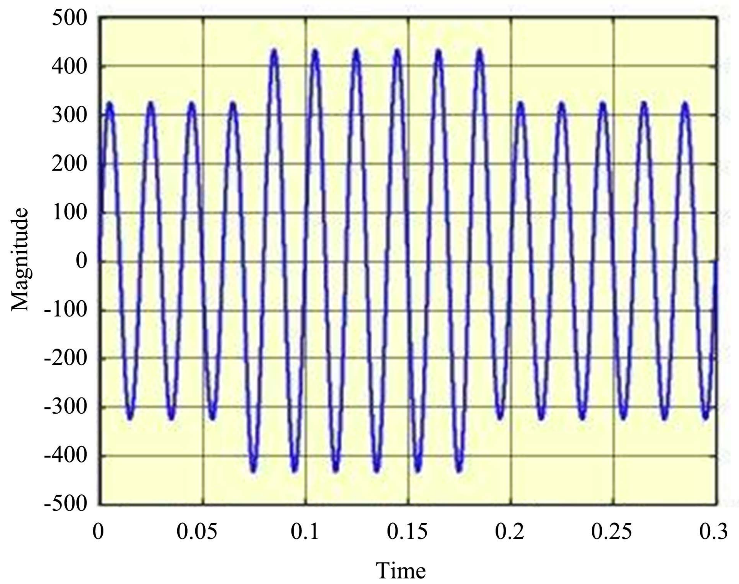


Figure 4. Overvoltage [13].

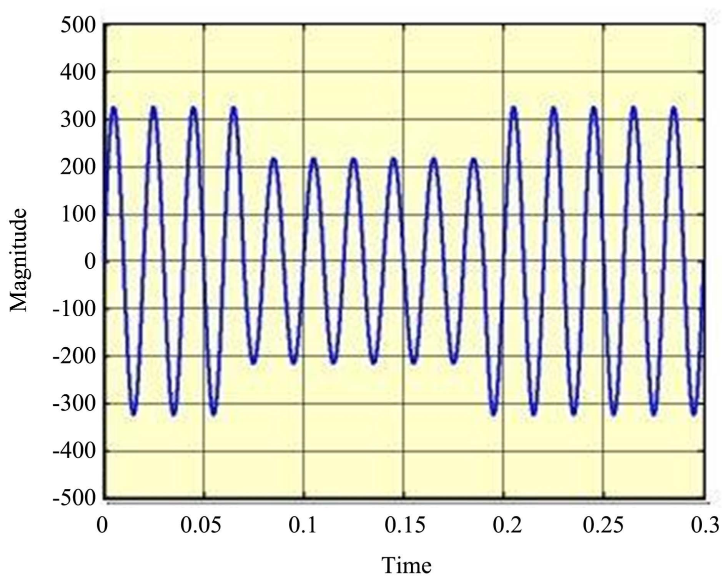


Figure 5. Undervoltage [13].

Most electricity end users are non-technical people and maybe more attuned to discussions related to overvoltage, undervoltage, and voltage interruption but not sags and swells. These non-technical users may also be more attuned to another power disturbance referred to as voltage fluctuation; which is defined as a variation in the voltage magnitude from 0.9 - 1.1 pu. Voltage fluctuations depicted in **Figure 6** are caused by pulsed-power output, resistance welders, start-up of drives, arc furnaces, drives with rapidly changing loads or load impedance, and rolling mills and their effects include equipment performance degradation, internal voltage and currents instability, and problem in reactive power compensation [10].

