OFF-GRID ELECTRIFICATION SOLUTION

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Abstract: This paper aimed at providing an off-grid electrification solution that will provide daily consumption of 150Wh of energy daily to a remote area, with the solution being user-friendly. The solar panel is modelled using the single diode model. The choices of the panel are based on the energy requirement considering the worst month and charging method, the 50W panel with direct charging are found to efficient. Modified sine wave inverter is selected over pure sine wave considering the cost and the advantage that the load to the inverter have the harmonic distortion protection. The system can harness and provide 150Wh of energy daily. The inverter overload is functional and automatically reinstate when a fault is cleared, but with heavy overloading, the protection response is found to be less than temperature rise on Veroboard due to high current. The overcharge protection oscillates the connection and disconnection of the panel at battery fully charge start, but the issue is solved by limit the battery to charge only when its charge level is below 80%. The energy cost per kilowatt of this off-grid solution is found to be higher compared to City Power and ESKOM. The current-carrying capabilities of the trace can be improved by soldering a copper wire along that trace.

Key words: DOD-Dept of discharge, GHI-Global Horizontal Irradiance, MSW - Modified sine wave, SANS - South African National Standards, THD - Total Harmonic Distortion, SOC - State of charge

1. INTRODUCTION

Access to electricity is vital for human well-being, economic growth, and development. Over 17% of the global population lack access to electricity for which 95% is a contribution of Africa and Asia [1].

The research discussed in this paper aimed at providing an off-grid electrification solution that will provide daily consumption of 150Wh of energy daily to a remote area, with the solution being user-friendly.

The rest of the paper is structured as follows. The methodology for the selection of the panel, battery, and inverter including testing techniques for system protections provided are outlined. Testing results are discussed and analyzed followed by the conclusion.

2. BACKGROUND

2.1 *Constraints and Assumptions*

- The project is constrained to a duration of 6 weeks.
- The budget for the project is R3000.
- The conduction of the project is under the standard working calendar (8 hours a day, Monday-Friday).

2.2 *Success Criteria*

The solution will be deemed successful if it can provide the daily consumption of 150Wh of energy, be used without the need for third-party interaction, the system should also protect itself to increase its life-span.

2.3 *Literature Review*

Several model of PV exist as found in [2–4]. Most of these models are accurate but they have limitations which makes them unsuitable for selection of panel. There is a high number of parameters required by the models for which most of them are not easier to extract. Reference [5] provides an excellent representation using a single diode model which is applied in the design and used to determine power.

Reference [6] provides the off-grid electrification with solar home systems, the research provides protection mechanisms and their test methods, therefore they will be applied to this paper.

The research conducted by [7] shows that the specific power of the transformer is quoted for an ambient temperature of 40-45^oC. Reference [8] provides the transformer temperature curves that allows determination of the transformer power rating.

3. METHODOLOGY

The key objectives of this research have been mentioned earlier. Figure 1 below provides the system overview of the proposed solutions.

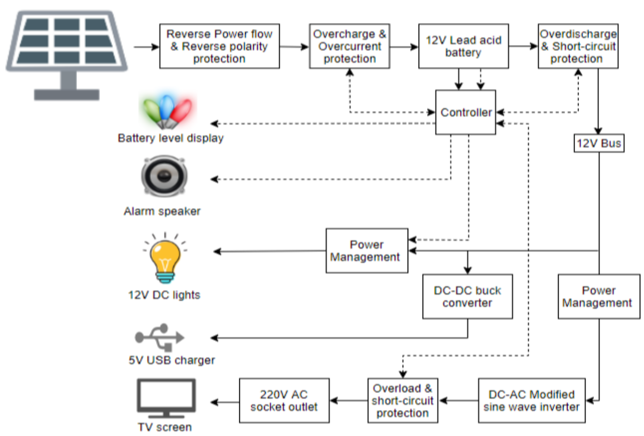

Figure 1: Proposed system overview.

3.1 *Panel Size Selection*

The selection of the panel size depends on the energy requirement, battery charging method, costs, and durability. In this case, the direct charging of the battery using the panel and MPPT charging method are evaluated.

3.1.1 ***Irradiation*** The current produced by the PV-panel is directly proportional to the radiation, thus it becomes important to consider the worst-case on the design. Figure 2 below shows the GHI for the year 2018 and 2019. The results show that there is less radiation on June (winter season), therefore the design must consider that period.

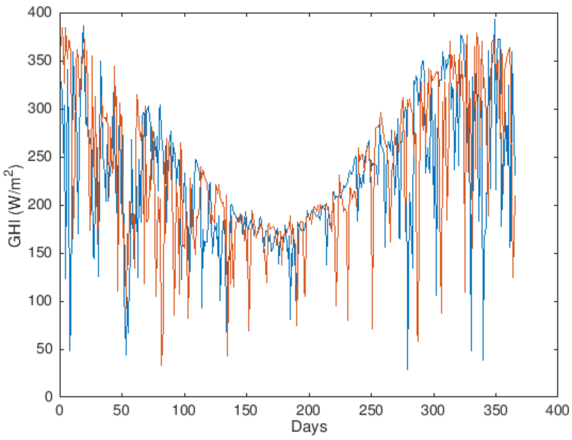

Figure 2: Daily average GHI for 2017 and 2018 using SAURAN data for Pretoria.

3.1.2 ***Modelling of the PV-panel*** This design uses the application of [5] to model the PV panel as a single diode. The advantage of using this model is the fact that its parameters are obtained from the datasheet provided the PV-panel manufacturer. The model has also been proven to robust and can be used to determine maximum power obtained from PV-panel with knowledge of the temperature and irradiation. Equation 1 shows the model of the PV-panel, this equation is further elaborated in Appendix E.

$$V = V_{oc} + V_T \ln{(1 - \frac{I}{I_{sc}})} - R_s I \tag{1}$$

3.1.3 ***Energy harness through the panel for different charging methods*** The energy absorbed daily under direct charging and MPPT charging is simulated using an algorithm coded in C++ with the help of Excel. The SAURAN data is used to model the behavior of the PV-panel. Under direct charging, the battery will force the PV-panel to match its voltage. This moves the operating point of the PV-panel to the left about MPPT point resulting in less power produced by the panel.

Figure 1, Appendix E, shows the simulated daily harnessed energy by applying direct charging and using MPPT charge method. The minimum size PV-panel that manages to provide the 150Wh of energy on a worst-case month under direct charging is found to be 50W panel. From the figure is observed that the direct charging satisfy the absorption of the required energy but it also fails on cloudy as witnessed by energy absorbed going below 150Wh.

For the MPPT charging, the charging system uses the buck-converter with MPPT algorithm to operate the panel at MPPT with high output current and low output voltage for which the boost converter is then used to ensure the battery is charged with a constant voltage. Both the buck and the boost converter have the maximum efficiency less than 95% for which 90% is mostly assumed, this efficiency is considered when determining the harnessed energy. The MPPT charge method is found to harness maximum energy compared to the direct charging as expected, the energy difference is found to be 20% ± 3% for the same 50W PV-panel between the charging methods.

3.1.4 ***Charging method selection*** Concerning the simulations results aforementioned, it is observed that using the MPPT charging mechanism add no significant advantage since the difference energy is found to be 20% ± 3% compared to direct charging. Also, the buck and boost efficiency can go below 90% since the duty cycle increase reduces the efficiency as well [9, 10]. The MPPT controller design available is composed of MOSFETS which are bound to failure in most cases [11], failure of MOSFET will compromise the charging system thus using MPPT charge method puts durability and life-span of the system at risk. Figure 1, Appendix E also shows that going for a 40W panel using MPPT charge method cannot meet the required minimum energy of 150Wh daily, which shows that the MPPT charge method cannot reduce the size of the panel from the 50W of which direct charging can satisfy the 150Wh of energy with.

From the simulation analysis, the 50W PV-panel and direct charging method are selected for which they are cost-effective, meet the energy requirements and improves the durability and life-span of the system.

3.2 Battery Selection

There are a variety of existing batteries, amongst them the most efficient is the Lithium-ion battery followed by the Lead-acid battery [12]. The choice of the battery is taken by considering the costs, capacity, depth of discharge, efficiency, and life-span.

3.2.1 ***Lead acid battery*** Considering the daily energy requirement, this energy can be provided using 12V, 14Ah Lead-acid battery. But this implies 90% of the battery capacity should discharge to obtain 150Wh. This will result in a battery cycle being less than 300, which is less equivalent to 10 months when charged daily at the cost of R488.56. The 12V, 24Ah Lead-acid battery will provide the 150Wh of energy required at the DOD of 52% which gives 900 battery cycles, which is equivalent to 2 years and 6 months at the cost of R890.16. Comparing the two batteries it is clear that in 5 years 6 of 12V, 14Ah batteries will be required amounting to R2931.36 while 2 of 12V, 24Ah will be required at the total cost of R1780.12 which allows it to suitable in this category.

3.2.2 ***Lithium-ion acid battery*** The Li-ion battery under 100% DOD last for 2000 cycles which is 5 years and six months at the cost of R2145.06 for 12V, 14Ah.

With the data presented is observed that the 2 0f 12V, 24Ah Lead-acid batteries can replace a single Li-ion battery over 5 years period at lower saving R364.94. using the Lead-acid battery will also reduce the system total cost of production thus making the system affordable in the market. The Li-ion batteries are not as robust as other rechargeable batteries, they require a lot of protection [13]. The Lead-acid battery is a suitable choice. Table 1 below shows the summary of the comparison between the 12V, 24Ah Lead-acid and 12V, 14Ah Lithium-ion battery.

Table 1: Cost analysis for Lithium-ion and Lead acid battery

Cost savings	**Lead acid**	**Li-ion**
Life-span (in daily cycles)	900 (50% *DOD*)	2000 (100% *DOD*)
Amp Hours	24	12
Cost	R890.16	R2145.06
batteries needed in 5 years	2	1
Total cost for 5 years spend	R1780.12	R2145.06
Total savings	R364.94	R0.00

3.3 Inverter Selection

The size of the inverter required is of 150W. Going for a bigger inverter will result in rapid consumption of the battery. Choosing 1500W inverter implies a kettle, stove or iron can operate for 7.5 minutes with 150Wh of energy stored since they require 1200W of power. The operation time is not enough to complete the usage of the appliance such as cooking and ironing clothes. This shows that the inverter selected should tally with stored energy and operation time for the appliance.

The initial plan aimed at building a new inverter as observed in Appendix C. Table 3 on Appendix E shows the cost of production for building a MSW inverter to be R758.64. The cost of buying a MSW inverter was found to be R150. The results show that buying a MSW inverter is cost-effective compared to building and saves time.

The selection of the inverter type depends on the cost and quality of the output. The modified sine wave is cheaper than the pure sine wave but has poor performance as mentioned in literature. The inverter required can only power appliances such as LED TV and PC monitor, from reference [14, 15] it is observed that these appliances are compensated with filters and SMPS (switch mode power supply), which reduces the total harmonic distortion of the MSW inverter [16]. This makes the MSW inverter suitable for the lower power requirement in terms of costs.

3.4 Protection

The charge controller monitors and control the charging and discharging of the Battery. It protects the battery from both overcharging and discharging. It protects the load and battery from overcurrent (short-circuit and overload) and prevents the battery from discharging through the panel.

3.4.1 ***Reverse current and polarity*** The reverse current protection is required to prevent the current of the battery from flowing to the PV-panel when the is no sunlight for the PV-panel to generate electricity. To test for this protection, the terminals of the panel that connect to the battery were short-circuited then an ammeter was used to check if current flow in reverse direction.

The reverse polarity protection is essential to offer PV-panel reverse polarity connection to the battery. The following tests were done on the protection.

- Panel connected in reverse polarity with battery and the load disconnected.
- panel connected in reverse polarity with battery with load and the battery connected.

3.4.2 ***Overcurrent protection*** For the input short-circuit test, the panel input terminals are short-circuited while an ammeter is connected in series to the battery to observe if the extra current is consumed in the battery considering the consumption of the controller. For the output short-circuit test the load terminals are short-circuited still monitoring the current.

The datasheet of the Lead-acid battery used state maximum charge current to be 6A. The overcurrent protection from the panel is therefore necessary. The protection is tested by varying the power of the voltage supply while an ammeter is connected to confirm the battery is not charging when the current exceeds the limits.

The overload protection is required to protect the transformer of the inverter from overheating. Before the protection, the ratings of the transformer were tested then the protection was implemented. The protection is tested by applying the load to the inverter with energy requirements greater than the transformer rating of the inverter.

3.4.3 ***Undercharge and Overcharge protection*** This protection system uses the voltage method to monitor the SOC. The recommended high voltage disconnect and low voltage disconnect for the battery used are 13.9V and 9.6V respectively. To test overcharge protection, the solar panel was simulated by a power supplier, the battery was charged while the voltage readings were observed and noted down when the charge controller prevented the battery from overcharging.

