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Electrical Smart Grid Resilience Based on GSM Technology

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Abstract: *This paper is about a smart grid resilience three-phase power selector, voltage regulator, and overload protection system based on a GSM technology present three-phase power supply, solar mains and generator sources to supply electrical energy to the load centers. It incorporates three steps down transformers that step down the input voltage from 230V or 240V to 12V alternating current (AC). Using the AC to DC converters, this 12V AC is rectified and regulated to 5V direct current (DC), which is fed to the microcontroller as its input. when the microcontroller receives this input of a given source, the relay module will either switch ON/OFF the system. In the event where all the three sources are present, the android app is used to select a suitable source. When the amount of load demand exceeds the capacity of the source, the mobile app is employed to trigger the other remaining sources to meet the load demand. The GSM module controls and sends messages to the GSM operator for any overload notifications. The operator then initiates an operation to the loads utilizing GSM by sending a text message "normal" to restore the system operation.*

Keywords*:* ACS712 current sensor, ATMEGA328P, Bluetooth module, GSM SIM900A Module.

1.0 Introduction

One of the most important requirements for electrical power distribution systems is that they need an automatic operation, equipment that sensitive and reliable to ensure that there is minimal failure in the supply of power. An automatic phase selector and overload protector is an electrical device that is designed to alternate and transfer loads from one phase to the other of power supply and to initiate other phases to come in in the event where one phase becomes incapable of supplying power the loads. The conventional electrical systems in developing countries are based on more than one source of power supply at the generation points, though one supply source is placed at consumers' end. This system demands that an individual should monitor the continuity of supply at the interconnection station closely. In the event where the system is overloaded, it may cause fatal injuries to electrical personals and damage to the utility equipment, and that is the reason why Qualified Electrical Workers (QEW) with enough competence should be the ones always to do the works of installation and maintenance. One major concern of utility companies in the protection of this equipment as they are costly and replacement from time to time is very costly. With the ever-growing population, there is a huge demand for electrical energy, and different schemes have to be employed to meet that demand. However, wherever there is electrical energy, you cannot eliminate problems such as power outages, transients, voltage surges, and overload due to the under-utilizing of other energy resources and increased demand for electricity. Other factors include industrialization and domestic use. Therefore, this system ensures that there are uninterrupted power supply, voltage stabilization, and overload protection schemes to the different kinds of loads and integral utilization of other sources of energy like solar and generator power supplies.

Existing Technologies

Kasali et al., 2019. Designed an automatic transfer switch for households solar Photovoltaic systems providing a solution to households that want to have continuity of power supply during an event where there is a power supply failure from the utility company or when no sufficient sunlight or heat is being radiated from the Photovoltaic solar systems. On the other hand, it also eliminates the problem of drawing too much current at a given time, since most small business and domestic utilities do not buy or rarely buy solar photovoltaic systems that meet their load requirements.

Praful et al. 2018, Designed an auto-selection system for a three-phase electrical power supply system that is used to select any available phase in the three-phase system, the load will thus be connected only to that particular live phase by using an ATMega328 microcontroller.

Hassan et al., 2018. Proposed an automatic power supply with a continued supply of power to a load through any available source, for example, solar, mains, thermal, or wind energies when the other ones are unavailable.

In 2017, Nirbhay et al. Proposed an automatic system selector that selects any active phase for a single-phase load from a three-phase supply. However, this proposal did not address the connection of electricity in an apartment where each apartment uses a separate meter. Secondly, there is a protective system incorporated in this design, which poses a major threat to the electrical equipment.

Prasad et al., 2017. Designed an automatic phase selector using microcontroller ATMEGA 89c51. This system did not consider the use of a GSM to enable the control of sources or phases when the operator is unavailable. Also, there is a protection scheme built into the system.

Alexander & Gyimah, in 2017. Designed an automatic phase selector for a multisource power supply. However, they did not consider any protection scheme into the system; neither did they consider communication means such as IT and GSM.

Ofualagba & Udopha, 2017, designed an Automatic Phase Selector and Changeover Switch for three-phase Supply. This design was an improvement to the already existing types of electro-mechanical devices that have been in use over the years. This has been achieved by the use of 1- of - 4 analog multiplexers (CD4052), analog to digital converter (ADC0804), AT89C51 microcontroller, and relay switches. Being a comprehensive system, it lacks the protection system and communication means.

Atiqul Islam, 2017, designed an automatic phase changer. The idea was to simulate the design using Proteus 8. An Automatic Phase Changer (APC) automatically changes the phases. In a three-phase power system, three inputs of the Automatic Phase Changer (APC) circuit are connected to three phases of the system, and its three outputs are connected to three different loads.

Ihedioha, 2017, designed an automatic three-phase selector using a microcontroller. It had an interesting construction but also stimulating and challenging. Its level of success can be measured by its efficient performance and reliability.

Vipula & Karuna, 2017, designed an Automatic Phase Changer. This was aimed at improving power stability in developing countries. With the need for more power, it necessitates the need for operations that are automatic in the generation power. This automation is required because power outages in the power system are common due to various kinds of faults such as voltage surge, short circuit, etc.

In 2016, Ayan et al. designed an Automatic Phase Selector from Any Available Three Phase Supply was designed using a microcontroller. It was noticed that most power interruptions on the distribution systems, about 70% of them are due to single-phase faults, while the other two phases are in normal working conditions.

Lalit et al. 2016 designed an automatic phase selector using micro-controller 89C52. It was realized that, in three-phase equipment, the supply voltage is usually low in any one of the phases, and there is a need to run all the equipment properly by phase balancing.

