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Design of prototype for the short circuit protection of DC bus using Arduino Uno and DSP controller

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ABSTRACT

Micro-grids (MGs) play a prominent role in the exchange of bulk power between loads and the central grid. MG can run in an islanding mode or grid-connected mode. When the central grid fails to provide power in such situations, MG's serve as power sources for critical facilities such as coordination facilities in railway stations and airports, transportation, university and research facilities. MG's use energy sources such as solar, wind, hydro, geothermal and biomass to produce electricity along with rechargeable batteries, aircraft applications is continuously increasing. This leads to the development of DC MG's. A model of DC MG is located at the disaster management lab in the Department of Electrical and Electronics Engineering. MG consists of a step-down and rectified DC power supply from conventional 230 V AC source, PV array, wind, battery bank and source supplying power to a set of nine DC loads. Although DC MGs have many advantages compared to AC MGs, one of the challenges faced is the study of faults and protection of the DC MG. In this paper, a prototype model for the existing system in the disaster management lab is designed in hardware and tested.

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1. INTRODUCTION

Given the strong reliance of the modern societies on their adequate supply, energy security is becoming a major concern around the world. The disruption in the electric power can be unavoidable. When central grid is unable to deliver power under these circumstances, MG's provide power to the loads. Distributed Energy Resources (DERs) can provide an alternative power source in certain instances. As a result, renewable energy sources (RESs) are now widely recognized as viable alternatives for delivering micro grid energy needs. In this research, the study of Short Circuits (S.C.) is specifically discussed in relation to a simulation and analysis performed on a 132 kV substation situated in western Iraq. The major goal of the study is to better manage and coordinate the protective technology used at this specific grid interconnection site. The investigation includes a power flow study that was carried out utilizing a simulator for the electrical transient analyzer programmed (ETAP). For improved grid performance and safety, the authors of this study want to maximize the efficiency and dependability of the substation's protective system [1]–[3]. This abstract discusses the utilization of biogas produced from liquid waste generated during palm oil processing, known as Palm Oil Mill Effluent (POME), as a renewable energy source in Biogas Power

Plants (BPP's). To ensure the reliable functioning of the BPP's electrical system and to maintain uninterrupted electrical service in unaffected areas during disturbances, a coordinated protection system is essential. The study employs the Electrical Transient Analysis Program (ETAP) for short circuit current analysis and establishes coordination for over current protection using inverse-definite minimum time characteristics [4]–[6]. Significant challenges and the demand for energy is increasing as fossil fuel sources are disappearing. Moreover, the high cost of construction of large production plants and the obligation to reduce greenhouse gas emissions are among the factors pushing the energy sector to integrate Distributed Generators (DGs) based on renewable energies into power grids [7]–[10]. However, the integration of these generators increase the values of short-circuit currents in the network, which poses a real threat to the existing protection coordination systems in the distribution network. The aim of this paper is to bring together in a single platform addressing the issue of protection coordination in the presence of DGs in the distribution network [11]–[14]. This work introduces a new architecture for a Li-Ion battery charger that incorporates a charge mode selection feature. The primary objectives of this design are to achieve high efficiency, accurate charging and complete protection for the battery. The proposed architecture relies on a variable current source, temperature detector and power control to attain these goals [15]–[18]. The main objective of this paper is to detect the short circuit faults at the DC feeder, to protect and isolate DC loads on the bus during the fault. LCD displays the state of the system during fault and no-fault condition.

2. BLOCK DIAGRAM

Figure 1 shows the block diagram of the DC network which is designed based on the existing DC micro grid. The entire system works on 12 V DC supply. The proposed prototype consists of the solar panel and rechargeable battery as DERs, AC to DC converter unit to connect 230 V DC to system, Arduino Uno along with voltage regulator, capacitor is used to control the system, electromagnetic relays are provided to protect the loads from the over currents, three DC loads (i.e., two DC motor load and one LED) each on three DC lines, LCD to display the type of fault occurred in the system [19], [20].