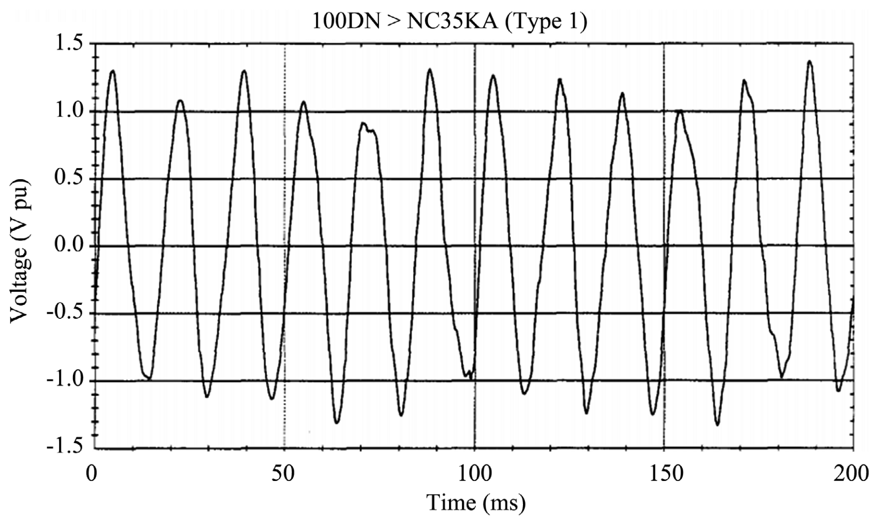


Figure 6. Voltage fluctuation [11].

2.2. Protection Technologies and Related Works

The protection of electrical equipment and control of various parameters in power systems can be traced to have begun toward the end of the 19th century with the use of lead, tin, and silver fuses for the protection of generators, cables, and motors from overheating [14]. Over the centuries, protection technology evolved from the use of fuses through relays to the emergence of electronic protection devices in the 1950s. Digital protection technology emerged in the 1970s with the use of microcomputers for the control of various processes in the power industry [15], which eventually extended to the use of microcontrollers as known today.

Application-oriented research on voltage variation protection has employed technology based on the use of operational amplifiers and voltage regulator integrated circuits (IC) and various microcontrollers. Thentral *et al.* [16] designed and implemented an overvoltage and undervoltage protection system using operational amplifiers based on the LM424 IC and IC7812 voltage regulator. For an input voltage of 230 V, the system considers a safe voltage supply between 195 V and 215 V, triggering off for voltages out of this range. The system proposed by Bhosale *et al.* [13] also uses the LM424 and IC7812 but its input and safe voltage range are not specified. Overvoltage and undervoltage protection systems developed on the basis of microcontrollers include those that use the PIC16F877 and ATmega328 family of microcontrollers.

Based on the use of PIC16F877 family, Ponnle and Omojoyegbe [17] developed a system using the PIC16F877A microcontroller and incorporated the LM7806 voltage regulator. For an input voltage of 220 V, the system considers a safe voltage supply of 200 - 240 V, triggering off for voltages outside this range. Based on the use of the ATmega328 family, overvoltage and undervoltage systems have been designed and implemented using the ATmega328 in standalone mode or via the Arduino Uno and Arduino Nano boards that incorporate the

ATmega328 as the controller. For example, Savita *et al.* [18] designed and implemented a system using ATmega328 alongside with an LM324N IC voltage amplifier and a SIM900A GSM module. The system considers 6 - 10.5 V as a safe voltage range, triggering off the system when the input voltage is out of this range. Furthermore, the system uses the SIM900A GSM module to send alerts about the system to the user. Another system has been designed and implemented by Simatupang *et al.* [19]. These authors used the Arduino Uno board alongside with the LT1083 IC voltage regulator. The system offers two safe voltage ranges: 3 - 5 V; and 10 - 15 V. Tung and Khoa [20] developed a system using the Arduino Uno board, a voltage sensor (ZMPT101B), and a current sensor (ACS712). The system was used to measure electrical system parameters during induced conditions of overvoltage and undervoltage.

3. Methods and Materials

3.1. System Block Diagram and Component Specifications

The normal line voltage in the locality is 220 V. In order to ensure flexibility and the ability of the system to protect appliances during periods of huge voltage variation in the locality, the system is designed to handle voltages in the range of 110 - 330 V. The protection system targets single-phase powerlines and is based on the Arduino Uno R3 microcontroller, GSM/GPRS SIM A6 module, voltage regulators (LM7812 and LM7805), a relay (SRD-05VDC-SL-C), and a step-down transformer. The hardware design is presented as a block diagram in **Figure 7**, while the specification of the components is presented in **Table 2**.