Himadri & Sayan, 2016, Designed an automatic phase selector using the logic gate and relay driver. This was because they discovered that power failure is a common problem that cannot be completely be done away with. This helps the production in industries, construction of new plants, and building. This problem can be overcome by using a backup power such as a standby generator, which automatically switches on in the event of a power failure.

2.0 Materials and Methods

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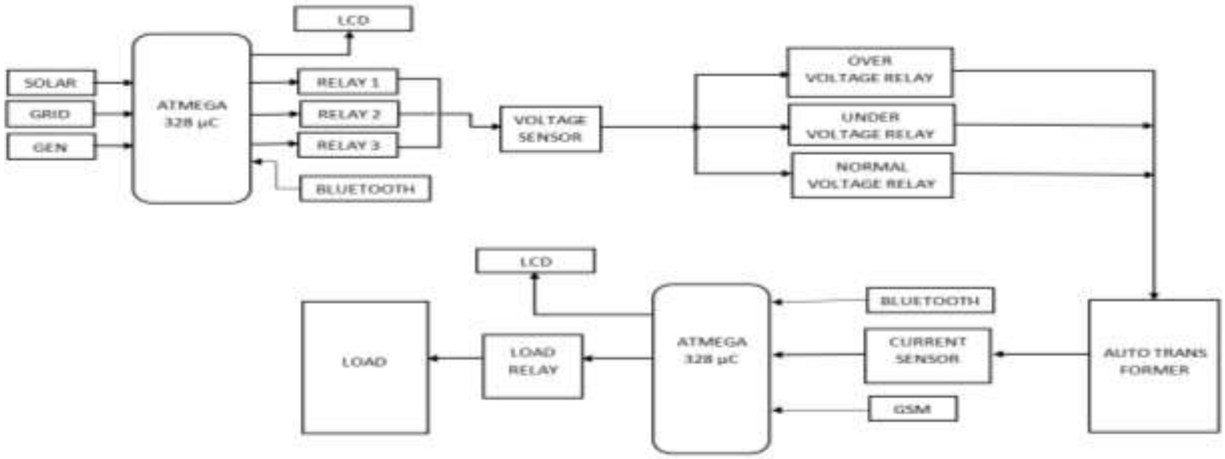

Figure 1: Block Diagram, Smart Grid Resilience Protection System.

2.1 Bluetooth module (HC-05)

Bluetooth is one of the most popular wireless communication technologies because of its properties of drawing less power, has low cost, and has a light stack but can compensate on the range. Having a connection between the Bluetooth module and the android application requires a smartphone with Bluetooth enabled. The HC-05 module connections are VCC to 5V output of the circuit, GND to ground, RX to TX of the microcontroller, and vice versa. Since the RX pin is designed for 3.3V signals, a voltage divider will be used to ensure no damages are done to the Bluetooth module.

Figure 2: Showing Bluetooth Module HC-5A

2.2 GSM SIM900A Module

GSM SIM900A Modem is constructed using a Dual Band GSM/GPRS based SIM900A modem from SIMCOM on frequencies 900/1800 MHz SIM900A two bands. The frequency bands are set by using AT Commands. The band rate is configurable from 1200-115200 through AT command. The GSM/GPRS Modem has an internal TCP/IP stack that makes it possible to connect to the internet via GPRS. The SIM900A is a reliable and ultra-compact wireless module. This is a complete GSM/GPRS module in an SMT type, and it is designed with a single-chip processor that is very powerful integrating AMR926EJ-Score, and it allows you to enjoy the benefits of small dimensions and cost-effective solutions.

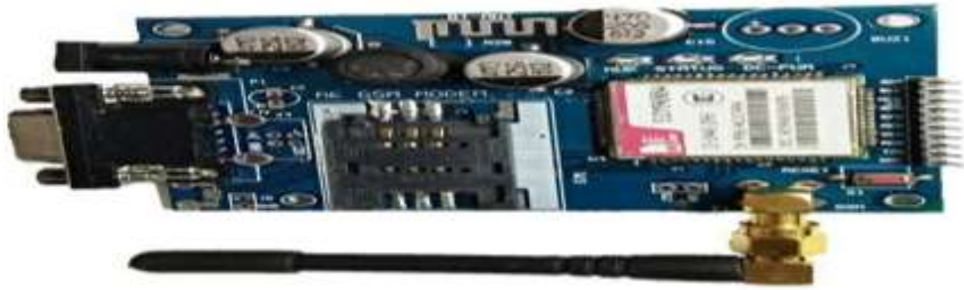

Figure 3: GSM Module SIM900A

2.3 ACS712 current sensor

ACS712 current sensor is designed by Allegro, which is a Hall effect-based current-sensing chip that is used to measure both DC and AC sources. It conforms to the property of linearity and has other properties or features such as that of noise cancellation and very high response or operating time. The error signal at the output is about 1.5%, and this can be eliminated using some standard intelligent programming and multiplying measured values with a standard error of sensor. If you fed a DC to an input, it would give a proportion of DC voltage at the output of the sensor, and if you fed AC at the input of ACS712 current sensor, it would give you a proportion of ac voltage at the output. The proportionality depends on the output sensitivity of the sensor.

Figure 4: showing ACS712 current sensor

2.4 ATMEGA328P

ATMEGA328P is a very high performance that consumes low power controller Microchip. ATMEGA328P is an 8-bit microcontroller based on AVR RISC architecture. It is the most popular of all AVR controllers as it is used in ARDUINO boards.