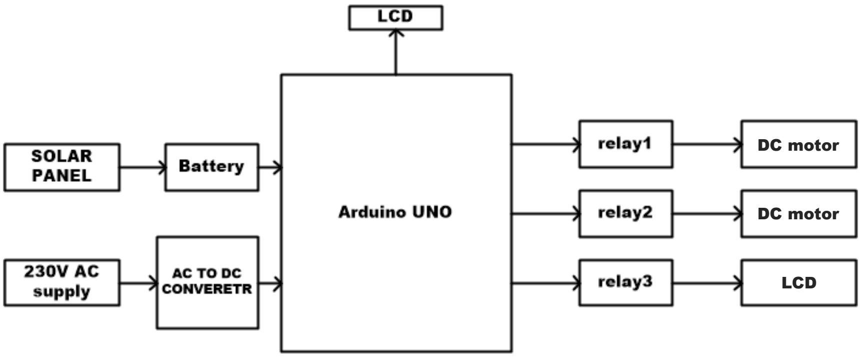

Figure 1. Block diagram of the proposed model

3. PROPOSED MODEL

Figure 2 shows the hardware implementation of the proposed model. The controlled power source provides the circuit with its input. The transformer steps down the main supply AC input i.e. 230 V to 12 V, which is then sent to a rectifier. A pulsating DC voltage is produced by the rectifier as its output. Therefore, the output voltage from the rectifier is passed to a filter to eliminate any transients remaining even after rectification in order to obtain a clean DC voltage. To create a pure constant DC voltage, the voltage is now sent into a voltage regulator to get a stable 12 V DC voltage. The 230 V AC electric power supply flow is depicted in Figure 3. An alternate power supply of 12 V from DERs (i.e., from PV and battery) is given to the system. The specifications of the solar panel are shown in Table 1. A 12 V, 1.3 AH rechargeable lead acid battery source is connected in parallel with the solar panel and given to the system. This 12 V DC supply may contain ripples. So, it is given to the filter. The output from rectifier is given to 25 V/1000 µF capacitive filter to remove the ripples [21]. A stable 12 V DC supply is now obtained from the capacitor. However, the output from this filter tends to change when there is a disturbance between main voltage supply and load. Therefore, a regulator is applied at the output stage to regulate the 12 V output. In this model, a power supply of 5 V DC is needed for the input to Arduino Uno and a power supply of 12 V DC is needed to drive the loads on the bus. So, 7805 and 7812 voltage regulators are used to get these voltages. 78 represents positive power supply and 05, 12 represent the voltage levels 5 V and 12 V respectively.

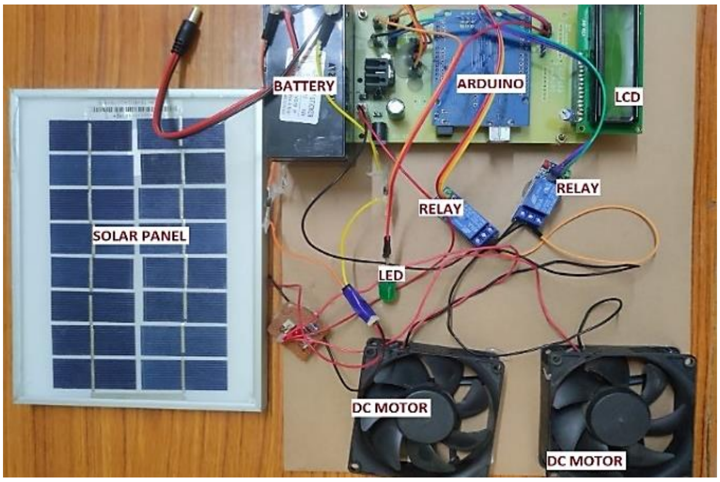

Figure 2. Hardware implementation of proposed model

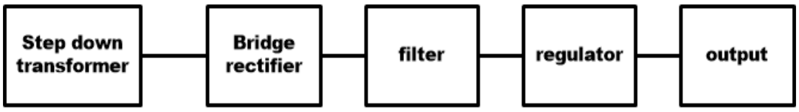

Figure 3. 230 V AC power supply flow

Table 1. Solar panel specifications

S. No.	Parameter	Rating
1	Power	3 WP
2	Open circuit voltage	10.1 V
3	Short circuit current	0.43 A
4	Voltage at maximum power	8 V
5	Current at maximum power	0.37 A
6	Maximum system voltage	1000 V DC