To test the undercharge protection. The loads were connected to the 12V bus including the inverter. The voltage readings were observed and recorded as the charge controller separated the battery from the load. Figure 3, Appendix E shows the circuit diagram for the undercharge and overcharge protection.

4. RESULTS AND ANALYSIS

4.1 Inverter

4.1.1 ***SANS on Harmonics*** The inverter bought was found to be more of a square wave inverter. This implies the inverter does not conform with SANS 62282 since the THD for the square wave is found be 48.3% [17] while the SANS require THD less than 5%. This is still suitable since the appliances the design is for already have THD compensation circuit aforementioned.

4.1.2 ***Transformer rating*** The inverter was exposed to different loads in ascending order. Before adding another load to the inverter, the current and voltage consumed by the inverter were recorded. After adding the load, the data was recorded after 5 minutes to allow the stability of temperature on the surface of the transformer.

Table 2 below shows the recorded results for the transformer. It is observed from the table that the temperature of the transformer increases with increasing load. When the energy consumed by the inverter reaches 131.52W the surface temperature of the transformer was measured to be 48^{o}C, at this temperature the transformer has reached its power limits. Using load/ambient temperature curve on Figure 3 in Appendix E, it observed that at the temperature of 48^{o}C the corresponding power/power rated ratio is equal to 0.96 which gives the transformer rated power 137W from the power 131.52W.

The shows that the overall inverter can tolerate the maximum power of 137W instead of the 150W specified by the manufacturer. The overload protection of the inverter should therefore prevent the load from exceeding this new power limit.

Table 2: Power delivered by the transformer at different loads and its corresponding surface temperature

Inverter loads	**V** (V)	**C** (A)	**P** (W)	**T** (^oC)
Soldering iron (40W)	12.41	3.00	37.23	24
Soldering iron (40W) oscilloscope (50VA)	12.26	5.06	62.04	25
Soldering iron (40W) oscilloscope (50VA) soldering iron (50W)	12.08	9.06	109.4	30
Soldering iron (40W) oscilloscope (50VA) soldering iron (50W) glue gun (20W)	12.00	10.96	131.5	48

4.2 PV-panel

The 12V, 24Ah battery was charged and discharged for 3 consecutive as shown in Figure 3.

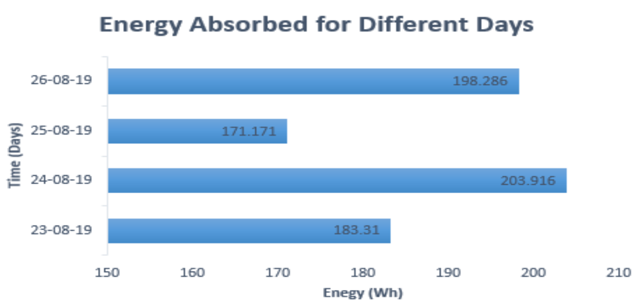

Figure 3: Energy harnessed using the 50W solar panel.

The results shows the amount energy stored in the battery daily, which shows that the PV-panel and direct charge method are able to satisfy the primary requirement.

4.3 Protection

4.3.1 Reverse current and polarity

With the PV-panel cord connect correctly to charge the battery, the relay used as switch remain normally closed as expected. With reverse polarity, the relay switched preventing reverse power to the battery. The red LED indicating reverse polarity switch on as well. The reverse polarity state was held for 5 minutes. The voltage drop across the relay is observed to be close to the open-circuit voltage which forces the panel current to be a the lower points. The temperature of the relay was normal throughout this due to the power consumed by the relay always less than the rated power of 720mW.

4.3.2 Inverter overload protection

The tested results of the transformer rating for the inverter aforementioned were used to set the reference point for the overload. Any load requiring power greater than 131.52W results in the overloading of the inverter. Since the current monitoring technique is used, the current relating to the inverter limits is 10.96A as shown in Figure 2 above thus this current was used as the reference for overload.

The load used and order of adding the loads is similar to that done in the transformer rating. Figure 4 shows the measured current and voltage of the inverter at different loading. It is observed that the current increases with increasing load while the voltage decreases as expected. With the laptop charger added to the load, the current and the voltage are observed to be 0.451A and 12.63V respectively, which are conditions for no load. This result shows that overload detection is fully operational. The loads also switched off showing cut of power supply. The green LED showing the normal operation of the inverter switched-off as well while the red LED turned ON to indicate overloading. After 10 seconds the control system enable the inverter to check for the existence of the overload, it was observed that the inverter is turned-off immediately when the laptop charger is not offloaded from the inverter. The laptop charger was removed, and after the 10-second delay of disabling the inverter, the inverter was switched-on again by the controller. The system returns to the normal state as observed by the current increase and voltage drop on the inverter input. The red LED switch off and green LED switched on showing normal operation. This protection is advantageous compared to the existing solution of using circuit breakers. Circuit breakers require the user to reset it after tripping and removing the overload fault. The circuit breakers are sometimes rigged not to trip which lead to compromise of protection.

The overload protection was further tested with 1200W iron. Before protection, the input side of the inverter was measured draining a current of 17.23A from the battery when iron was connected. When the iron was now connected to the protected inverter, the strip of the Veroboard connecting the 12V bus with the battery terminals melted and remained open-circuit before the system detected the overload. It was observed that the Veroboard used has the copper foil weight of 1oz and trace width of 1.9mm, which implies the temperature of the trace will be 20^oC and 30^oC when the current of 4.5A and 6A pass through it respectively [18]. At the current of 17.23A, the temperature of the copper trace exceeds the maximum temperature rise of 100^oC. Due to time limit, it was difficult to move the circuit to a Veroboard allowing higher current to pass, the other option was to improve the current-carrying capability of the trace by soldering a copper wire on the trace. This method was not applied as well due to the time limit.

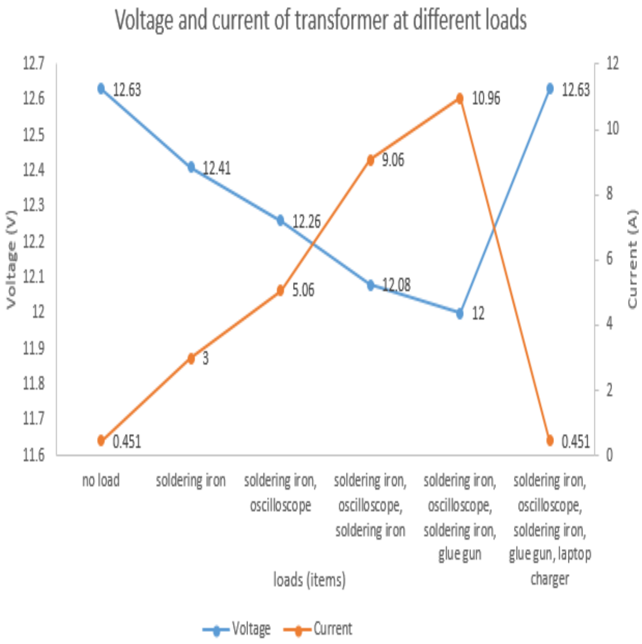

Figure 4: Voltage and current consumed by the inverter at different loads.

4.3.3 ***Short-circuit protection*** The short-circuit protection for the panel input side is provided by the reverse current protection. When the terminals were short-circuited no current was observed passing through, which indicate the success of the protection.

There short-circuit test on the load was not performed due to observing the trace of the Veroboard used fails to allow the 17.23A to pass through it. During short-circuit the lead-acid battery selected release 240A according to the manufacturer datasheet [19], therefore it can be concluded that failure of overload protection at 17.23A due to the Veroboard will lead to failure of short-circuit protection at 240A.

4.3.4 ***Battery overcharge current protection*** Testing for the overcharging current protection was difficult as the charging current more than 6A was required, yet the power suppliers available had the maximum current limit of 3A. In this case, the reference for the overcharge current was set to 1A, 1.5A, 2A, and 2.5A respectively. For every set, the supply voltage was increased from 0 and stopped when the system detects the overcharging current then separate the panel charging input from the battery.

Table 3 below shows the tested overcharge currents and their equivalent reference voltages for the comparator, the last column on the right shows the actual current measured when the overcharging occurred. When the overcharge occurs, the charge controller prevented the panel from charging the battery. The prevention of charging under overcharging was observed by the absence of continuity between the positive terminals of both the panel and the battery. From the results, it is observed that the measured overcharge current does match the reference current in all the test, this implies setting system will still operate as expected with reference changed to 6A (2.078V).

Table 3: Tested results for the battery overcharging current protection accuracy.

Overcharge test current (A)	**Reference voltage (V)**	**Measured overcharge current (A)**
1.0	2.430	1.01
1.5	2.394	1.52
2.0	2.359	2.02
2.5	2.32	2.53

4.3.5 ***Overcharge protection*** At the battery voltage of 14.02V, the charge controller separated the solar panel from charging the battery. The voltage of the battery decreases quickly when the PV panel, the PV panel is then connected back to the battery which, result in the oscillation of connecting and disconnecting the PV panel. This issue was solved by adding a code to a controller to allow charging of the battery only when the charge volume is below 80%.

4.3.6 ***Undercharge protection*** The undercharge protection operated as expected. The load was separated from the battery when fully discharged, the load was connected back when the battery voltage reaches 12.7V.

4.4 System Cost and Return of Invest

Table 4, Appendix E shows the total cost of building the off-grid solution. The total cost amounted to R2726.71. Table 5, Appendix E showcases the returns with time for going off-grid with the build system. It is observed that the system will take 32 years to return the investment, but considering replacement of the battery every 2.5 years, it is observed that the returns are R218.89 while R890.16 is required for the new battery. Overall this result shows that this off-grid system has no return on investment and its energy cost per kilowatt more compared to the buying electricity.

5. FUTURE RECOMMENDATIONS

The inverter used in the system did not conform with the SANS 62282 regarding total harmonic distortion, it is recommended for future research to focus on providing inverter for the solar panel at a lower cost but conforms with the SANS 62282.

6. CONCLUSION

An off-grid electrification solution that uses solar PV-panel to generate electricity has been designed and implemented. The system is provided with overcurrent protection, battery charge protection, reverse polarity and reverse current. Overall the project is deemed successful as the system provides the required 150Wh of energy daily and every process is automated. However, the system requires improvements that will increase the response time of the overload detection.

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APPENDIX A: REFLECTION ON GROUP WORK

Working with a partner of choice in a group allowed good project workflow. The participation of partners allowed effective teamwork. The outcome of the project was improved by group discussions, division of work, constructive criticism and the mutual desire to meet the success criteria of the project. Students had to meet regularly for a progress update.

Table 4 below shows tasks of the project and student responsible for the task completion. Every decision on the project was communicated amongst the students. The meetings with the supervisor were helpful. Providing the overload protection for the inverter was one of the challenging task. The inverter bought had no protection. It was difficult to provide overload protection using the transformer winding.

Table 4: Division of tasks

Task	**Teboho**	**Thapelo**
reverse current and polarity protection	X	
inverter overload protection	X	
Overcharge current protection	X	
Overcharge & discharge protection		X
Energy management		X
Emergency alarm system		X
Short-circuit protection	X	X
Soldering	X	X
Sub-systems integration	X	X
Enclosure cart fabrication	X	X

School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg
ELEN4002/4012: Project Specification Outline

To be completed by supervisor
Assessment:
☐ Deficient ☐ Acceptable
☐ Good ☐ Excellent

Project Title: Solar Electrification Solution

Group Number:	19G30	Supervisor Name:	Ivan Hofsajer
Student Name A:	Thapelo Makhalanyane	Student Name B:	Teboho Lekeno
Student Number A:	875691	Student number B:	1130992

Ethics:
☒ Request for waiver (does not involve human participants or sensitive data)
_________________ ☐ Copy of ethics application attached (Non-medical) – School Committee
Supervisor Signature ☐ Copy of ethics application attached (Medical) – University Committee

Project Outline: *(give a brief outline such that ethics reviewers understand what will be done, 100 words maximum)*

A low cost, off grid solar electrification system will be designed, built, and tested. The system will have two main sub systems namely: Battery Charging system which includes MPPT, and DC-AC Inverter. The system will deliver power to three different loads which are 12V DC lights, 5V DC charging unit, and 220V AC socket outlet. Protection circuits will be implemented for loads, battery, and a solar panel. No human participation will be required and the use of sensitive data is not involved.