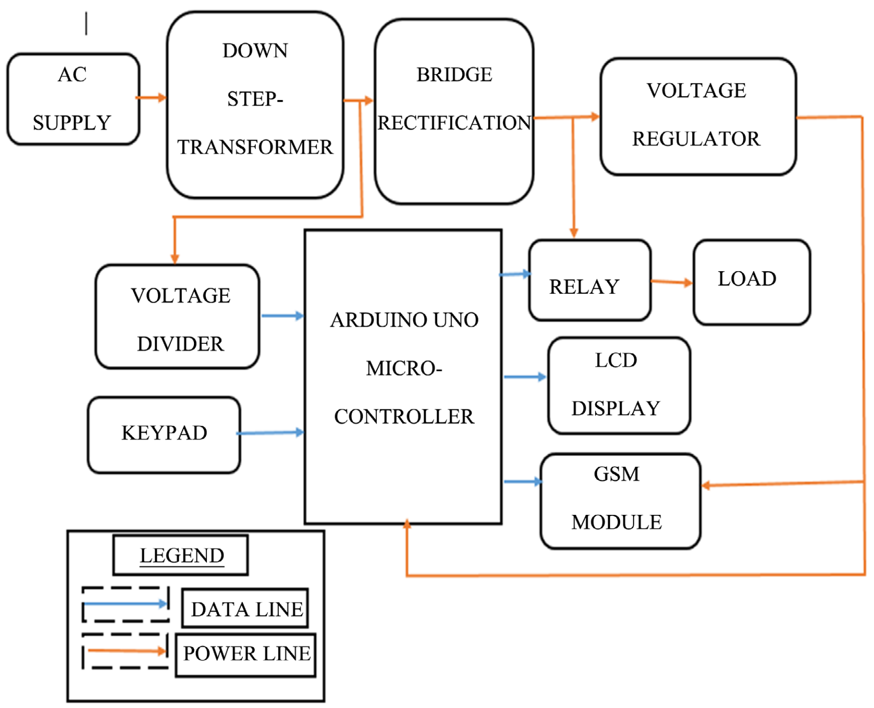


Figure 7. Block diagram of the system.

Table 2. System component specifications.

Component	Specification
Microcontroller	Arduino Uno R3
LCD	LCD 16 × 2 with I2C
Relay	SRD-05VDC-SL-C
GSM	The GSM/GPRS A6
Keypad	4 × 4 keypad
Step-down transformer	Center-tapped 220/12 V/2 A
Voltage Regulator	7812, 7805
Resistors	10 kΩ, 1 kΩ and 200 Ω
Capacitors	2200 µF
Bulb	7 W

3.2. Power Supply for the System

The system receives power from the 220 V AC supply block through a step-down transformer. The purpose of the transformer is to provide the system with the required levels of AC needed for the operation of the electronic appliances and the system itself. A battery backup system is considered for the functioning of the microcontroller system. The transformer is selected to support high voltages up to 380 V AC; and to ensure such a voltage, we opted for two transformers, such that $V_p = V_{1p} + V_{2p} = 440VAC$ with step down to $V_s = V_{1s} + V_{2s} = 24VAC$. For the current, $I_{1p} = I_{2p} = I_p = 2A$. Since the system contains DC components that cannot be supplied by an AC voltage, an AC rectifier bridge is required after the AC transformer. The rectified AC voltage is subsequently filtered and smoothened by using electrolytic and ceramic capacitors respectively. These ceramic capacitors are coupled with a 12 V DC and 5 V DC regulator to produce fixed DC output voltages: 12 V for the relay, and 5 V for the Arduino controller and GSM module. The combination of the transformer, the rectifier bridge and associated elements constitutes the power supply unit for the system and is presented in Figure 8.