3.1. Arduino Uno

The ATmega328 serves as the controller of the Arduino Uno, a standard board from Arduino and a microcontroller. Relays, LEDs, servos, motors, and other electrical devices can all be controlled by the Arduino Uno board. The components present on the Arduino board makes us easy to operate the microcontroller. Initially, a universal serial bus (USB) cable, an AC-to-DC adapter, or a battery one connected to start the Arduino. The microcontroller in Arduino Uno is used to provide short circuit faults in the DC bus. The input digital data pins in the controller gets the digital input (gnd or 0, +5 V or 1) from the user to provide intentional fault in the bus as explained under-operation of the network. Even though electromagnetic relays have contact loses, vibrations and mechanical shocks, they can be used for any network irrespective of the ratings and type of current (i.e., AC or DC). A 12 V electromagnetic induction type relay is used for the protection of DC bus. The specifications of the relay used are given in Table 2.

Table 2. Solar panel specifications

Variable	Parameter	Rating
1	Channel	1
2	Trigger voltage (VDC)	12 V
3	Switching voltage (VAC)	250 V @ 10 A
4	Switching voltage (VDC)	30 V @ 10 A
5	Dimensions (Labxh)(mm)	53×18×18.5
6	Weight (gm)	16

3.2. Loads connected

There are three buses in the network. Each bus is supplied to a single load. The bus-A is connected to a fan type DC motor load. The bus-B is connected to another fan type DC motor load and the bus-C is connected to a light load (i.e., LED) as shown in Figure 2. The fan type brushless DC motor load is operated at 12 VDC and can draw a current upto 0.3 amps. While the LED is operated at 5 VDC given from the microcontroller directly because the rating of LED is 5 V and it does not require any relay. Figure 4 shows the block diagram of driver circuit. The driver circuit has a transistor which acts as switching in between Arduino and electromagnetic relay. The input to the transistor is given to the base. As the Figure 4 shows, the data pin on the Arduino board (D1) is connected to the base of transistor. When the given voltage input (i.e., base to emitter voltage) is greater than 0.7 V (cut-in voltage), then base to emitter junction is in forward bias and thus transistor conducts [22]. Therefore, the digital input given to D1 pin must be HIGH to turn ON the transistor. During the ON condition, the relay is working and loads connected will be operating at a voltage of 12 V. Similarly, when the digital input given to D1 is LOW, then the transistor does not conduct and the relay is turned OFF. Transistor acts as driver between Arduino and relay.

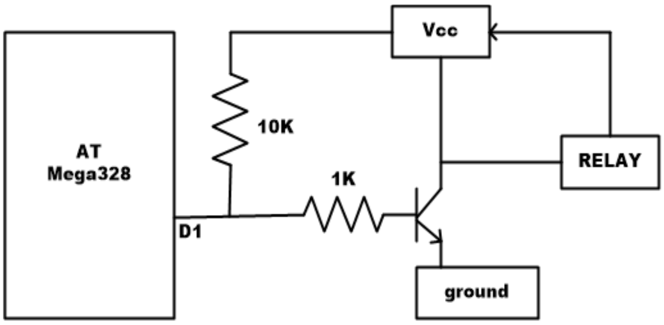

Figure 4. Driver circuit

4. HARDWARE RESULTS WITH ARDUINO CONTROLLER

4.1. No fault conditions

A DC supply of 12 V is given to all the three buses A, B and C through the Arduino Uno. The relay gets 5 V DC from microcontroller of the Arduino Uno. The current flows through the coil in electromagnetic relay. Now, when the coil gets energized, the common terminal and normally open terminal are connected and supplies power to the loads. All the loads that are connected to the DC bus are turned ON as shown in Figure 5. The LCD displays the message “NO FAULT, PHASE LOAD: ON”. Thus, the relay takes 5 V from the microcontroller and drives the loads which consumes high currents.