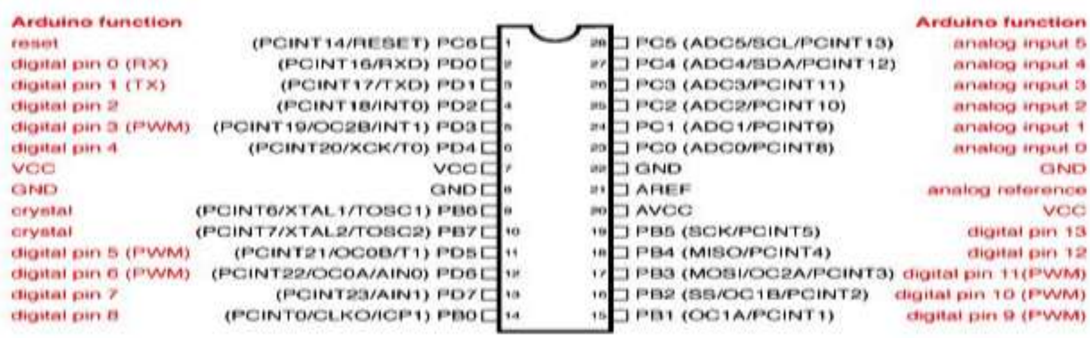

Figure 5: ATMEGA 328P Microcontroller & Arduino Uno Pin Mapping

3. 0 Working Principle

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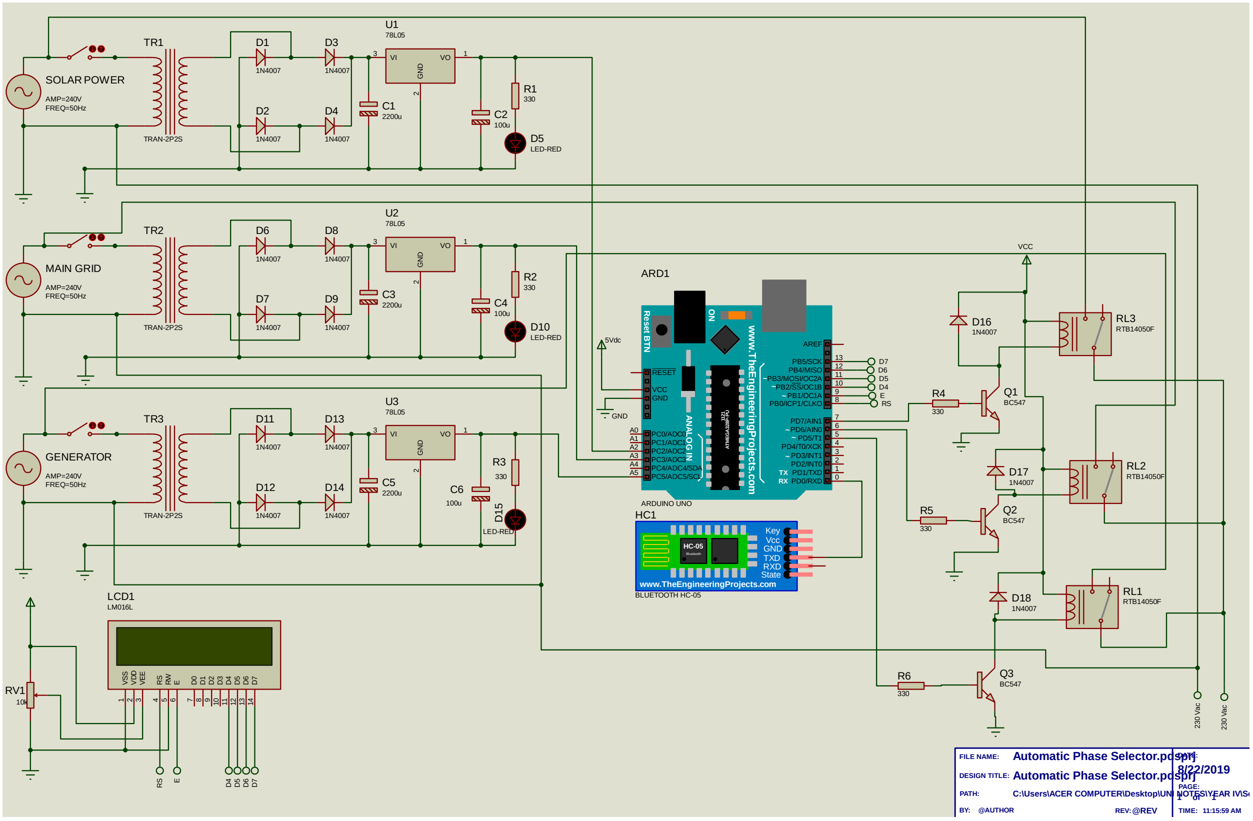

Figure 6: Automatic Phase Selector Circuit

Three power supplies of 5V DC each have been used as the voltage sensors to the microcontroller. The sequence of operation is in such a way that the primal power source is solar energy, the second one being the primary grid, and the third is the generator. The microcontroller is programmed in such a way that it will isolate all other available sources of supply from the load remaining only the solar power to supply to the load. If there is no solar power due to say insufficient radiant heat from the sun, then the main grid line will supply power to the load, thereby isolating the generator from the load. This process will continue until it reaches the generator. Once the generator is on, this indicates that the other sources are unavailable. However, in the case where the solar energy is available when either of the primary grid or generator is on, then the microcontroller switches the load to solar and isolate the other sources.