3.3. System Operation

In operation, the system automatically measures the line voltage level and triggers a tripping mechanism to protect the electronic appliances from voltage variations (overvoltage and undervoltage) whenever the need arises. In effect, when the system is switched on, it operates based on the following steps and sequence:

1) The initial parameters of the system are set, followed by the display of a "Welcome Message" on the LCD;

2) The system requests the user to input the preset voltage range, *i.e.*, threshold values for overvoltage and undervoltage (based on appliances to be protected);

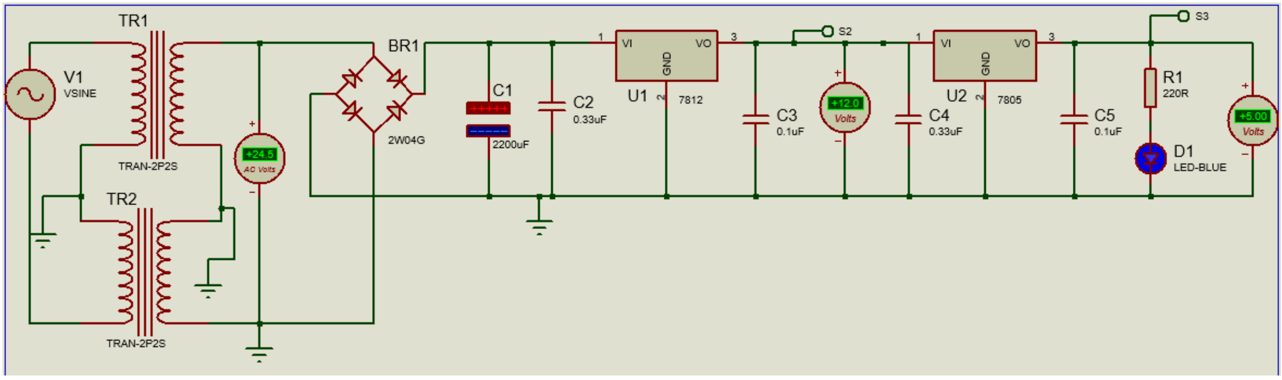


Figure 8. Power supply of the system.

3) The system starts/continues monitoring the state of the line voltage and performs the following: a) reads the line supply voltage and b) compares the reading with the user's preset threshold values (from step 2 above);

4) If the line supply voltage is above the user's preset overvoltage threshold value, the system does the following: a) triggers the tripping mechanism to disconnect the appliance from the line supply voltage; b) displays an overvoltage presence message on the LCD; c) sends an alert SMS to the user, and d) continue monitoring the system (step 3 above);

5) If the line supply voltage is below the user's preset undervoltage threshold value, the system does the following: a) triggers the tripping mechanism to disconnect the appliance from the line supply voltage; b) displays an undervoltage presence message on the LCD; c) sends an alert SMS to the user, and d) continue monitoring the system (step 3 above);

6) If the line supply voltage is within the user's preset voltage range, the system does the following: a) triggers the tripping mechanism to connect the appliance to the line supply voltage (if the appliance had been disconnected due to overvoltage or undervoltage as per step 4 and 5 above; b) displays the normal voltage presence message on the LCD; c) sends an alert SMS to the user, and d) continue monitoring the system (step 3 above).

4. Results

4.1. Simulation of System Startup, Initialization, and Output

At the start of the system, the LCD screen is blank and after successful set up and initialization of various components of the system, the user is requested to input the voltage range threshold values as in Figure 9.

Following successful initialization and input of voltage range by the user, the system reads the line voltage and provides output, the nature of which depends on the value of the line voltage: undervoltage, Figure 10(a); normal voltage, Figure 10(b); and overvoltage, Figure 10(c).

4.2. Experimental Output

Testing the system followed after design, simulation, and implementation. The system provides output, the nature of which depends on the value of the line voltage: undervoltage, Figure 11(a); normal voltage, Figure 11(b); and overvoltage, Figure 11(c).