Project Specification:

This project specification presents the desired user interface and the necessary requirements to complete the project. The components and subsystems that will be build are specified.

a. User Interface

- **5V DC USB charging port (Buy):** There is no switch, the user can just plug the USB cable.
- **2x 10W LED Lights (Buy):** The user does not have access to the electrical connections, they can only switch the light ON/OFF using a switch. They can also replace the damaged lights.
- **100V-220V Socket Outlet (Buy):** The outlet will be dual-pin plug with a switch.
- **Arduino LCD Display (Buy):** This will display charge level of a battery in percentage.

b. Requirements

- 12V-18AH Battery (Buy), 50W Solar Panel (Buy), and Battery monitoring circuit (Build our own)
- MPPT charge controller
  1) Buck Converter (Build our own)
  2) MPPT Algorithm (Implement our own)
- ATMEGA328 Microcontrollers (Buy), Arduino development board (Buy)
- 5V DC/DC USB step-down module (Buy)
- Inverter for 220V AC (Build our own) and High Frequency Transformer (Build our own)
- Socket outlet (Buy)
- Overload and short circuit protection (Build our own), Lightning/overvoltage protection (Build our own), Reverse power flow protection (Build our own), and Systems integration and product testing

Vital	Necessary	Nice
• Battery • Solar Panel • Lights	• MPPT charge controller which includes Buck converter • Battery protection circuits 1) Overcharge and Over-discharge protection 2) Short circuit protection • USB step-down module • Arduino LCD display • Lightning and short circuit protection for solar panel • Overload and short circuit protection • DC-AC Inverter • Microcontroller • Arduino development board	• Socket outlet for TV • Panel's dust detection system • Switching off heavy loads automatically if there is less power in the battery. • Storage container

Milestones:

Week 1
- Buying vital components aforementioned
- Testing of bought components, to confirm if they are working as expected
- Design and simulation of a DC-AC Inverter
- Design and simulation of a buck converter that will be used on an MPPT

Week 2
- Building and testing of a Buck Converter
- Coding MPPT algorithm

Week 3
- Design and simulation of a High frequency transformer
- Building and testing a High frequency transformer
- Building and testing of a DC-AC Inverter

Week 4
- Design and simulation of Lightning and overvoltage protection systems
- Design and simulation of short circuit protection system
- Design and simulation of reverse power flow protection system

Week 5
- Building and testing lightning and overvoltage protection system
- Building and testing short circuit protection system
- Building and testing
- Connecting a display to a charge controller and other systems to display battery life, power harnessed, and display active loads

Week 6
- System Integration and Product testing
- Design and construction of product packaging

Preliminary Budget & Resources:

The prices below are taken from MANTECH website

Items	**Available/ Buy**	**Cost**
2x Current Sensors (20A)	Buy	R102.60
2x Microcontroller (ATMEGA328)	Buy	R57.06
Arduino LCD display	Buy	R128.13
USB step down module	Buy	R41.38
50W Solar Panel	Buy	R500.00
12V-18AH Battery	Buy	R623.00
Arduino development board		R272.00
13 liter Decor storage container	Buy	R119.00
Printed board	Available	-
Oscilloscope	Available	-
Multimeter	Available	-
Breadboards	Available	-
Resistors and capacitors	Available	-
Relays	Available	-
Comparators	Available	-
Diode, Fuses, Mosfets, Transistors	Available	-
Inductor	Available/ Build	-
Wires	Available	-
Soldering Iron	Available	-
Driller	Available	-
Total		**R1843.17**

Risks / Mitigation:

Risk	**Effect on the project**	**Mitigation**
Late delivery of components	The project can be behind schedule	Order before the project commence
Components not working	• Increases the estimated cost of the project • The project can be behind schedule	Test component as soon as they arrive
A system not working after milestone evaluation	The project can be behind schedule as this will delay building of successive sub-systems	• Increase working hours • Divide the work, One person will work the problematic system and the other will focus on the upcoming tasks as indicated in the milestones
Overbudget	Result to change of the design	Eliminate systems that are costly and are not vital to the project.
Lack of communication	• Introduce changes to the design without informing the other member • The project might be behind schedule	• Meet frequently and inform each other of the changes made on the design • Both parties must approve the changes that are made • Keep record of what's needed and what's available
One member not being able to continue with the work due to sickness or other unforeseen circumstance	The project might be behind schedule due to the fact that all the work will be handled by one person	• Increase working hours on the project • Buy some of affordable subsystem modules to keep the project within schedule
Components burning	• Delays the project • Introduce more costs	Tests will be made before systems are combined

Project Plan: An off-grid Solar Electrification Solution

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Abstract: This paper documents a detailed project plan that will provide the road-map for the implementation of the off-grid electrification system. The project will be complete by always having a minimum viable product at every stage of the project lifecycle, which increases the probability of obtaining a fully operational system compared to using divide and conquer. The incremental conductance algorithm is chosen for the control of charge controller mechanism due to its superior advantages over other existing algorithms. A $5\,\mathrm{V_{dc}}$ USB module load supply is added for cellphone charging and a 220V AC load supply socket outlet is also added for loads such as TV and laptops. This is done to ensure that the system is not constrained to one outlet. The overall cost of the electrification system is calculated to be R2063.435.

Key words: AMV- Astable multivibrator, DOD- Dept of discharge, MPPT- Maximum power point tracker, MVP- Minimum viable product, PMBOK- Project management body of knowledge, MS- Microsoft, SOC - State of charge

1. INTRODUCTION

The use of renewable energies such as solar-photovoltaic has been increasing. The electrification solutions are used to properly harness energy from solar but most of the existing ones are not automated enough to ensure that the system requires less interaction with the user, which does not include the maintainer's intervention. The paper aims to draw the project plan that will serve as an agreement between the project sponsor, supervisor, and students. The project will be managed through PMBOK project management methodology where software such as MS Project and MindGenius will be used. The paper will highlight possible risks which will further be monitored during the project lifecycle.

The document covers project background in section 2 which includes 'requirements', 'success criteria', and 'Constraints Assumptions'. Design overview is covered in section 3 which includes improvements to the basic electrification solution prototype. Section 4 covers the project management, section 5 risk assessment, and the conclusion is covered in section 6.

2. BACKGROUND

2.1 Literature Review

The use of solar PV systems has been increasing to enhance electricity access in developing communities and remote areas. A solar electrification solution involves the solar panel, DC-DC converter, battery, and a load. Many papers have been published about the modelling of the PV panel in order to accurately predict its performance. A paper in reference [1] focuses on the modeling of a PV module using a single diode model. This model has been found to very efficient and easy to implement. There are other modules such as the ones in reference [2] and reference [3]. The paper in reference [4] describes the performance, design, and optimization of dc-dc converters for battery-operated systems. It has been found that the loss mechanisms scale with frequency to a good approximation. The efficiency was found to be independent of the load.

2.2 Requirements

- Deliver a fully functional residential off-grid electrification solution which will be suitable for daily consumption of 150 Wh.
- The delivered product need to be user-friendly where a third party can use the product without the manufacturer's intervention.
- The product has to be relatively cheaper compared to the existing products on the market.

2.3 Success Criteria

The project is deemed successful if the developed prototype is user friendly, fully functional and it is suitable for a daily consumption of 150 Wh.

2.4 Constraints & Assumptions

- The project is constrained to a duration of 6 weeks.
- The project is not allowed to exceed a budget of the maximum budget of 3000 ZAR.
- The project is constrained to 3 human resources (2 students and a supervisor).
- It is assumed that there will not be delays on the material procurement.
- The project will be conducted under the standard working calendar (8 hours per day, Monday-Friday).

3. DESIGN OVERVIEW

The electrification solution will include multiple systems which will work together to ensure the full functionality of the product. The systems include the charge controller, Inverter, Protection, and User interface. The systems will be built sequentially from a charge controller to the user interface. The product will need a proper enclosure which will allow a user to easily use it.

The selected approach to complete the project is to always have a Minimum Viable Product (MVP) at every stage of a project lifecycle. MVP is the portion of the product with enough features to satisfy the client and can also be tested on the market. It is required but with no efficiency thus MVP provides feedback for future improvements while also developing major sequential steps to reach project completion. With this approach, the project stands a higher chance of success compared to using approaches such as 'Divide and Conquer'. This approach reduces mistakes, saves money, and it brings focus on the core value proposition. The lifecycle of the project is simplified by a block diagram in figure 1 below, where MVP block comprises of multiple improved versions of the prototype. Different versions of the project are shown in detail by figure 2 in Appendix A.

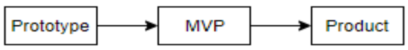

Figure 1: Project Lifecycle

Table 1 below outlines the highest level milestones of the way the electrification solution will be rolled following the MVP approach. Phase I shows the initial prototype, then the sequential phases show improvements to the systems until the final product is obtained.

Table 1: Highest level milestones.

Phase	Milestones
I	Demonstrating a working system with a solar panel, battery, switch, and lights only.
II	Demonstrating an Improved system with an MPPT (Maximum Power Point Tracker) charge controller.
III	Demonstrating a working system with additional DC load (USB charging unit with its DC-DC converter)
IV	Demonstrating a working system with an added AC load which includes a working DC-AC inverter.
V	Demonstrating a working system with added load protection and load automatic control.
VI	Demonstrating a packaged working product.

3.1 Basic Electrification System Prototype

The implementation of the electrification solution will commence with a simple prototype composed of a solar panel connected directly to charge a battery which will be discharged by a load of 12 Vdc lights. A switch will be connected in series with the load to connect or disconnect it from discharging the battery, Figure 3 on the Appendix shows a prototype that will be implemented.

3.2 Charge Controller

Since charging the battery directly from the panel does not ensure that maximum energy is harnessed and the battery is protected, the charge controller has to be used. This will be the first improvement to the prototype. There are two different types of charge controllers which are 'MPPT (Maximum Power Point Tracker)', and 'PWM (Pulse Width Modulation)' charge controllers [5]. The MPPT charge controller was chosen because it allows maximum power to be harvested from the panel. The MPPT charge controller will involve the construction of a DC-DC converter and the MPPT algorithm implementation. A buck converter will be used with an algorithm implemented in C.

3.2.1 ***Simplified Model of PV Panel:*** It is very important to predict the performance of a solar panel when designing a buck converter to ensure that the accuracy is improved. The behaviour of a PV panel that is going to be used is evaluated below. A single diode model is used, and is adapted from the paper in reference [1]. A Monocrystalline silicon solar module (CHN55-40M) will be used, which can operate from a temperature of $-40\,^{\circ}\mathrm{C}$ to $85\,^{\circ}\mathrm{C}$ and has a maximum system voltage of $715\,\mathrm{V_{dc}}$. The panel has an optimum voltage of $20.2\,\mathrm{V}$, optimum current of $2.7\,\mathrm{A}$, open-circuit voltage of $24.7\,\mathrm{V}$, and short-circuit current of $2.8\,\mathrm{A}$. The V-I curve of the panel is determined by equation 1 below, where $\mathrm{V_T}$ and $\mathrm{R_s}$ are determined by equation 7 and equation 8 in Appendix B. The V-I curve and power curve of the panel at STC (Standard Testing Condition) are shown by figure 10 and figure 11 in Appendix B, where MPP (Maximum Power Point) is indicated by an asterisk. At STC, the cell Temperature and Irradiance are assumed to be $25\,^{\circ}\mathrm{C}$ and $1000\,\mathrm{W/m^2}$ respectively.

$$V = V_{\mathrm{oc}} + V_{\mathrm{T}} ln(1 - \frac{I}{I_{\mathrm{sc}}}) - R_{\mathrm{s}} I \tag{1}$$

3.2.2 ***Buck Converter:*** It has been stated that the optimum voltage and optimum current of a PV panel to be used are $20.2\,\mathrm{V}$ and $2.7\,\mathrm{A}$ respectively [6]. Since the battery to be used is a $12\,\mathrm{V_{dc}}$ and the panel can give more, the voltage needs to be stepped and a buck converter is chosen. This will ensure that fast-charging is achieved. The buck converter will reduce the voltage seen by the battery from the panel while increasing current compared to the boost converter which step-up the voltage. The output voltage and current will be adjusted by the MOSFET driver. The general circuit of a buck converter to be built is shown by figure 4 in Appendix B, consisting of a MOSFET driver, diode, inductor, and a capacitor. The buck converter circuit has to be build because the commercial circuit modules cannot suit the specifications. The buck converter's MOSFET driver will be controlled by PWM generated from the MPPT algorithm. The commercial buck converter modules already have embedded IC that controls the PWM, this issue enforces the design and implementation of buck-converter as the MPPT needs a buck converter to be controlled by an external PWM source. Table 2 below outlines the simulated values of the desired buck converter.

Table 2: Buck-converter components.

Components	**Details**
Capacitor	150 μF
Inductor	115mH
Diode	Schottky Diode
MOSFET	IRFZ44n

A 150 μF capacitor, a Schottky diode, and IRFZ44n MOSFET can be obtained but a 115 mH inductor has to be built. A type of an inductor that is going to be built is an EE Ferrite Core because is relatively cheaper and has lesser core losses. The current from the microcontroller is not enough to charge the gate of the MOSFET which is capacitive, thus a driver is necessary, figure 5 in Appendix B shows the simple bootstrap circuit that will drive the MOSFET. This driver is cheap and easier to build compared to the commercial pull-up driver.

3.2.3 ***MPPT algorithm:*** The MPPT algorithm is the functional unit of the charge controller. It changes the operating point of the solar panel on its V-I curve and ensures it is operated on its optimum powerpoint. It will achieve its objective through varying the PWM that drivers the MOSFET of the buck-converter.