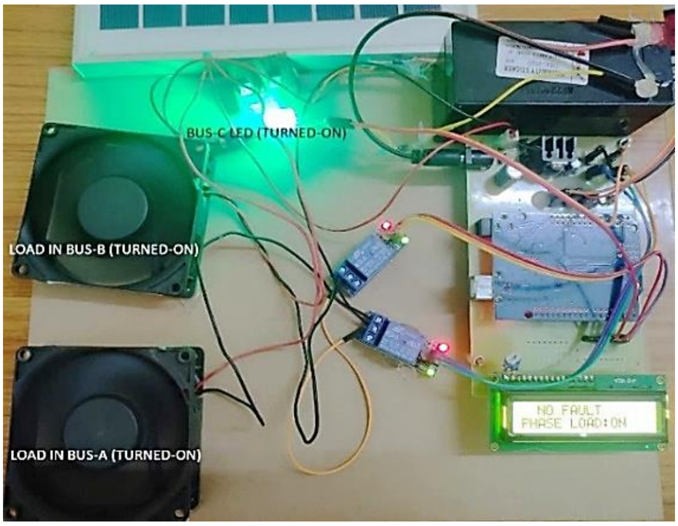

Figure 5. State of loads in no fault condition

4.2. Faults in a bus

Now, an intentional fault is introduced in bus-A. The bus-A experiences short-circuit. The voltage across the coil in the relay becomes zero (0 V). High currents flow through the coil which demagnetizes the coil. The common terminal of relay is disconnected from normally open terminal and gets connected to normally closed terminal. The fan type DC load is turned OFF as shown in Figure 6. The LCD displays the message "FAULT IN LG, PHASE LOAD: OFF". As a result, the load is disconnected from the supply whenever a short circuit fault occurrs. Similarly, when an intentional fault is introduced in bus-B, the bus-B experiences the short-circuit. Thus, the relay isolates the load in bus-B from the supply and turns OFF the load. While the loads connected to other buses continues to get uninterrupted power supply from the source as shown in the Figure 6.

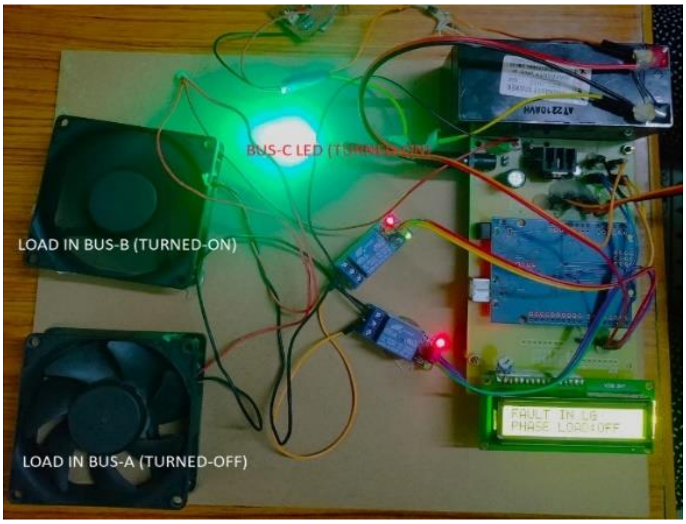

Figure 6. State of loads during fault in bus-A

4.3. Fault in two buses

An intentional fault is introduced in both the buses i.e., bus-A and bus-B. The bus-A and bus-B experiences short circuit fault. The voltage across the coil in the relay becomes zero (0 V). High currents pass through the coil, demagnetizing it in the process. Relay's common terminal is connected to the normally closed terminal instead to the normally open terminal. The fan type DC load in bus-A and bus-B turned OFF as shown in Figure 7. The LCD displays the message "FAULT IN LL, PHASE LOAD: OFF". As a result, the relay protects the loads in the network by disconnecting them from the supply whenever a short circuit fault is occurred.