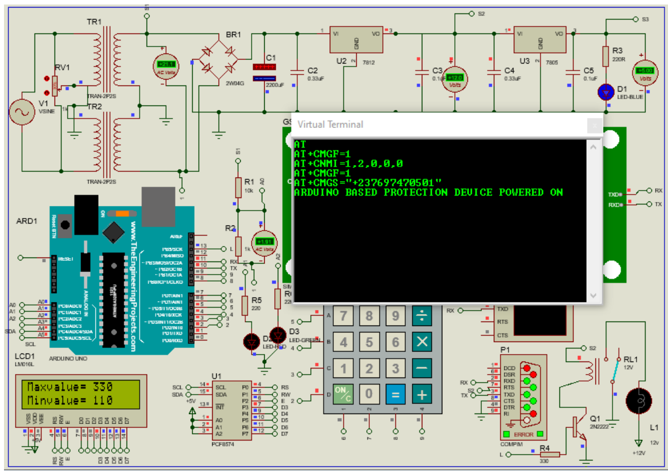
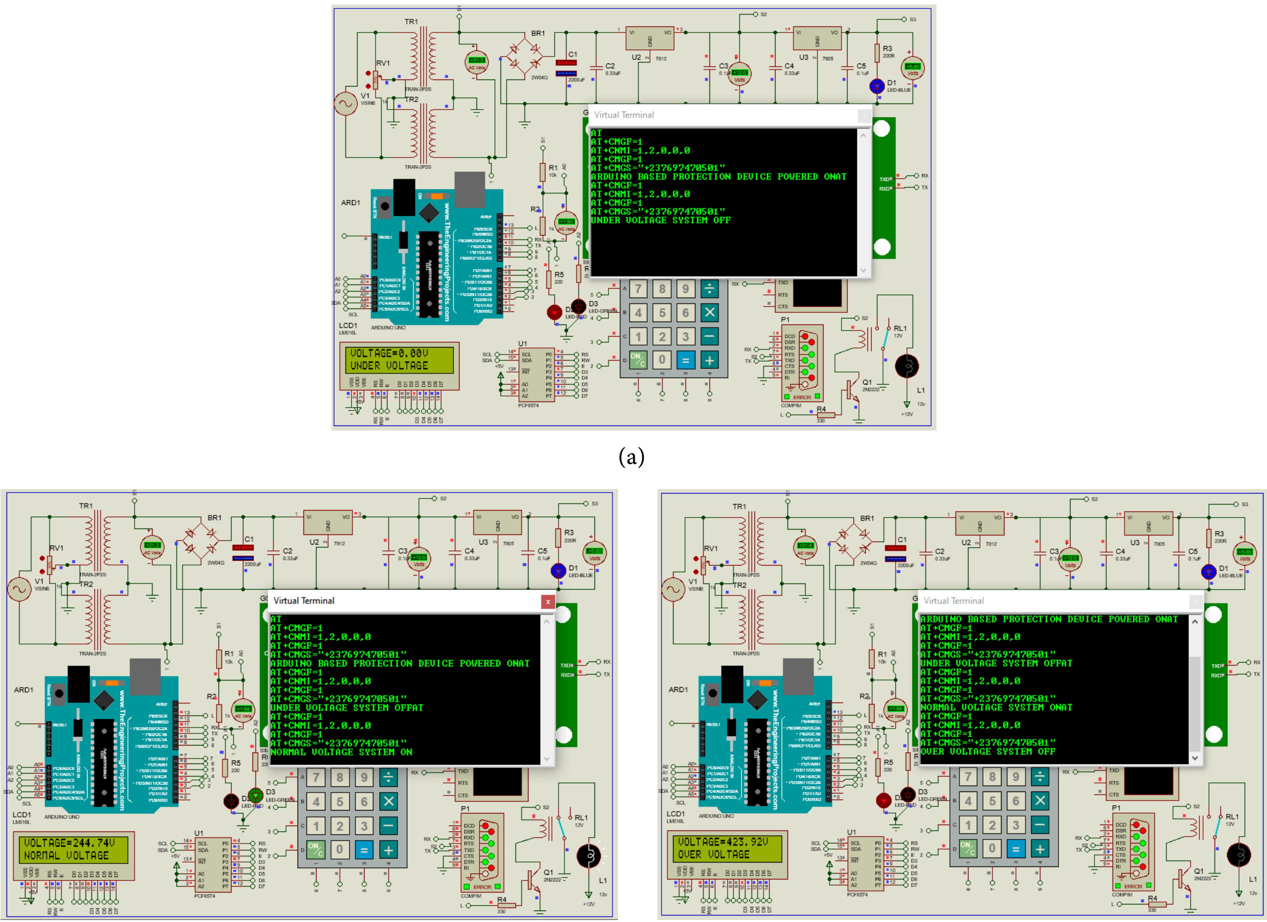