Figure 7: Smart Grid Sequence of operation

In case the load increases such that the solar power becomes insufficient, the Bluetooth device with an android app is used to bring on board all other sources depending on the load demand.

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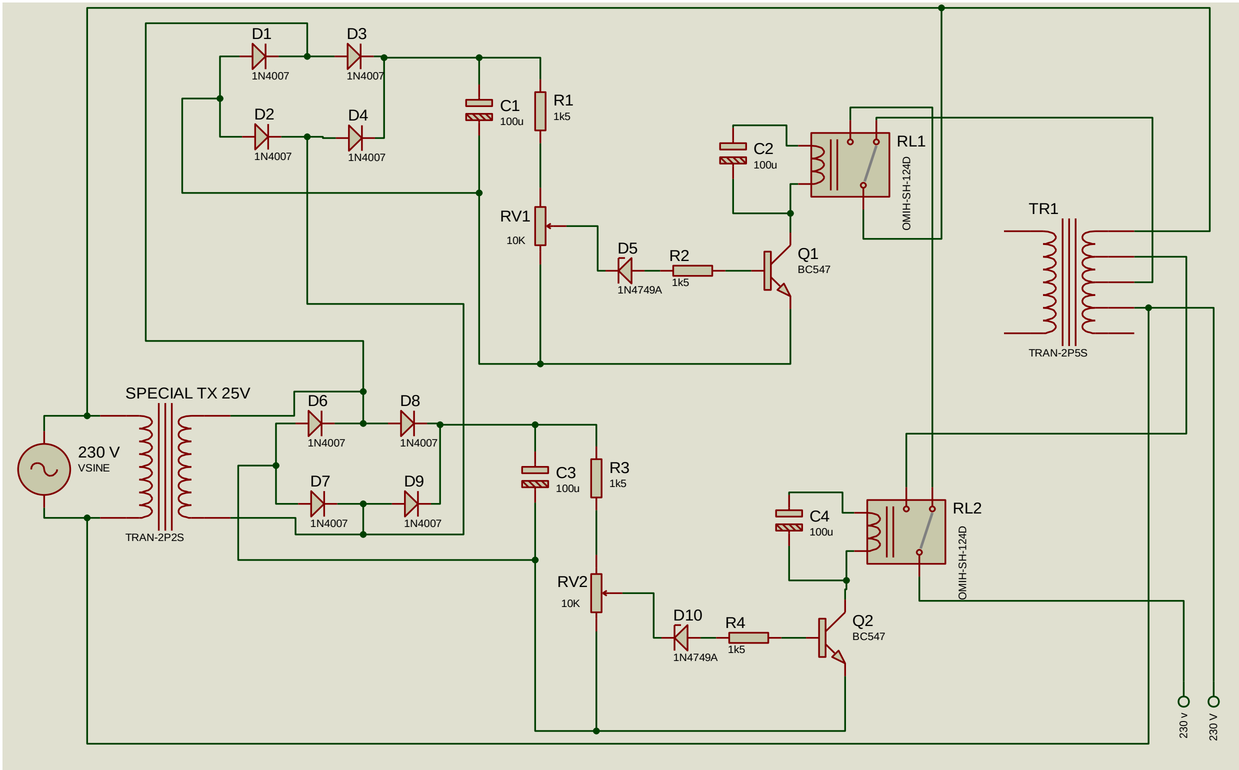

Figure 8: Automatic Voltage Stabilizer Circuit

The input voltage from different sources was passed through a voltage sensor which monitors the voltage parameters and stabilizes the output voltage by switching between the relays that are connected to the autotransformer of many taps. The transformer taps are of readings 0V, 220V, 240V, and 274V. The input voltage from the sources is less than the standard voltage of 190V. The sensor will stabilize the voltage by adding an extra voltage such that the output is maintained at stabilizing the level of 220V. However, when the output of the different sources is more than the standard voltage say 260V to 270V, the sensor will switch to 220V of the autotransformer such that the output voltage is still reasonable to the load. This stabilizing circuit enables the load to be powered no matter what the input voltage may be. Therefore, instead of switching off the source in case of voltage fluctuation, the stabilizing circuit with an auto-transformer will stabilize the voltage to the required level hence keeping the load connected power sources under reasonable condition.