There are a variety of existing MPPT charge algorithms such as perturb and observe, incremental conductance, short-circuit current, open-circuit voltage and ripple correlation [7]. The widely used method is the perturb and observe, it is easy to implement and reduces the number of parameters necessary, but the drawback with the algorithm is its tendency to continuously oscillate around the MPP which results into power loss [8]. To counteract the drawbacks of the perturb and observe algorithm, the incremental conductance method will be used. The algorithm has the ability to determine when the MPP has been reached thus minimizing oscillations even though it increases complexity [7, 9]. The algorithm for the incremental conductance can be understood by following Figure 6 in Appendix B.

Table 3 below outline the software and hardware required to complete the MPPT mechanism that will control the buck-converter.

Table 3: MPPT algorithm software and hardware.

Software/Hardware	**Details**
Microcontroller	Atmega328
Chip coding platform	Arduino IDE
Sensors	Current & Voltage

The algorithm will be implemented using Arduino IDE since it is user-friendly and contains libraries that make the programming of the chip easier. Atmega328 microcontroller will be used due to its ability to handle complex decision and has more memory. The current sensor and voltage sensor will both be bought.

3.3 DC-AC Inverter

The energy required from this electrification solutions is small but it is enough to power modern LCD TV's (especially with less than 40W power requirement) for several hours [10]. In South Africa, most AC appliances require 220AC at 50Hz to operate efficiently [11]. An inverter is therefore required to achieve this objective. To minimize the cost of production for the system, the inverter will be implemented using an astable multivibrator cascaded with a simple third-order low pass filter as shown in Figure 7, Appendix B.

The astable multivibrator will turn the $12\,\mathrm{V_{dc}}$ into a square wave, the desired 50Hz fundamental frequency will be set on the square wave using equation 2 and 3 below.

$$f = \frac{1}{T} = \frac{1}{0.69(C_5 \cdot R_8 + C_6 \cdot R_9)} \tag{2}$$

$$f = \frac{1}{1.38R \cdot C}; \quad C_5 = C_6, \quad R_8 = R_9 \tag{3}$$

The third-order low pass filter will then allow only the set 50Hz fundamental frequency of the square wave to pass which is just a single pure sine wave required, with a cut-off frequency and gain at that point determined using equation 4 and 5 respectively. The attenuation of the signal increases with increasing order. For the filter in this application, the gain will be 0.354 at the cut-off.

$$f_c = \frac{1}{2\pi R \cdot C}; \quad R_1 = R_2 = R_3, \quad C_1 = C_2 = C_3 \tag{4}$$

$$Gain = \left[\frac{1}{\sqrt{2}}\right]^n \tag{5}$$

Using the Fourier series for a square wave, it can be observed that it is infinite addition of odd sine waves at different harmonics. The second harmonic of the square wave generated by the astable multivibrator will at 150Hz using equation 6 below. Therefore the cut-off frequency of the filter should be less than 150Hz but also be closer to it than being greater 50Hz and closer to it, this will improve magnitude of the sine wave while still allowing only the 50Hz fundamental harmonic to pass, this results are shown by Figure 8 and 9 in Appendix B. Cut-off frequency of 120Hz will be used for the third-order low passive filter.

$$x(t) = \frac{4}{\pi}\left[sin(\omega{\cdot}t) + \frac{1}{3}sin(3\omega{\cdot}t) + \frac{1}{5}sin(5\omega{\cdot}t).....\right], \quad \omega = 2\pi \cdot f \tag{6}$$

Table 4 below shows the value of components that will be used to implement the inverter containing a low pass filter with a cut-off frequency of 120Hz as shown if figure 8. Variable resistors will be used for the filter to allow efficient turning of the frequency to the one required.

Table 4: inverter components.

Components	**Details**
Capacitor ($C_5 = C_6$)	10 μF
Capacitor ($C_1 = C_2 = C_3$)	10 μF
Resistor ($R_8 = R_9$)	1.45kΩ
Resistor ($R_7 = R_{10}$)	25Ω
Resistor ($R_1 = R_2 = R_3$)	130Ω

A high-frequency transformer will be used on an inverter. This will be built in order to minimize the costs. A high-frequency transformer was chosen because, for any given power rating, higher frequency results in a smaller transformer. This is an advantage because a smaller transformer requires less copper, thus reducing the losses which improve the efficiency of the transformer.

3.4 Protection Systems

3.4.1 ***Over-voltage and under-voltage protection:*** This protection mechanism is vital for the life of the battery. It will be used to prevent the battery from overcharging and full discharging. To limit the cost of the project, the detection, and control mechanism for the protection will be based on the microcontroller already available for MPPT instead on adding additional cost by using analog circuits.

To prevent the battery from fully discharging, the standard 50% DOD will be used [12]. The battery that can allow 50% DOD and also satisfy the 150Wh required is the 12V-24Ah of type lead-acid, when the battery reaches 50% DOD will be considered fully discharge. Before the 50% DOD is reached, the power to different loads will be switch off from the system depending on their significance to the user. This will be done as follows:

- If the battery life is greater than 30%, all the loads will be connected to the bus bar supplied by the battery.
- If the battery life is within the range 25% - 30% The 220V AC load supply will be switched off.
- If the battery life is less 25% only the 12Vdc lights will be active
- If the battery life is 0% the battery will be separated from the load.

To prevent the overcharging of the battery, the microcontroller will be given the voltage details of the battery when fully charged. It will then keep on measuring the voltage of the battery, it will disconnect the battery from the MPPT charge controller when the voltage of the battery exceeds that of the battery when fully charged. The battery will immediately be connected to the MPPT charge controller when the battery voltage drops below 100% full charge.

The battery SOC and DOD will be monitored using the terminal voltage method [13], thus the voltage sensor will be implemented using a high resistance potentiometer to reduce power loss and to accurately divide the battery voltage to match microcontroller ADC reference voltage.

3.4.2 ***Overcurrent Protection:*** Overload and short-circuit protection are types of overcurrent protection. The overcurrent protection system will be implemented using the same microcontroller used for MPPT with the help of the current sensor. This method of applying digital circuit reduces cost, consume less energy and improves efficiency compared to using analog circuits since an existing microcontroller is used for various activities.

The current sensor will monitor the current consumed by the load on the 220V AC supply, it will then send the current signal to the microcontroller for decision making. If the current is greater than the set threshold current by either overloading or short-circuit, the 220V AC supply will be removed from the $12\,V_{dc}$ bus bar. Switching off this supply from the $12\,V_{dc}$ bus bar will save energy compared to switching it off at the primary or secondary side of the transformer.

The system will be programmed to switch-off the 220V supply as required during the overcurrent period, it will then switch-on the supply again to check if the fault was not false, if the overcurrent is detected it will hold on the switch-off state until the user fixes the overcurrent issue then press the reset button to switch on the supply. The supply will continue as normal if on the second attempt the overcurrent was not detected.

4. PROJECT MANAGEMENT

To successfully complete the project, one needs to know the tasks and sub-tasks necessary to complete a certain task. Figure 12, Appendix C provides the WBS (work breakdown structure) of the project, with major tasks of which each contains sub-tasks that lead to the success of the milestones aforementioned.

The 2^{nd} figure on Appendix C provides the Gantt chart which is the road-map of the project. The chart provides time management for the project. The chart also shows that there is no work conducted at the weekend. If the project is delayed then crashing techniques may be applied to bring the project on track.

The cost management is required to ensure the cost for material resources required to complete the project is not greater than the provided project budget. Table 5 provides all the material resources that should be bought for the implementation of the off-grid electrification system. The total cost for material is calculated to be R2063.435, which is less than the R3000 budget amount thus allowing the project to proceed without raising the additional budget.

5. RISK MANAGEMENT

Risks will be monitored throughout the lifecycle of the project. This will reduce the probability of the project failing. The tasks or activities that have a high risk will be given more attention. The risk management will be done by risk register in table 6 in Appendix D.

6. CONCLUSION

The buck converter topology has been proposed and it is going to be built and tested. It can still be modified if time allows. The DC-AC inverter will also be built and be tested. The designs might change depending on the availability of the required components. The buck converter's driver and the protection system will both use a microcontroller. The product will be in a safe and portable enclosure.

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APPENDIX A: MVP

The figure below shows different versions of the product:

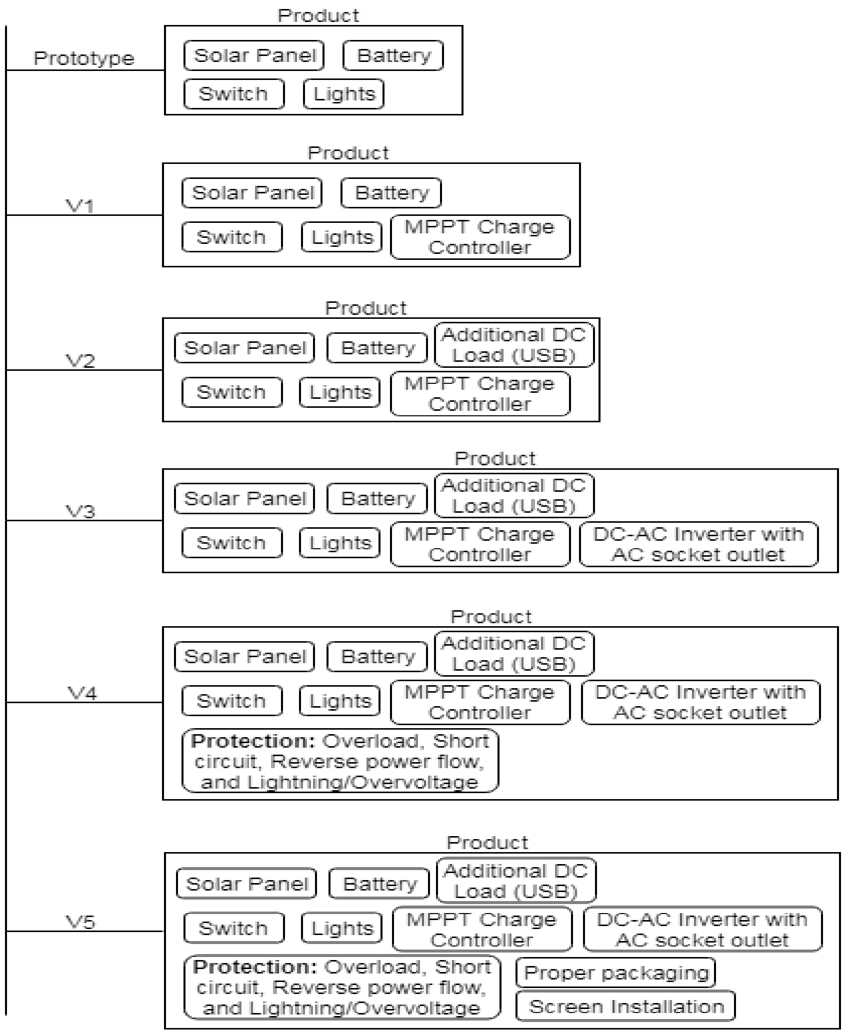


Figure 2: Versions of the product

APPENDIX B: Subsystems Circuits and simulations

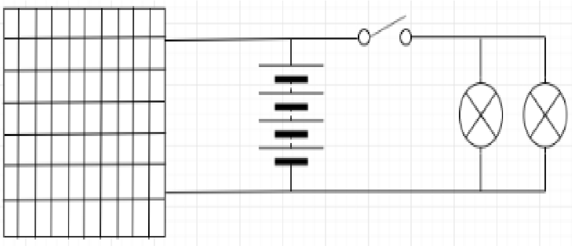


Figure 3: Electrification system prototype

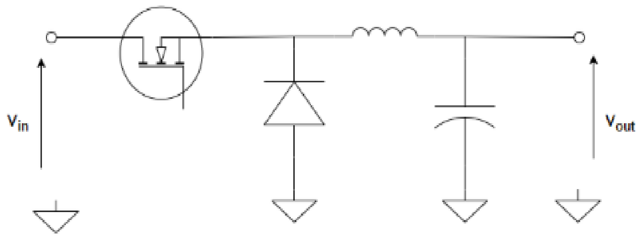


Figure 4: Buck converter schematic

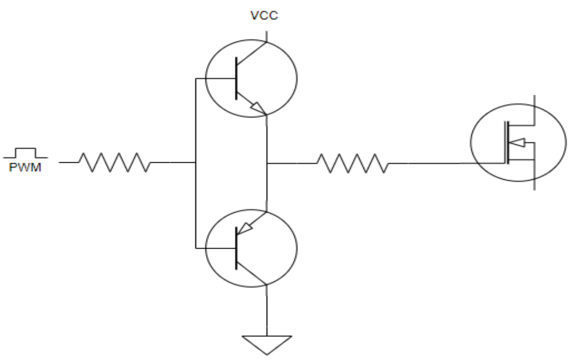


Figure 5: MOSFET driver schematic

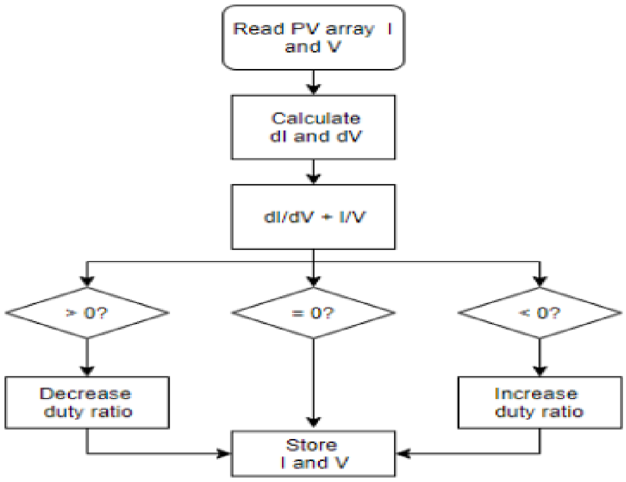


Figure 6: Incremental conductance algorithm

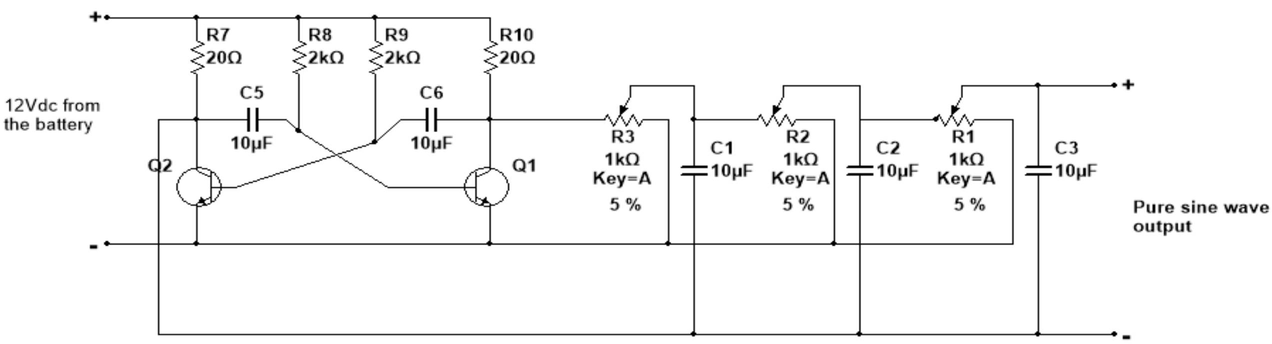


Figure 7: DC-AC inverter using Astable multivibrator cascaded with third order filter.

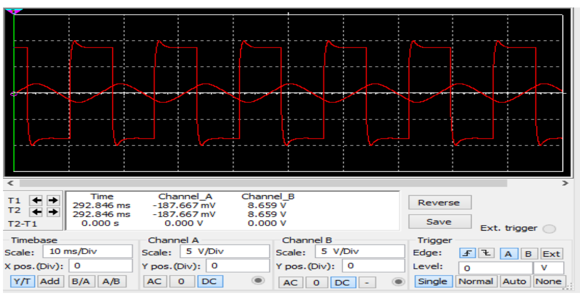


Figure 8: Input square wave at 50Hz with sine wave out at 50Hz using 60Hz filter.

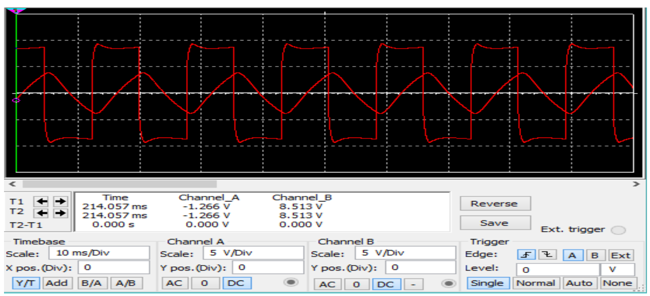


Figure 9: Input square wave at 50Hz with sine wave out at 50Hz using 120Hz filter.

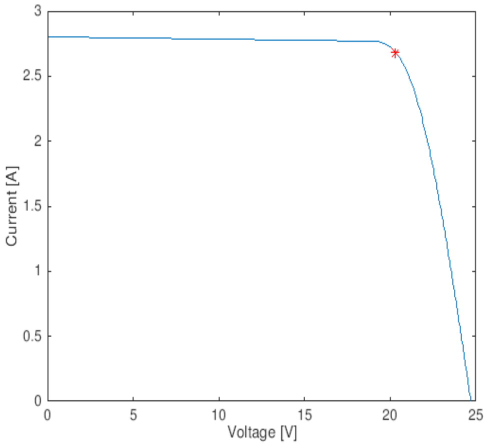


Figure 10: V-I Curve at STC

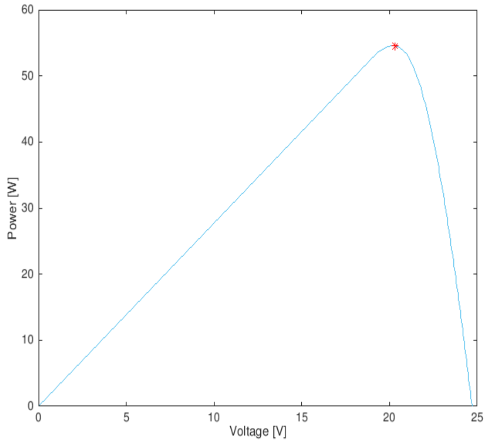


Figure 11: Power Curve at STC

$$V_{\mathrm{T}} = \frac{(2V_{\mathrm{mp}} - V_{\mathrm{oc}})(I_{\mathrm{sc}} - I_{\mathrm{mp}})}{I_{\mathrm{mp}} + (I_{\mathrm{sc}} - I_{\mathrm{mp}})ln(1 - \frac{I_{\mathrm{mp}}}{I_{\mathrm{sc}}})} \tag{7}$$

$$R_{\mathrm{s}} = \frac{V_{\mathrm{mp}}}{I_{\mathrm{mp}}} - \frac{2V_{\mathrm{mp}} - V_{\mathrm{oc}}}{I_{\mathrm{mp}} + (I_{\mathrm{sc}} - I_{\mathrm{mp}})ln(1 - \frac{I_{\mathrm{mp}}}{I_{\mathrm{sc}}})} \tag{8}$$

APPENDIX C: Project Management

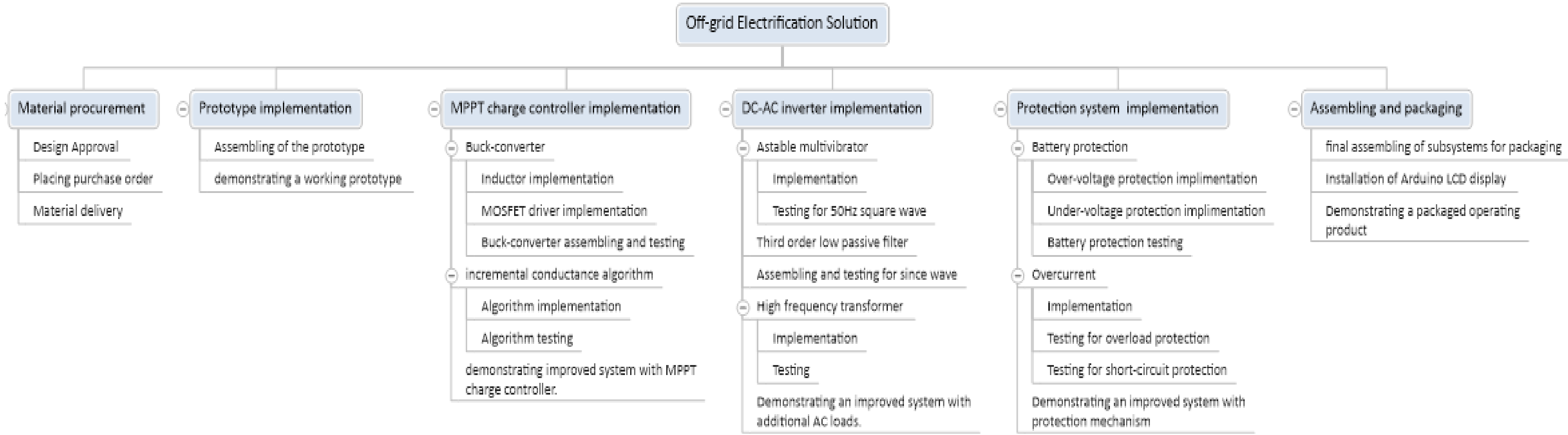
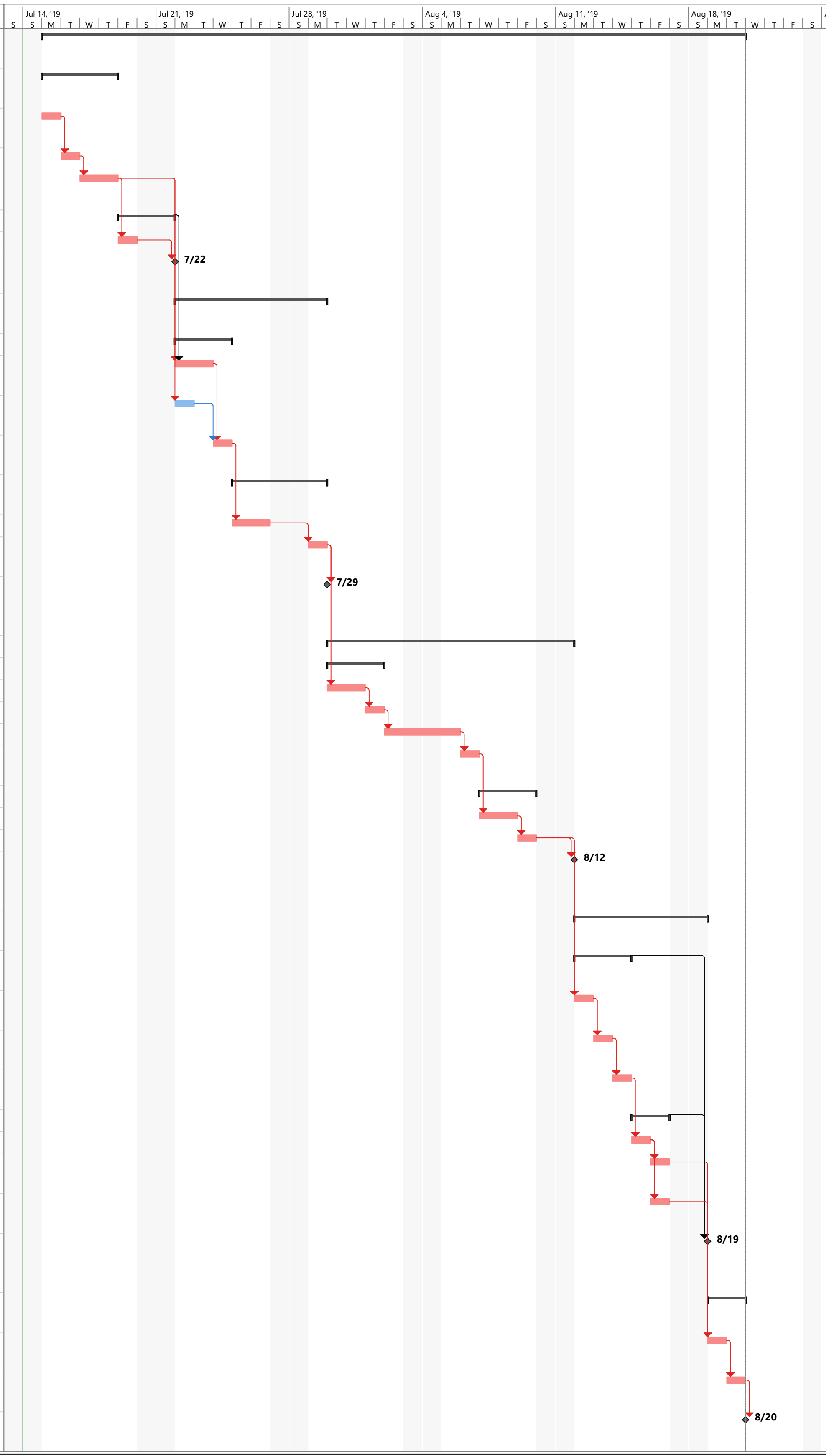


Figure 12: Off-grid electrification solution work breakdown structure.