Figure 9. System initialization and input of voltage range.



(a)

(b) (c)

Figure 10. (a): System output: case of undervoltage (line voltage = 0.0 V < 110 V); (b): System output: case of normal voltage (line voltage = 110 V < 244.74 V < 330 V); (c): System output: case of overvoltage voltage (line voltage = 423.92 V > 330 V).

(a)

(b)

(c)

Figure 11. (a): System output: case of undervoltage (line voltage = 0.0 < 110 V); (b): System output: case of normal voltage (110 V < line voltage = 171.55 V < 330 V); (c): System output: case of overvoltage (line voltage = 450 > 330 V).

5. Conclusion

Power disturbances are a major concern to industrial and domestic electricity users. With highly sensitive electronic equipment and appliances, there is a need for the development and deployment of protection systems for end users. Acute power disturbances, particularly overvoltage and undervoltage are particularly experienced in developing country environments such as those of Sub-Saharan Africa, where end users often suffer damaged equipment and are obliged to buy multiple voltage stabilizers for home use which raises a cost incident. This study designed and implemented a low-cost system suitable for over/undervoltage protection in such environments. Compared to other systems, the system presented here introduces the novelty of flexibility and gives the end user the ability to specify different voltage variation ranges (*i.e.* different overvoltage and undervoltage threshold values, depending on the appliances owned). A direction of future research includes the ability to maintain a memory function to track and report to the user the history of voltage variation events over specified time periods.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

References

[1] Muhwezi, B., Williams, N.J. and Taneja, J. (2021) Ingredients for Growth: Examining Electricity Consumption and Complementary Infrastructure for Small and Medium Enterprises in Kenya. *Development Engineering*, **6**, Article ID: 100072. https://doi.org/10.1016/j.deveng.2021.100072

[2] Few, S., Barton, J., Sandwell, P., Mori, R., Kulkarni, P., Thomson, M., Nelson, J. and Candelise, C. (2022) Electricity Demand in Populations Gaining Access: Impact of Rurality and Climatic Conditions, and Implications for Microgrid Design. *Energy for Sustainable Development*, **66**, 151-164. https://doi.org/10.1016/j.esd.2021.11.008

[3] Emetere, M.E., Agubo, O. and Chikwendu, L. (2021) Erratic Electric Power Challenges in Africa and the Way Forward via the Adoption of Human Biogas Resources. *Energy Exploration and Exploitation*, **39**, 1349-1377. https://doi.org/10.1177/01445987211003678

[4] Andersen, R. (1997) Challenges for Sustainable Energy Sectors in Developing Countries—With Case Studies from Zambia, Zimbabwe, India and Thailand. The Fridtj of Nansen Institute, Lysaker.

[5] European Regulators' Group for Electricity and Gas (2006) Towards Voltage Quality Regulation in Europe—An ERGEG Public Consultation Paper. European Regulators' Group for Electricity and Gas (ERGEG), Bruxelles.