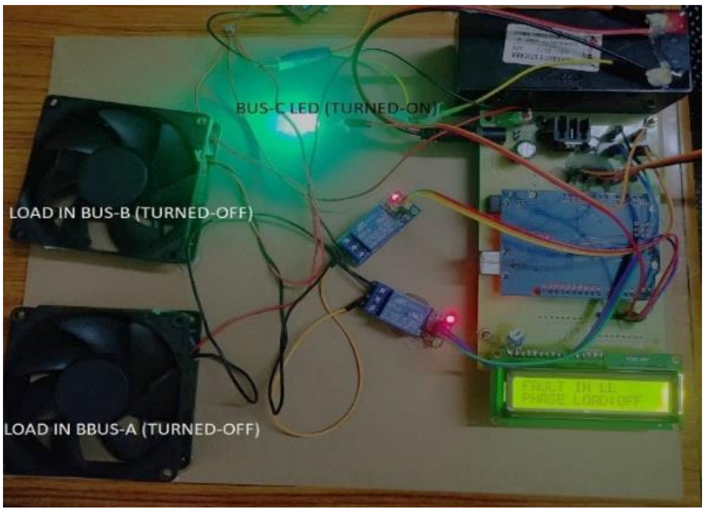

Figure 7. State of loads during fault in bus-A and bus-B

4.4. Fault in all the three buses

An intentional fault is introduced in all the buses i.e., bus-A, bus-B and bus-C. There is a short-circuit fault on every bus. The relay's coil experiences a voltage drop to zero (0 V). The coil is demagnetized as a result of high currents flowing through it. The normally closed terminal is linked to the common terminal of the relay rather than the normally open terminal, shutting OFF all the loads as shown in Figure 8. The LCD displays the message "FAULT IN LLL, PHASE LOAD: OFF". As a result, whenever a short circuit fault occurs, the relay disconnects the loads in the network from the supply, protecting them. Table 3 shows the short circuit faults that occur in network along with the state of loads during these faults.

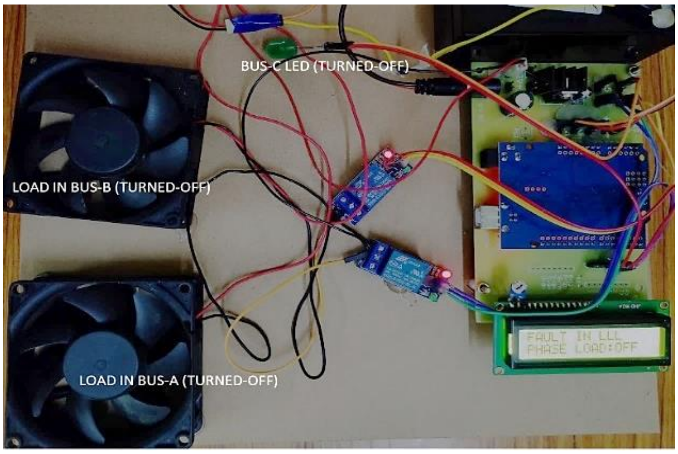

Figure 8. State of loads during fault in bus-A, B and C

Table 3. Faults in the system

S. No	Type of fault	Fault at the bus	State of fault in bus-A (fan Type DC motor)	State of fault in bus-B (Fan type DC motor)	State of Fault in bus-C (light load)
1	No fault condition	-	ON	ON	ON
2	Fault In single bus	A	OFF	ON	ON
		B	ON	OFF	ON
		C	ON	ON	OFF
3	Fault in two buses	A, B	OFF	OFF	ON
		B, C	ON	OFF	OFF
		A, C	OFF	ON	OFF
4	Fault in all the three buses	A, B, and C	OFF	OFF	OFF