Task Name	Duration	Start	Finish
Off-grid Electrification Solution	**27 days**	**Mon 7/15/19**	**Tue 8/20/19**
Material procurement	**4 days**	**Mon 7/15/19**	**Thu 7/18/19**
Design Approval	1 day	Mon 7/15/19	Mon 7/15/19
Placing purchase order	1 day	Tue 7/16/19	Tue 7/16/19
Material delivery	2 days	Wed 7/17/19	Thu 7/18/19
Prototype implementation	**1 day**	**Fri 7/19/19**	**Mon 7/22/19**
Assembling of the prototype	1 day	Fri 7/19/19	Fri 7/19/19
demonstrating a working prototype	0 days	Mon 7/22/19	Mon 7/22/19
MPPT charge controller implementation	**6 days**	**Mon 7/22/19**	**Mon 7/29/19**
Buck-converter	**3 days**	**Mon 7/22/19**	**Wed 7/24/19**
Inductor implementation	2 days	Mon 7/22/19	Tue 7/23/19
MOSFET driver implementation	1 day	Mon 7/22/19	Mon 7/22/19
Buck-converter assembling and testing	1 day	Wed 7/24/19	Wed 7/24/19
incremental conductance algorithm	**3 days**	**Thu 7/25/19**	**Mon 7/29/19**
Algorithm implementation	2 days	Thu 7/25/19	Fri 7/26/19
Algorithm testing	1 day	Mon 7/29/19	Mon 7/29/19
demonstrating improved system with MPPT charge controller.	0 days	Mon 7/29/19	Mon 7/29/19
DC-AC inverter implementation	**9 days**	**Tue 7/30/19**	**Mon 8/12/19**
Astable multivibrator	**3 days**	**Tue 7/30/19**	**Thu 8/1/19**
Implementation	2 days	Tue 7/30/19	Wed 7/31/19
Testing for 50Hz square wave	1 day	Thu 8/1/19	Thu 8/1/19
Third order low passive filter	2 days	Fri 8/2/19	Mon 8/5/19
Assembling and testing for since wave	1 day	Tue 8/6/19	Tue 8/6/19
High frequency transformer	**3 days**	**Wed 8/7/19**	**Fri 8/9/19**
Implementation	2 days	Wed 8/7/19	Thu 8/8/19
Testing	1 day	Fri 8/9/19	Fri 8/9/19
Demonstrating an improved system with additional AC loads.	0 days	Mon 8/12/19	Mon 8/12/19
Protection system implementation	**5 days**	**Mon 8/12/19**	**Mon 8/19/19**
Battery protection	**3 days**	**Mon 8/12/19**	**Wed 8/14/19**
Over-voltage protection implimentation	1 day	Mon 8/12/19	Mon 8/12/19
Under-voltage protection implimentation	1 day	Tue 8/13/19	Tue 8/13/19
Battery protection testing	1 day	Wed 8/14/19	Wed 8/14/19
Overcurrent	**2 days**	**Thu 8/15/19**	**Fri 8/16/19**
Implementation	1 day	Thu 8/15/19	Thu 8/15/19
Testing for overload protection	1 day	Fri 8/16/19	Fri 8/16/19
Testing for short-circuit protection	1 day	Fri 8/16/19	Fri 8/16/19
Demonstrating an improved system with protection mechanism	0 days	Mon 8/19/19	Mon 8/19/19
Assembling and packaging	**2 days**	**Mon 8/19/19**	**Tue 8/20/19**
final assembling of subsystems for packaging	1 day	Mon 8/19/19	Mon 8/19/19
Installation of Arduino LCD display	1 day	Tue 8/20/19	Tue 8/20/19
Demonstrating a packaged operating product	0 days	Tue 8/20/19	Tue 8/20/19



Project: New Project
Date: Sun 7/14/19

Task	Inactive Task	Manual Summary Rollup	External Milestone	Manual Progress
Split	Inactive Milestone	Manual Summary	Deadline	
Milestone	Inactive Summary	Start-only	Critical	
Summary	Manual Task	Finish-only	Critical Split	
Project Summary	Duration-only	External Tasks	Progress	

Table 5: Cost for implementing off-grid electrification solution

Task	Components	Details	Quantity	Price
Prototype implementation	Solar panel	55W	1	R518.07
	Lead-acid battery	12V-24Ah	1	R801.14
	Light bulb	12Vdc (5W)	2	R126.5
MPPT charge controller	Diode	Schottky Diode(40V 3A)	1	R3.16
	MOSFET	IRFZ44n	1	R19.56
	Capacitor	150μF (electrolytic)	1	R20.97
	Transistor	PN2222A (PNP)	1	R9.73
		NPN	1	R9.73
	Microcontroller	ATMEGA328p	2	R114.12
	Current sensor		1	R70.32
	Voltage sensor		1	R7.87
	Buck-converter module	stock-code (15M8180-A)	1	R37.53
DC-AC inverter	Capacitor	10μF	5	R17.475
	Resistor	10kΩ (Potentiometer)	3	R15
		1.5kΩ	2	R1.04
		10Ω	4	R2.08
	Transistor	PN2222A (PNP)	2	R19.46
Protection system	Relay	5VDC RECT 8PCB	4	R63.36
	Current sensor		1	R70.32
	Voltage sensor		1	R7.87
Assembling and Packaging	Display screen	Arduino LCD display	1	R128.13
Total Cost				**R2063.435**

APPENDIX D: Risk Register

Symbol meanings:

H = High
L = Low
M = Medium

Table 6: Electrification Solution Project Risk Register

Risk	Causes (due to)	Probability	Impact	Risk Rating	Response	Actions
MPPT algorithm not operational	Complexity of the incremental conductance method	M	M	M	Mitigate	Switch to perturb and observe method in time since it is easier to implement and efficient enough to replace incremental conductance
Project behind schedule	delay in material procurement	M	H	H	Mitigate	Add extra hours to the project by working on weekends or increasing normal working hours.
Budget overrun	unexpected incurred costs, bad resource utilization	M	H	H	Avoid	Try to regain budget from the sponsor, set up cost management with cost control system
Design approval takes time	Design failure to meet requirements or rejected by supervisor	M	M	M	Mitigate	Add extra hours to the project by working on weekends or increasing normal working hours.
Components burning	Negligence	M	H	H	Avoid	Before connecting any system, proper precautions must be made. The voltage and current should be at required level.
Breaking or cracking the solar panel	Dropping to ground, hit or compressed by heavy solid object	M	H	H	Mitigate	handle with car all the time and place it where there less human activities.

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Minutes of Meeting for 4th Year Power and Energy 2019 Lab Projects

Date: 15 July 2019

Time: 11h00

Venue: Genmin Laboratory

Chaired by: Raisibe Maila

Scribe: Khomotjo Kekana

Attendees

Supervisors: Prof Ken Nixon, Prof Willie Cronje, Dr Mercy Shuma-Iwisi, Dr Lesedi Masisi, Mr James Braid, Ms Yu-Chieh (Jessie) Yen

Technical stuff: Frank, Mr Diale, Kyle

Groups: 19G02, 19G37, 19G42, 19G40, 19G33, 19G26, 19G30, 19G48, 19G07, 19G19, 19G32

Apologies

Prof Ivan Hofsajer

Discussions

Ms Jessie welcomed everyone to the meeting. She explained the objective of the weekly group meetings, which is for students to share the progress and challenges of their projects. Each group to give a brief description of their project along with a plan for the week.

The following remarks were made by supervisors, technical stuff and students during the meeting:

- The Power and Energy group will be divided into two and have separate meetings (at 11h00 and 12h00).
- Groups should decide on working space.
- Groups can still set meetings with their supervisors in addition to Monday joint meetings.
- A few house rules for Genmin Lab (Complete list of the rules will be sent once the group is divided)
  - Lab operating times: 08h00-17h00
  - Lab coats must always be worn (see Kyle or Mr Diale to get a coat)
  - Closed shoes must always be worn
  - Ask for permission to use equipment and sign up for it

- Prof Nixon mentioned that the projects are not necessarily about building as almost all groups mentioned that they will be starting to build soon. The projects are rather an investigation. He further said the groups need to know the question they need to answer.

Discussion of projects

1. Group 19G02

Members: Milliscent Mufunda and Tshegofatso Matlou

Project title: Smart meter for DC energy trading in rural environments

Week plan: Finalise design and simulation of current and voltage measurements using flyback converter.

2. Group 19G37

Members: Chizeba Maulu and Mabatho Hashatsi

Project title: Electricity theft detection in Low Voltage networks.

Week plan: Set up all software required and wait for data from City Power. Find open source data that can be used for back up.

3. Group 19G42

Members: Masalane Maroga and Mbongeni Mankge

Project title: Electrically assisted waste pickers trolley.

Week plan: Continue with investigations on existing models and collect data.

4. Group 19G40

Members: Mokgoba Mhlongo and Ladislous Kumirayi

Project title: Downloading geoscience field instrument measurements over Wi-Fi.

Week plan: Acquiring components according to design. Fix and test the prototype they already have.

5. Group 19G33

Members: Mongezi Chitha and Daniel Glenn Tarlton

Project title: PV sources under non-DC conditions.

Week plan: Carry on with testing from last week.

6. Group 19G26

Members: Thato Serai and Kgakololo Mosiane

Project title: Solar PV cooling using Peltier cells.

Week plan: Collect material, further modelling then start building.

7. Group 19G30

Members: Thapelo Makhalanyane and Teboho Lekeno

Project title: Off grid electrification solution.

Week plan: Procure equipment and build first prototype.

8. Group 19G48

Members: Sidwell Nkosi and Lloyd Patsika

Project title: Low cost position sensor development.

Week plan: Research, material procurement, configuration of microcontroller and do mechanical and electrical circuit technical drawings.

9. Group 19G07

Members: Tyron Reddy and Yasteer Sewpersad

Project title: Automated characterisation of heat replacement element pattern of a horizontal geyser.

Week plan: Collect more data and connect the geyser to laptop.

10. Group 19G19

Members: Nhlanhla Lucky Vukeya and Khanimamba Ndlovu

Project title: A guideline and feasibility study on the use of electric buses in the city.

Week plan: Measure and record route data of various buses to various places using GPS.

11. Group 19G32

Members: Raisibe Maila and Khomotjo Kekana

Project title: Arc mitigation in Photo-Voltaic systems using passive circuits.

Week plan: Generating arc and measuring arc voltages and currents.

Next meeting

22 July 2019

Closure

Raisibe Maila adjourned the meeting.

School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg

Minutes of Meeting for 4th Year Power and Energy 2019 Lab Projects

Date: 21 July 2019

Time: 11h00

Venue: Genmin Laboratory

Chair: Vincent Matlou

Scribe: Milliscent Mufunda

Attendees

Supervisors: Prof Willie Cronje, Mr James Braid, Ms Yu-Chieh (Jessie) Yen, Prof Hofsajer

Technical stuff: Frank, Mr Diale, Kyle

Groups: 19G02, 19G33, 19G26, 19G30, 19G07, 19G32

Group 19G33 came late

Apologies

Yasteer Sewpersad from 19G07 could not attend the meeting because of an injury.

Acceptance of Minutes

The minutes from the previous meeting were accepted by everyone in attendance.

Agenda

- Each group is to give a lab project progress report

The following items were added to the agenda:

- The times that groups can be in the Genmin lab.
- A discussion on safety
- Planning (scheduling when a group can get assistance or help)

Discussions

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The chair opened the meeting and gave each group an opportunity to report on the work they had done during the previous week, that is, the progress they made and any issues they encountered during the previous week as well as their plans for this week.

Discussion of projects

1. Group 19G26

Members: Thato Serai and Kgakololo Mosiane

Project title: Solar PV cooling using Peltier cells.

Work done and issues experienced during the previous week

They:

- Determined how the load operates without an MPPT
- Got a Peltier cell
- Got all their other required materials except for thermocouples and a pyranometer
- Built a prototype of a cooler box, the cooler box was built on the 19^{th} of July 2019

Proposed solutions to experienced issues

- Mr Braid suggested that they use the thermocouple that is outside or ask Dr Shuma-Iwisi for the portable thermocouple
- Mr Braid stated that they try connecting the Peltier cells to a DC supply to check the temperature; the group stated that they had already done this
- They could use 2 PT 100

Work to be done this week

The group is going to:

- Test the heat exchanger with the PV panel

2. Group 19G30

Members: Thapelo Makhalanyane and Teboho Lekeno

Project title: Off grid electrification solution.

Work done and issues experienced during the previous week

They:

- Worked on the buck converter, it worked partially but there were issues with the voltage being supplied to the MOSFET gate. The gate voltage was greater than the input voltage
- Were planning on demonstrating the prototype but couldn't because they didn't have all the required materials

Proposed solutions to experienced issues

- It was asked why the group was using a buck converter as the PV panel will not be producing 22 V constantly throughout the day, at other times the PV panel will be producing less than the 12 V that the battery requires and as such a boost converter will be required
- Mr Braid suggested that the group should first connect PV panels directly to the battery and ensure that this works and then focus on adding the MPPT. However, this will mean that they will only be able to charge the battery at 50% efficiency
- It was suggested that the group look at frameworks that will help back up the reasoning for the scope of the project
- It was suggested that groups that need to use the pyranometer should set it up and get the relevant measurements together.
- Prof Cronje stated that they need to think about the properties of their batteries and think about the protection and management of the battery.