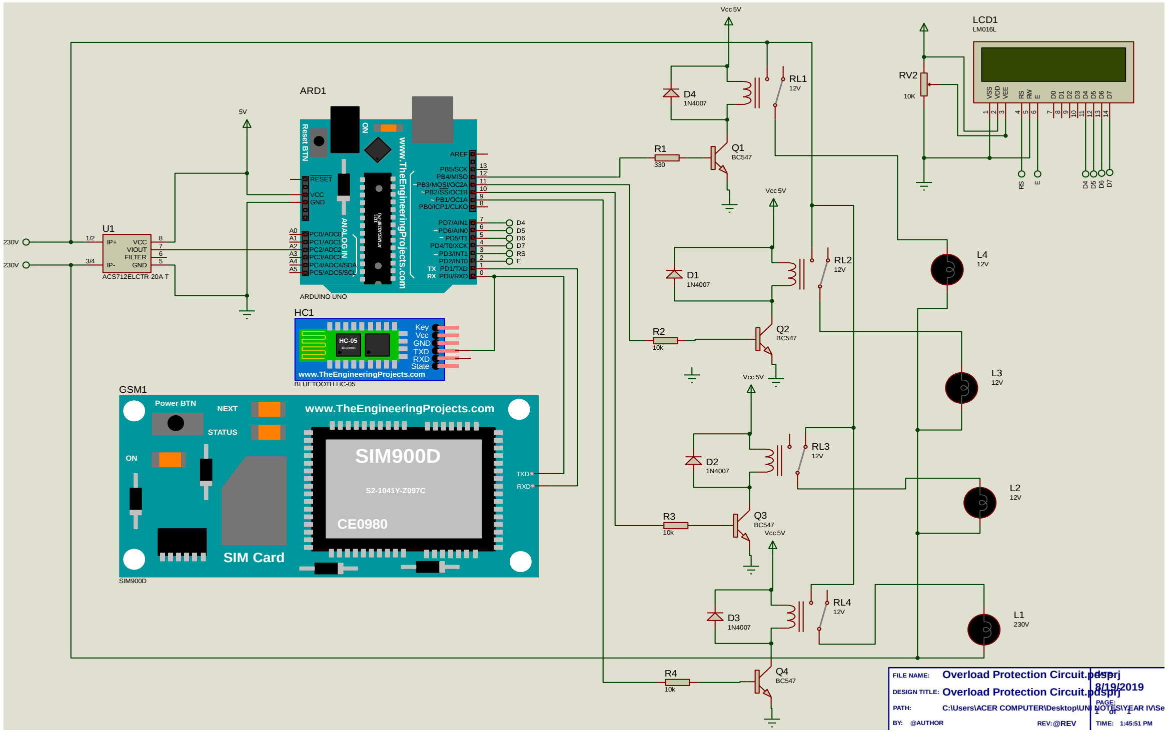

Figure 9: Automatic Overload Protection Circuit

The stabilized power source 220V AC is then connected to the load through an overload protection system. This system measures the current drawn by the load and determines whether the system is overloaded or not. The loads are switched ON using an android app that operates through Bluetooth. This system does not need the operator to be there in person to switch ON the load but to be at some distance away from the load source such that the Bluetooth will be within the range of connectivity. This prevents the operator from being exposed to the switching surges and sparks that may cause injury to the personnel. In case the operator is within the range, the mobile device is connected to the Bluetooth device in the circuitry. Once the connectivity is established, the operator can switch on the loads while the current sensor measures the amount of current drawn by the load.

Before turning ON any load, the system initially draws a current of 0.04 amps, this ampere was considered in the design of the system. When loads 1 & 2 are switched ON, the current sensors record the current value and are read on the LCD; at the same time a green led was turn on, indicating that the system is standard. When load-3 is ON, the system is at its maximum capacity, and this was indicated by turning on the blue LED, whereas the green LED is switched OFF. At this point, the current through the load is that the current system can handle without any problem.

When the fourth load is switched ON, at this point, the system is overloaded, the blue LED turns OFF, and the red LED then switches ON, which indicates that the system is under overload condition. The system will then isolate the fourth load automatically and, in turn, activate the GSM to send the message "circuit overloaded" to the operator. The operator will respond to the message "all-loads-off," and all the loads will be turn off. After the loads are turned OFF, the operator can send another message "normal" to return the system to be controlled again by Bluetooth device.

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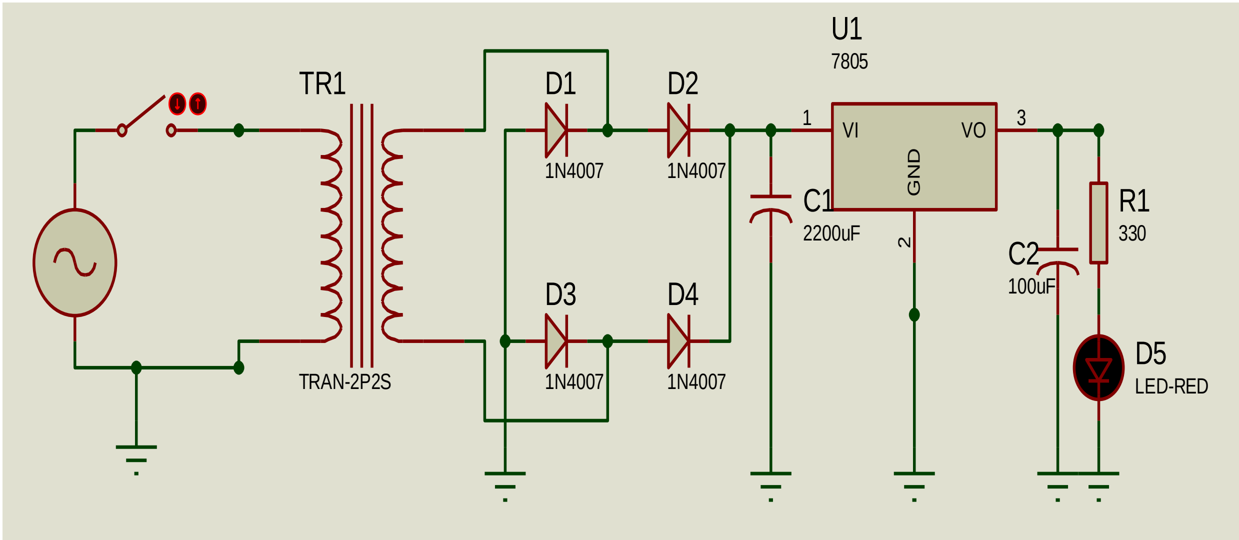

Figure 10: Regulated Power Supply Circuit

3.1 Transformer

This system uses a transformer that steps down the voltage from 230V AC to 12V AC with less power loss depending on the transformer *turns* ratio.