[6] Zhang, L. and Bollen, M. (1998) A Method for Characterizing Unbalanced Voltage Dips (Sags) with Symmetrical Components. *IEEE Power Engineering Review*, **18**, 50-52.

[7] Institute of Electrical and Electronics Engineers (1995) IEEE Std 1159-1995(R2001) -IEEE Recommended Practice for Monitoring Electric Power Quality. Institute of Electrical and Electronics Engineers, New York.

[8] Bollen, M.H. (2000) Understanding Power Quality Problems—Voltage Sags and Interruptions. IEEE Press, New York. https://doi.org/10.1109/9780470546840

[9] Lee, S., Cha, H. and Han, B.-M. (2009) A New Single-Phase Voltage Sag/Swell Compensator using Direct Power Conversion. 2009 *IEEE Energy Conversion Congress and Exposition*, San Jose, 20-24 September 2009, 2704-2710. https://doi.org/10.1109/ECCE.2009.5316394

[10] Chattopadhyay, S., Mitra, M. and Sengupta, S. (2011) Electric Power Quality. Springer, New York. https://doi.org/10.1007/978-94-007-0635-4

[11] Institute of Electrical and Electronics Engineers (1995) IEEE Standard 1159-1995. IEEE Recommended Practices for Monitoring Electric Power Quality. Institute of Electrical and Electronics Engineers, New York.

[12] Polycarpou, A., Nouri, H., Davies, T. and Ciric, R. (2004) An Overview of Voltage Sag Theory, Effects and Equipment Compatibility. *Proceedings of Universities Power Engineering Conference* (*UPEC* 2004), **3**, 966-972.

[13] Bhosale, G., Vakhare, A., Kaystha, A. and Aher, A. (2018) Overvoltage Undervoltage Protection of Electrical Equipment. *International Research Journal of Engineering and Technology* (*IRJET*), **5**, 29-32.

[14] Electrical Engineering Academy (2020) History of Protection Engineering. https://www.electrical-engineering.academy/posts/history-of-protection-engineering

[15] Bachmann, B., Cvetko, H. and Schurtenberger, M. (1986) Microcomputer Application in Large Power Plants. In: Adali, E. and Tunali, F., Eds., *Microcomputer Application in Process Control*, Pergamon, Oxford, 137-142. https://doi.org/10.1016/B978-0-08-034340-2.50027-3

[16] Thentral, T.M.T., Palanisamy, R., Usha, S., Geetha, A., Reagan, A. and Ramanathan, T. (2021) Implementation of Protection Circuit for Over Voltage and under Voltage. *Materials Today*: *Proceedings*, **45**, 2460-2464. https://doi.org/10.1016/j.matpr.2020.11.022

[17] Ponnle, A.A. and Omojoyegbe, M.O. (2014) Development of a Low Cost Microcontroller Based Under and Over Voltage Protection Device. *International Journal of Scientific Engineering and Technology*, **3**, 1225-1229.

[18] Savita, S.S., Arora, A. and Varshney, V. (2018) Overvoltage and Undervoltage Protection of Load Using GSM Modem SMS Alert. 2*nd IEEE International Conference on Power Electronics*, *Intelligent Control and Energy Systems*, Delhi, 22-24 October 2018, 249-252. https://doi.org/10.1109/ICPEICES.2018.8897428

[19] Simatupang, J.W., Andrian, L.M., Zhuang, W. and Prasetyo, H. (2019) A Prototype of an Arduino-Based Protection System to Overcome Voltage Fluctuations. 2019 *International Conference on Computer*, *Control*, *Informatics and its Applications*, Tangerang, 23-24 October 2019, 172-176. https://doi.org/10.1109/IC3INA48034.2019.8949584

[20] Tung, D.D. and Khoa, N.M. (2019) An Arduino-Based System for Monitoring and Protecting Overvoltage and Undervoltage. *Engineering*, *Technology & Applied Science Research*, **9**, 4255-4260. https://doi.org/10.48084/etasr.2832