Work to be done this week

The group is going to:

- Keep testing and working on the buck converter as they designed a MOSFET driver
- Have procured everything by the end of the week
- Have the demonstration ready by next week Monday

3. Group 19G07

Members: Tyron Reddy and Yasteer Sewpersad

Project title: Automated characterisation of heat replacement element pattern of a horizontal geyser.

Work done and issues experienced during the previous week

They:

- Continued collecting data

Work to be done in this week

The group is going to:

- Investigate the effect of flow rate on the element pattern
- Put the collected data into a regression model

4. Group 19G32

Members: Raisibe Maila and Khomotjo Kekana

Project title: Arc mitigation in Photo-Voltaic systems using passive circuits.

Work done and issues experienced during the previous week

They:

- Worked on generating an arc
- Had problems generating the arc and they solved this issue by adding an inductor in series
- Had another issue were the arc they generated couldn't be sustained
- Had an issue with the heat being dissipated as it was burning the plastic

Proposed solutions to experienced issues

- With regards to using an inductor to generate an arc, Mohammed questioned if they are sure that's what they need to do. The inductor is not the solution, a resistor will work just as well.
- Mr Braid suggested that they use a resistor which will aid in pulling the arc

Work to be done this week

The group is going to:

- Model the VI curve
- Create a model for the PV panel

5. Group 19G33

Members: Mongezi Chitha and Daniel Tarlton

Project title: PV sources under non-DC conditions

Work done and issues experienced during the previous week

They:

- Were compiling software for data logging for the oscilloscope

Work to be done this week

The group is going to:

- Measure the luminosity, temperature, pressure …etc of the PV panel
- Build a PV emulator that they will use for testing

Proposed solutions to experienced issues

- With regards to building a PV emulator, that will be used for testing, it was suggested that the group should just go outside and do the measurements there.
- It was suggested that the group try to simply the problem, this is to be done by focusing on the core project and then adding extra features after

6. Group 19G02

Members: Milliscent Mufunda and Tshegofatso Matlou

Project title: Smart meter for DC energy trading in rural environments

Work done and issues experienced during the previous week

They:

- Were designing the fly-back circuit to and procuring the necessary components
- Were experiencing problems with orientation of the fly-back in relation to the line

Proposed solutions to experienced issues

- Prof. Hofsajer mentioned that the orientation is entirely up to the group, but the end objective is that it should work

Work to be done this week

The group is going to:

- Build the fly-back converter circuit and test it.

Discussion of times that groups are allowed in the Genmin lab

No group can stay after 5 p.m.

Discussion of safety

For the sake of safety:

- No one is allowed touch machines that they are not trained to use. Always ask someone to assist you.

Discussion on planning and scheduling

Planning is part of what groups need to learn, if any group requires help with anything, they should ask for help before-hand. If anyone needs assistance, they should go to Mr Diale to schedule.

General Discussion

The following remarks were made by supervisors, technical stuff and students during the meeting:

- Not everyone was emailed the minutes from the previous meeting and as such the mailing list should be updated.
- Each group should have a group number and a circuit schematic on their workspace. The circuit schematic should be updated as changes are made to the physical circuit. Not having a circuit diagram will delay a group's progress.
- Every group should now have their ethics letters; these can be amended if the need arises.
- A white board with the relevant accessories will be added to the work area, everyone is free to use it.
- Don't move stuff around, place something back where you found it.
- Go home with your personal multi-meters etc… they might get stolen.

Next meeting

The next meeting will be on the 29th of July 2019. Group 19G33 will chair the next meeting.

Closure

Vincent Matlou adjourned the meeting.

Week 3 Minutes of Meeting for 4th Year Lab Projects

Date: 29 July 2019

Time: 11h00 (Group 1)

Venue: Genmin Laboratory

Chair: Mongezi Chitha

Scribe: Daniel Tarlton

Attendees

Supervisors: Prof Willie Cronje, Mr James Braid, Ms Yu-Chieh (Jessie) Yen, Prof Hofsajer

Technical stuff: Frank, Mr Diale, Kyle,Mohammed,Mohammed

Groups: 19G02, 19G33, 19G26, 19G30, 19G07, 19G32

Notes from supervisors:

Students are to please ensure they have clearly read their respective project briefs and that they are working towards the correct end goal objective. For groups that wish to change their titles or re-adjust their project specifications based on results obtained a meeting must be set with the respective supervisors. A further emphasis was placed on the relevance of experiments and information obtained towards the respective projects. A suggestion from staff was the availability of a data logger as well as the suggestion to automate results capturing processes.

This week's meeting was a short meeting.

Still to be completed:

Setup and programming of the pyranometer.

Meeting structure:

All groups are to present their current project progress for a constructive critique from staff and other group members. Once the progress reports are completed groups are required to sign off these comments on the scribes page.

Discussion of projects

1. Group 19G26

Members: Thato Serai and Kgakololo Mosiane

Project title: Solar PV cooling using Peltier cells.

Last Week

- Mounted P-V panel to roof

This Week

- Heat exchangers to be tested
- Poltier Heat exchange mounted by the end of the week.
- Cooling of the poltier cell

2. Group 19G30

Members: Thapelo Makhalanyane and Teboho Lekeno

Project title: Off grid electrification solution.

Last Week

- Completed the MPPT implementation for their off grid electrification solution
- The solution offers an average output of 150W/day

This Week

- Completion of Arc suppression circuit
- Work on inverter solution
- Modify the protection circuit to ensure the system is working properly.
- Charge controller IC

Suggestions:

There was a suggestion from staff and postgraduate students that there are protection IC circuits available.

3. Group 19G07

Members: Tyron Reddy and Yasteer Sewpersad

Project title: Automated characterisation of heat replacement element pattern of a horizontal geyser.

Last Week

- Completed linear regression model
- Completed multi-variac model

This Week

- Continue with experiments
- Figure out more testing procedures
- Begin Automation of data collection

4. Group 19G32

Members: Raisibe Maila and Khomotjo Kekana

Project title: Arc mitigation in Photo-Voltaic systems using passive circuits.

Last Week

- Completed the passive arc mitigation circuit
- Arc initially generated using an inductor is now being generated using a resistor
- Compiled V-I curves for the respective circuitry
- Stability arc for V-I curve has been compiled.

This Week

- Dynamic Characteristics of the system

5. Group 19G33

Members: Mongezi Chitha and Daniel Tarlton

Project title: PV sources under non-DC conditions

Last Week

- Completed testing equipment setup
- Derived baseline V-I curves for a 10W panel under DC conditions
- Designed and built the variable load circuit

This week

- Change the P-V panel to one outside on the roof connected to the pyranometer
- Continue developing the variable load circuit to included both pulsed and constant AC signals

6. Group 19G02

Members: Milliscent Mufunda and Tshegofatso Matlou

Project title: Smart meter for DC energy trading in rural environments

Last Week

They:

- Had issues with the fly-back circuit
- Decided to move on to the main project components as the fly-back converter wasn't considered a primary objective

This Week

- Testing functionality of measurement and display systems
- Continue work on flyback converter

General Discussion

The

following remarks were made by supervisors, technical stuff and students during the meeting:

- The previous weeks minutes were late and only delivered to the gemnin group on the thursday after, this should not happen again minutes should be delivered on the same day.

Next meeting

The next meeting will be on the 29th of July 2019. Group 19G33 will chair the next meeting.

Closure

Mongezi Chitha adjourned the meeting.

Week 4: Meeting Minutes for 4^{th} Year Lab Projects

Date: 5 August 2019
Time: 11:00 (Group 1)
Venue: Genmin Laboratory
Chair: Tyron Reddy (869409)
Scribe: Yasteer Sewpersad (782581)

Attendees:
Supervisors: Mr James Braid, Ms Yu-Chieh Yen, Prof Hofsajer
Laboratory Staff: Mr Lutchmanen, Mr Aswat
Groups: 19G02, 19G07,19G26, 19G30, 19G32, 19G33

Apologies:
Raisibe Maila of group 19G32 could not attend the meeting due to illness and Daniel Tarlton of group 19G33 could not attend due to a family emergency.

Discussion of project progress: Group 19G02 (Smart meter for DC energy trading in rural environments)
Members: Milliscent Mufunda and Tshegofatso Matlou

The following was achieved in the previous week:
Circuits were built to individually determine the current and voltage at various points within the system, however the accuracy of the measurements were poor. As such a Hall effect sensor was collected to be implemented in the system for better accuracy. Additionally, the fly-back circuit was tested, and it was revealed that the MOSFET component heats up rather quick. It is proposed that a larger heatsink may be required.

The following tasks will be worked on this week:
Testing the meter system on both current and voltage at the same time. A larger heatsink will be implemented, although the MOSFET's heating is thought to originate via parasitic components. The fly-back circuit seems unnecessary to the heart of the project and it was proposed that purchasing one may be a more effective methodology rather than designing one. Lastly, a member of the laboratory staff emphasized that there is no need to build very complicated circuits to improve accuracy by a small amount; instead it may be more suitable to mention improvements in the groups report.

Discussion of project progress: Group 19G07 (Automated characterisation of heat replacement element pattern of a horizontal geyser.)
Members: Tyron Reddy and Yasteer Sewpersad

The following was achieved in the previous week:
A multivariate model with six variables was built. Variables were chosen so as to have the highest correlation with the dependent variable but the smallest correlation with other independent variables. The model predicted draw volume with an R^2 value of around 0.99. The model was then modified incrementally by removing variables with the largest p-value until a model with two independent variables remained. The process of choosing the most suitable independent variables for the model is still not clear.

The following tasks will be worked on this week:
Collection of high flowrate data will be carried out this week. Code will be written to try all possible multivariate models and the model with the best characteristics will be chosen. Lastly, an investigation into the meaning of the regression coefficients will be carried out. It is hoped that the gradients of the model can be related to a physical model or equation originating in thermodynamics.

Discussion of project progress: Group 19G26 (Solar PV cooling using Peltier cells.)
Members: Thato Serai and Kgakololo Mosiane

The following was achieved in the previous week:
The prototype system was connected to a solar panel. The panel supplied 4A of current to the system which was within the 6A limit of the cell. Subsequently, data was collected on both sides of the Peltier cell by using water of different temperatures on either side. It was discovered that water at lower temperatures causes a smaller change in temperature, on the cell, than water at higher temperatures. Care was taken to standardize test times to make for a more accurate comparison.

The following tasks will be worked on this week:
The data will be used to find the power rating of the Peltier cell, and this will be compared to the maximum power output of the solar panel. This will allow for a load-matching factor to be determined which will assist in future calculations. The group's supervisor in addition to a member of the laboratory staff also stressed the importance of recording the ambient temperature, together with the rest of the data so as to account for environmental conditions present at the time of the measurements. Tests should also be done, whereby the Peltier cell is powered to identify changes in temperature. This of course has implications for the heat sink used. It was suggested that the Peltier cells be split into individual boxes to identify how the cells work for the report.

Discussion of project progress: Group 19G30 (Off grid electrification solution.)
Members: Thapelo Makhalanyane and Teboho Lekeno

The following was achieved in the previous week:
The panel was received towards the end of the week and protection circuits were designed and built. In particular, the short circuit protection circuit was thoroughly tested, although the other circuits did have testing done on them.

The following tasks will be worked on this week:
Voltage protection will be built into the system. Code will also be written onto the microcontroller to enable for an auto restart feature. More tests shall commence whereby the operation of the inverter as a result to different signals will be analysed. To enable the most effective testing, it is proposed by a supervisor that test cases should be written first so that the entire system is tested rather than focusing testing on a few modules.

Discussion of project progress: Group 19G32 (Arc mitigation in Photo-Voltaic systems using passive circuits.)
Members: Raisibe Maila and Khomotjo Kekana

The following was achieved in the previous week:
Dynamic characteristics of arc events were recorded. The system incorporates the use a solar panel as the main powering device. Due to the lack of sunshine and other environmental conditions, it was not possible to carry out many tests in the previous week.

The following tasks will be worked on this week:
Currently testing is done using a short circuit type load at 260mA on a 260W solar panel. It is still unknown as to what current is required for an arc to be generated, so the task for this week is to identify the minimum current required for an arc, and as such, the current rating for the device to be in a safe operating state. The group's supervisor also recommends finding the correct resistor for the load panel, with a high current rating and also mentioned the possibility of stringing together 2 solar panels in series. These configurations will be explored this week should time permit.

Discussion of project progress: Group 19G33 (PV sources under non-DC conditions)
Members: Mongezi Chitha and Daniel Tarlton

Current and voltage graphs were generated in the previous week using a resistor. Results for pulsating loads were recorded using a digital oscilloscope and the math function was used when necessary. It was discovered that when this function is used, a rather noisy signal was recorded.

The following tasks will be worked on this week:
A solution to the noise issue will be derived. CSV files will be used to manage the data collected from the scope and it is possible that the shunt resistor may need to be removed from the experimental setup. A laboratory staff member suggests that the resolution used on the oscilloscope is incorrect, especially if an 8-bit resolution is being used with the math function. As such, the staff member recommends using an analogue oscilloscope to prevent sampling errors.