The input AC varies from 160V to 270V in the ratio of the transformer primary voltage Vp to Secondary Voltage. The secondary transformer voltage (Vs) is governed by the formula; (Vp/Vs) = (Np/Ns)

Thus, if the transformer has 220V as the input or secondary voltage, it will deliver 12V at 220V and can be worked out as follows;

At 160V; (160/Vs) = (220/12)

Vs = (160 × 12)/220 = 8.72V

A 270V; Vs = (270 ×12)/220 = 14.72V

Therefore, a step down between 8V to 15V was sufficient since the current limitation was handled by the regulator.

3.2 Bridge Rectifier

The next stage is the process where AC is converted to DC, which involves inverting the negative cycles of the input AC source. The circuit for this process is built using a full-wave rectifier diode bridge and requires a specific bridge rectifier that would be able to handle a peak voltage of 20V and 2A. The 2W04G rectifier was used for the simulation process.

At 220V; $input\ voltage\ Vs$ = 12V

$Output\ dc\ voltage$ = 0.9Vs= 0.9×12= 10.8V

The bridge rectifier delivers pulsating DC

$Ripple\ factor$ = √{($Vrms/Vdc$)^2 – 1}

=√{(12/10.8)^2 −1}^0.5

=0.66

$Efficiency$ = $Pdc/Prms$×100%

= (10.8/12)×100%

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= 90%

3.3 Filter Capacitor

The capacitance value was needed to filter off the ripple voltage. The output of the transformer was 12V AC at 50Hz. The required minimum capacitor value can be calculated from the formula;

$C = Iout/(2\times f\times RF\times Vin)$

$Iout = Imax = 2A$, since it is the maximum forward rectified/output current of the bridge rectifier.

$C = 1/(2\times 50\times 0.66\times 12) \cong 1000\mu F$

Therefore, an electrolytic capacitor of about $470\mu F\ to\ 1000\mu F$ to filter the output DC from the bridge rectifier.

3.4 Voltage Regulator LM7805/LM7805A

After the filtering process, the DC that is obtained is unregulated. In the simulation process, the IC LM7805 was used to get 5V DC at its PIN 3, but the input DC varies from 8V to 15V, and the regulated output from the LM7805 remains constant at 5V.

A small electrolytic capacitor of 10μF is used to filter the regulated 5V DC further to eliminate any noise that may be generated by the circuit.

3.5 Resistor

One LED is connected to the 5V point in series with a 330Ω resistor that limits the current to the ground, i.e., a negative voltage indicates that 5V power supply is available. A 330Ω resistor is so connected to limit the flow of electric current through the LED by producing a voltage drop between its terminals following the current sensor, and the LED has a forward voltage of 2.2V and full drive current of 10mA.

From ohm's law; I=V/R=5/330=15mA

Therefore, a 330Ω was sufficient to produce a full drive current of 15mA required by the LED.