5. HARDWARE RESULTS WITH DSP CONTROLLER

Figure 9 shows how the LVDC distribution system is created in real-time. As seen in the same picture, it uses a rectifier unit to convert three-phase AC power from the main grid into LVDC, which is then connected to three LVDC lines. Three DC loads are linked to each line using load Feeder Monitoring Units (FMUs). A DSP has been chosen as the best option for the real-time implementation of the suggested deliberate islanding technique. The selection of the DSP was based on the hardware implementation of the islanding detection technique utilizing opal-RT [23], PSCAD/EMTDC [24], and the design of a controller for grid-connected and islanded mode operations using DSP [25], [26]. The suggested islanding algorithm has been successfully tested for efficient prototype LVDC distribution system with distributed energy resources (DERs), an automation system, as well as on a DSP controller. Combining a solar PV system, a Wind Energy Conversion System (WECS), a battery bank and automation hardware system create a robust DC microgrid for post-disaster conditions.

Due to its remarkable features, the DSP 33EP512MU814 has been carefully chosen to implement the suggested method. Notably, it has superior analogue technology and high-speed pulse width modulation (PWM) with a USB connection. Here are some of the processor's important characteristics: an effective code framework that supports programming in both C and assembly, having the ability to handle seven PWM pairs, each of which may be programmed with its own time and fault inputs, availability of two 32-channel analog-to-digital converters (ADC's) that use cutting-edge analogue technology, four 15 Mbps universal asynchronous receiver and transmitter (UART) modules provide flexible connectivity. Temperature tolerance is between -40 °C and +125 °C, with operational ranges between 3.0 V and 3.6 V. Figure 10 to shows the graphic representation of the on-board design of the CPU.

Figure 9. Real-time implementation of prototype distribution system

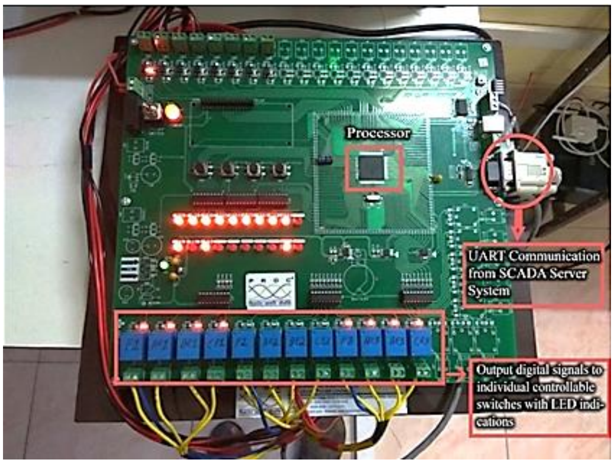

Figure 10. On board design of processor

5.1. Working in pre-disaster situations

This overview shows how the system operates normally and without interruption. The block diagram shows how a three-phase rectifier powers LVDC loads from the utility. Figure 11 shows the three-phase rectifier with bright LEDs in the ON state and Figure 12 shows the converter with bright LEDs in the ON state (RYB). These devices convert the three-phase AC supply from the main utility into three independent DC supplies, each at 48 V. By sending trip signals to the corresponding FMUs (F1, F2, and F3 feeders) and effectively disconnecting them from the system, the algorithm is essential in separating DERs from the LVDC loads.

Figure 11. Three phase rectifiers in ON mode

Figure 12. Control signal supplied from main grid to respective FMU's

6. CONCLUSION

A prototype for the protection of DC bus for short circuit faults is designed successfully using Arduino Uno. The entire network is controlled using the Arduino Uno. The Arduino Uno consumed a little amount of power from the regulated supply of 12 V. The intentional faults are introduced into the system using microcontroller in the Arduino Uno board.

The faults that are introduced in the system are divided into three categories. Firstly, fault is introduced in single bus. The relay disconnects the load in the bus from the supply during the fault, whereas, the loads in other two buses are continued to receive uninterrupted power supply. Secondly, fault is introduced in any of the two buses. The loads in the faulted bus are disconnected from the supply, whereas the load in remaining unfaulted bus is working. Lastly, the fault is introduced in all the three buses. The relay protects the loads by disconnecting them from the supply. It is observed that the relay detects and locates the fault, interrupting it rapidly to ensure that the loads are protected from high currents to receive a stable and continuous power supply.

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