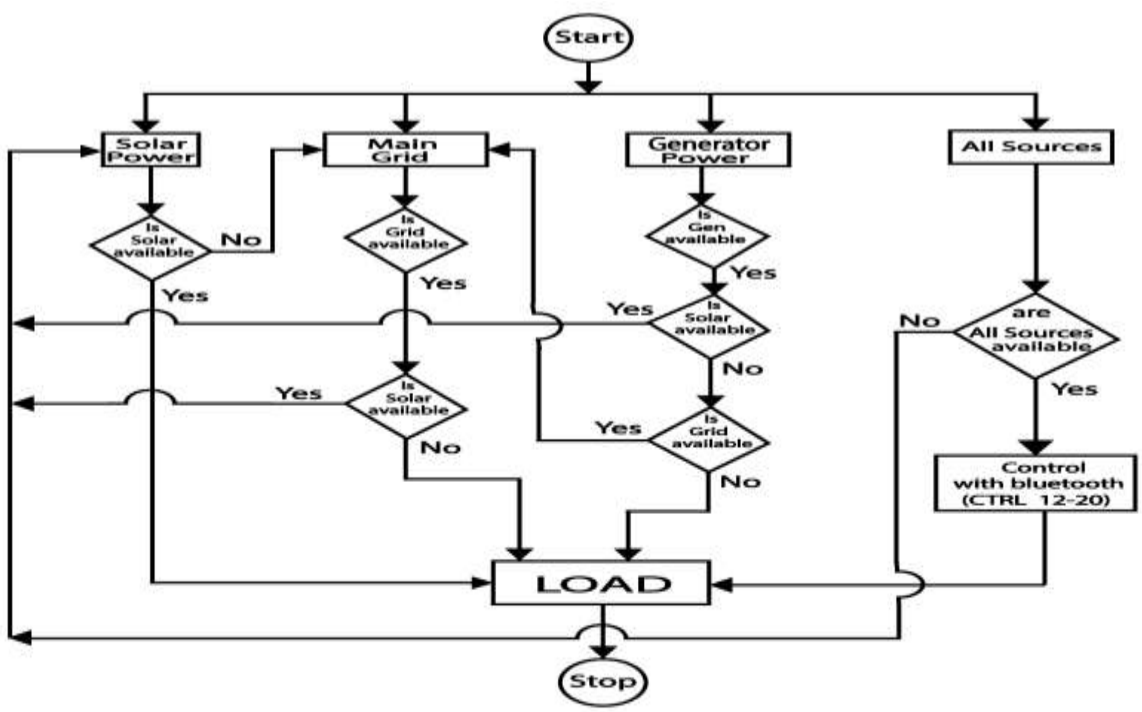

Figure 11: Flow Chart Automatic Phase Selector

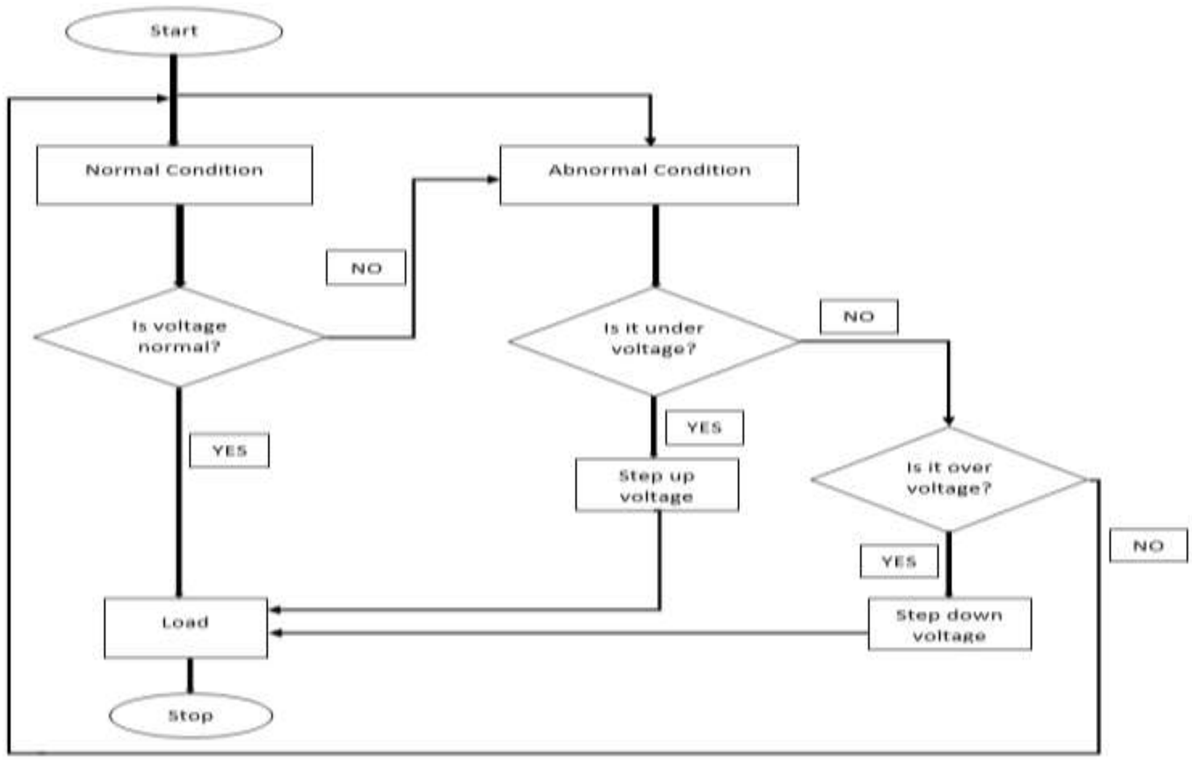

Figure 12: Flow Chart Automatic Voltage Stabilizer.

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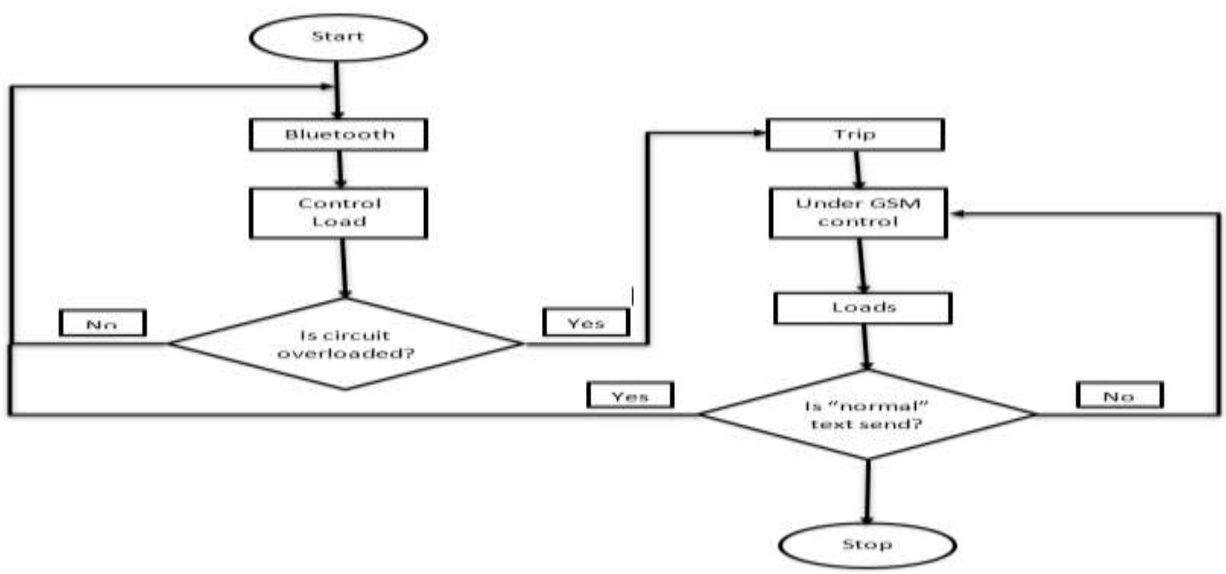

Figure 13: Flow Chart Automatic Overload Protector.

The power supplies are connected to three different socket outlets. The output of these three power supplies are connected to the Atmega 328P microcontroller, and they act as sensors to the analog input to the microcontroller. When a socket outlet is turned ON, a 240V (AC) is reduced to 14V (AC), which is then rectified and regulated to 5V (DC). This regulated voltage act as an input to the microcontroller. Once there is an input of 5V (DC) to the analog terminal of the microcontroller, a relay switch is turned ON to supply the load with an AC voltage. A Lamp rated 100W was used as a load for illustration, which draws power from the main.

When all the electrical energy sources are available, solar power takes the lead and supplies to the load. However, when whenever there is a failure in the solar power to supply to the load, the next source available automatically steps, for example, the main grid, and so on. However, if solar power is restored, it will take its leading position and supply power to the load surpassing all the other sources. In case the load is more than the capacity of one source, the Bluetooth is used to bring one or more sources on board to meet the load demand.

The output of the ATS is then connected to the voltage regulation circuit, which has an inbuilt voltage sensor to detect under or overvoltage. When there are any voltage variations in the supply, the sensor will activate the responsible relay to select an appropriate tap on the auto-transformer, thus maintaining a constant output voltage. From the voltage regulating circuit, a load is connected through an overload protection system. This will isolate the load from the supply in case of overload, and the system will notify the engineer/technician via message to control the load utilizing GSM messages.

4.0 Results and Discussions

The input from the three sources was given to the microcontroller, and the output of the microcontroller, in turn, sends to the relay that maintains continuous power supply to the load through a voltage stabilizer. Finally, the system status of the available sources and load characteristic is displayed on the LCD, the following modes of operation were obtained as shown by the figures below.

Figure 14: Smart Grid protection system

4.1 Results

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Table 1: Showing results of the DC power supply circuit and microcontroller

The output of the bridge rectifier	Input into the voltage regulator	The output of the voltage regulator	Input into the microcontroller (Vcc)
11.7Vdc	10.2Vdc	4.96Vdc	4.96Vdc

Table 2: showing Sources status when control by automatic mode.

Power source	The input of the power source (VAC)	Switch status	LCD Display
Solar	220V	ON	SOLAR ON
Solar	220V	OFF	SOLAR OFF
Grid	220V	ON	GRID ON
Grid	220V	OFF	GRID OFF
Generator	220V	ON	GENERATOR ON
Generator	220V	OFF	GENERATOR OFF
All source	220V	ON	CONTROL BY BLUETOOTH (CTRL WITH 12-20)

Table 3: Showing Sources status when control by Bluetooth

Power source	The input of the power source (VAC)	Input to the app	Switch status	LCD Display
Solar	220V	12	ON	SOLAR ON
	220V	13	OFF	SOLAR OFF
Grid	220V	14	ON	GRID ON
	220V	15	OFF	GRID OFF
Generator	220V	16	ON	GENERATOR ON
	220V	17	OFF	GENERATOR OFF
All sources	220V	18	ON	ALL SOURCES
	220V	19	OFF	NO POWER
Automatic controlled	220V	20	ON	ANY SOURCE AVAILABLE

Table 4: Showing status of voltage stabilizer

Input Voltages (V)	Relays	Relay Status	Output Voltage (V)
190	Relay 1	ON	220
260	Relay 2	ON	220

Table 5: Showing status of loads been controlled by Bluetooth

Loads	The input of the power source (VAC)	Input to the app	Switch status	LCD Display
All Load OFF	220V	Nothing	OFF	CTRL WITH 1-10
Load-1	220V	1	ON	LOAD-1 ON
	220V	2	OFF	LOAD-1 OFF

Load-2	220V	3	ON	LOAD-2 ON
	220V	4	OFF	LOAD-2 OFF
Load-3	220V	5	ON	LOAD-3 ON
	220V	6	OFF	LOAD-3 OFF
Load-4	220V	7	ON	LOAD-4 ON
	220V	8	OFF	LOAD-4 OFF
ALL LOADS ON	220v	9	ON	GSM CONTROL (circuit overloaded)

Table 6: showing loads status Controlled by GSM

Loads	**The input of the power source (VAC)**	**GSM Messages**	**Switch status**	**LCD Display**
Load-1	220V	Load1_on	ON	LOAD-1 ON
	220V	Load1_off	OFF	LOAD-1 OFF
Load-2	220V	Load2_on	ON	LOAD-2 ON
	220V	Load2_off	OFF	LOAD-2 OFF
Load-3	220V	Load3_on	ON	LOAD-3 ON
	220V	Load3_off	OFF	LOAD-3 OFF
Load-4	220V	Load4_on	ON	LOAD-4 ON
	220V	Load4_off	OFF	LOAD-4 OFF
All loads on	220v	All_loads_on	ON	GSM CONTROL (OVERLOAD STATUS)
All loads off	220V	All_loads_off	OFF	ALL-LOADS-OFF
Set to Bluetooth control	220V	normal	OFF	CTRL WITH 1-10

5.0 Conclusion

The main objective of this paper is to develop a smart grid resilience three-phase selector voltage regulator and an overload protection system based on GSM technology. It involves the selection of power supply from either solar power, the primary grid, or a standby generator. This is achieved automatically using the microcontroller and GSM concept. This system helps in protecting the load against voltage fluctuations and overloads. These protection schemes are not found in the currently developed systems, hence make APS and overload protector superior to all of them. The significance lies in the various and wide range of applications such as; power generation plants, schools, hospitals, manufacturing industries, and mining industries where continuity of power is needed.

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