Closing discussion:
Both supervisors and staff members alike stress the arrival of the open day date. It is estimated that there is only three weeks left to complete the laboratory projects, of which one week may need to be allocated for preparation of posters, models, etc. and for the cleaning of the laboratory. Professor Hofsajer recommends that all students should aim to be done by the Friday before the week of the open day. Mr Lutchmanen would also like to stress the importance of wearing ear plugs in the lab when noisy experiments are being carried out. Next week, group 19G26 has requested to chair the compulsory progress report meeting.

Lab Project Meeting Week 5

Held under the following details:

Date: 12 August 2018 at 11h00 am
Venue: Genmin Labs
Chairperson: Kgakololo Mosiane
Secretary: Thato Serai

Attendees:

Supervisors: Ms Yu-Chieh Yen, Prof Hofsajer
Lab staff: Mr Frank
Groups: 19G02, 19G07, 19G26, 19G30, 19G32, 19G33

Apologies:

Mr James Braid has sent his apologies.

Acceptance of Minutes:

The minutes from previous meeting were accepted without any corrections or additions.

Agenda:

- Each group to give a brief progress report from the previous week.
- Ms Yu-Chieh Yen added an item to help groups evaluate their progress.

Discussions:

Group 19G02 (Smart meter DC energy trading in rural environment)
Members: Milliscent Mufunda and Tshegofatso Matlou

In the last week, the bootstrap and switching circuits were built, and PC boards were designed. An attempt was done to power the Arduino through a flyback. The bootstrap and switching circuits were combined. This week, the enclosure for the smart meter will be built. 60 % of the project is done as the DC meter can measure voltage and current and there is also a backup current sensor.

Group 19G07 (Automated Characterization of heat replacement element pattern of a horizontal geyser)
Members: Tyron Reddy and Yasteer Sewpersad

Data was collected for the model last week. The automation part of the program has also been implemented. This week, the model will be evaluated against the data collected to determine its accuracy. 70 % of the project has been completed because the basic model has been achieved.

Group 19G26 (Solar PV cooling Using Peltier cells)
Members: Thato Serai and Kgakololo Mosiane

Data was collected to determine the relationship between cooling capacity, thermal difference as a function of current through the Peltier cells. Issues encountered include that fact that Peltier cells were operating at low power levels when connected in parallel. The Peltier cells were then connected in series which has improved efficient utilisation of solar power. In this week, more data will be collected to determine trends and relationships of different parameters will be graphically presented. 70 % of the project has been completed, because the operating characteristics of Peltier cells relative to solar power has been determined.

Group 19G30 (Off-grid Electrification Solution)
Members: Thapelo Makhalanyane and Teboho Lekeno

Since the inverter bought did not have overload protection, an attempt was made to build it but it was malfunctioning. Therefore, this week, non-inverting amplifier will be built, including an enclosure for the whole prototype. Current protection monitoring for the battery has been done and the code is being implemented on the Arduino. 60 % of the project has been completed, as the function of many parts of the system can work independently.

Group 19G32 (Arc Mitigation PV systems using passive circuits)
Members: Raisibe Maila and Khomotjo Kekana

The resistive load when there is an arc pushes the operating point closer to the y-axis of the characteristic I-V curve. Testing was done to generate the arc using two PV panels that are connected in series, an arc is observed at current levels exceeding 0.6 A. This week, mitigation of an arc will be investigated and a different current path through the arc will be explored. 60 % of the project has been completed as the static characteristics of an arc have been determined.

Group 19G33 (PV Sources under Non-DC conditions)
Members: Mongezi Chita and Daniel Tarlton

Data was collected and solar irradiance was tracked. The pyranometer was also set up. This week the AC model as a function of frequency will be developed under non-DC conditions. Data processing program is working, able to measure minimum and maximum overshoot. 65 % of the project completed as more data has been collected for DC and non-DC conditions for modelling purposes.

Concluding Remarks:
Ms Jessie Yen and Prof Hofsajer urged everyone to be cognisant of the limited time left before Open day. On the week of Open day, a meeting will be held to give advice on the posters and report writing. Frank also asked everyone to think about the objective of their project, the reason behind conducting the experiment and be able to explain that to anyone outside the engineering field. Group 19G30 will be chairing the meeting next week. The chair adjourned the meeting.

Week 6: Fourth Year Lab Project Meeting Minutes

Date: 19 August 2019
Time: 11h00
Venue: Genmin laboratory
Chair: Teboho Lekeno (1130992)
Scribe: Thapelo Makhalanyane (875691)

Attendees:

Position	Name	Late	On-time	Missing
Supervisors	Pro. Hofsajer		X	
	Pro. Willie Cronje		X	
	Mr. James Braid		X	
	Ms. Yu-Chieh (Jessie) Yen		X	
Technical stuff	Mr. Kyle		X	
	Mr. Frank		X	
	Mr. Diale			X
Students	19G30		X	
	19G07		X	
	19G02		X	
	19G26		X	
	19G32		X	
	19G33		X	

Apologies:

No apologies.

Agenda:

- Groups will give their weekly progress from the previous week and their plan for the current week.
- Ms. Yu-Chieh Yen recommended that the groups estimate their confidence level prior to the open-day.
- Thapelo Makhalanyane (19G30) added the issue of difficulty in getting assistance to drill the hole for wiring connecting to the panel.

Discussion of Project Progress

Group 19G07 (Automated Characterization of heat replacement element pattern of a horizontal geyser)

Members: Tyron Reddy and Yasteer Sewpersad

The group had evaluated the models and found greater errors on the data. They continued gathering data for the model. Currently they had identified the simplest model as the best. 85% of project is complete since they have the model, testing parameters and some solutions.

Confidence level: 85%

Group 19G26 (Solar Panel Cooling Using Peltier Cells)

Members: Thato Serai and Kgakololo Mosiane

The previous week the group changed the circuit configuration for the fans from series to parallel due to overloading the system. With the new configuration they started collecting better results. This week the group aim to analyze and compare the data they collected.

Confidence level: 85%

Group 19G32 (Arc Mitigation PV systems Using Passive Circuits)

Members: Raisibe Maila and Khomotjo Kekana

The group tried to mitigate the electric arc using a capacitor and they confirmed that it does work. The group decided that they need to change the operating point this week and conclude.

Confidence level: 90%

Group 19G02 (Smart meter DC Energy Trading in Rural Environment)

Members: Milliscent Mufunda and Tshegofatso Matlou

Last week the smart meter was tested, it was discovered that the sample rate affected the accuracy. The accuracy is currently 60%. It was also observed that the accuracy of arduino increases with external voltage. This week the group aims to improve the accuracy of the measurement and package the system as well.

Confidence level: 89%

Group 19G30 (An off-grid electrification solution)

Members: Thapelo Makhalanyane and Teboho Lekeno

Last week the group manage to complete all the implementation and testing of the sub-systems for the automation of the off-grid electrification solution for which they operate as expected. The enclosure for the system was also constructed. This week the group aims to have the final product and ensure the panel output is accessible inside Genmin lab.

Confidence level: 80%

Group 19G33 (PV Sources Under Non-DC Conditions)

Members: Mongezi Chita and Daniel Tarlton

The data has been collected and the group developed the AC model as a function of frequency under non-DC conditions. The group was modelling non linear models and different capacitors were added. The group was able to mitigate the spikes.

Confidence level: 85%

Conclusion

Groups were informed that on Thursday the lab for Electric and Magnetic Systems will take place in Genmin lab, as such, oscilloscopes and power supplies used during Lab project will be used EMS lab. Mr. James Braid addressed the issue of posters for the open day; he suggested that the A1 or A0 size may be used. Mr. Frank volunteered to assist group 19G30 with drilling the hole for wire path that connect the panel to the system. Group 19G30 volunteered to chair the meeting again next week.

Week 7: Fourth Year Lab Project Meeting Minutes

Date: 26 August 2019
Time: 11h00
Venue: Genmin laboratory
Chair: Thapelo Makhalanyane (875691)
Scribe: Teboho Lekeno (1130992)

Attendees

Position	Name	Late	On-time	Missing
Supervisors	Pro. Hofsajer		X	
	Pro. Willie Cronje		X	
	Mr. James Braid		X	
	Ms. Yu-Chieh (Jessie) Yen		X	
Technical stuff	Mr. Diale	X		
	Mr. Frank	X		
Students	19G30		X	
	19G07		X	
	19G02		X	
	19G26		X	
	19G32		X	
	19G33		X	

Apologies

Mongezi Chita apologize for the absence of his group partner, Daniel Tarlton.

Agenda

- Groups will give their weekly progress from the previous week and their plan for the current week.
- Discussion of the open-day.
- Discussion on the posters and locations for groups.
- Discussion on the presentation, interview and report.

Discussion of Project Progress

Group 19G07 (Automated Characterization of heat replacement element pattern of a horizontal geyser)

Members: Tyron Reddy and Yasteer Sewpersad

Last week large errors were encountered on the model. Data for different seasons was collected to account for temperature. The group settled for the best model. This will the focus of the group will be on the poster and building of the enclosure for the system.

Group 19G26 (PV Panel Cooling Using Peltier Cells)

Members: Thato Serai and Kgakololo Mosiane

The previous week more test were taken. The group tried to increase the power due to operating far from maximum point (high voltage with small current). This week the group will continue with data analysis and they have already started with the poster design.

Group 19G30 (Off-Grid Electrification Solution)

Members: Teboho Lekeno and Thapelo Makhalanyane

The integration of the sub-system was successful last week. The final product is complete. This week will be dedicated to the poster and data presentation.

Group 19G02 (Smart meter DC Energy Trading in Rural Environment)

Members: Milliscent Mufunda and Tshegofatso Matlou

Last week the group performed certain tests and managed to improve the accuracy of the voltage measurement. This week the group will test and record accuracy of the electrical energy measurement and conduct tests at different currents and deduce how the smart meter behave considering accuracy as well.

Group 19G32 (Arc Mitigation PV systems Using Passive Circuits)

Members: Raisibe Maila and Khomotjo Kekana

Last week the group looked at ranges of capacitors for mitigation, they performed tests with different airgaps. They have started the poster design, which almost complete. This week the PV-panels will be placed in parallel to investigate its effect on the capacitor values for mitigation and continue with poster.

Conclusion

Groups were informed that EMS lab will be running in parallel with the open day. Jessie mentioned that there should be running of machines or dangerous test for safety during open-day. Mr. Diale announced that SABC will be part of the open-day and confident groups can participate in their interviews. He also added that groups should certain regarding the position their posters and that Wednesday is the last working day on the projects. It was brought to attention that the absence of the student on the station during the presence of the external examiner will result into failure (SP requirement). Dr. Hunt was mentioned to be responsible for schedule of the presentation, conference and interviews. It was confirmed that students are allowed to use the lab after the open-day.

This Appendix present the modelling and simulations of the 40W and 50W PV-panel. The single diode model is used

1. PV-panel Single Diode Modelling

Equation 1 below is the relationship of the PV-panel current with voltage. Equation 2-6 are derivatives for variables used by equation 1. This parameters depend on the temperature and irradiation.

$$V = V_{oc} + V_T \ln{(1 - \frac{I}{I_{sc}})} - R_s I \quad (1)$$

$$V_{oc}(G, T_c) = V_{oc0}[1 + \beta(T_c - T_0)] + V_{T0} \ln{(\frac{G}{G_0})} \quad (2)$$

$$I_{sc}(G, T_c) = I_{sc0} \frac{G}{G_0}[1 + \alpha(T_c - T_0)] \quad (3)$$

$$R_s = \frac{V_{mp}}{I_{mp}} - \frac{2V_{mp} - V_{oc}}{I_{mp} + (I_{sc} - I_{mp}) \ln(1 - \frac{I_{mp}}{I_{sc}})} \quad (4)$$

$$V_T = \frac{(2V_{mp} - V_{oc})(I_{sc} - I_{mp})}{I_{mp} + (I_{sc} - I_{mp}) \ln(1 - \frac{I_{mp}}{I_{sc}})} \quad (5)$$

$$V_T(T_c) = V_{T0} \frac{T_c}{T_0} \quad (6)$$

where the constant are as follows:

- R_S is the series constant resistance.
- T_0 is the temperature $= 25°$, $G_0 = 100\text{W}/m^2$ is the irradiation and V_{T0} is thermal voltage all at STC.
- β and α are V_{oc} and I_{sc} temperature coefficients.
- V_{oc0} and V_{mp0} are corresponding open circuit and maximum power voltage at STC.
- I_{sc0} and I_{mp0} are corresponding open circuit and maximum power currents at STC.

2. Direct Charging

When charging the battery directly using the PV-panel, the battery forces the panel voltage to operate at its state of charge voltage. The algorithm shown on the code listing below uses the PV-panel parameters (I_{sc0}, V_{oc0} and V_t) as input and generate the V-I characteristic of the point. The algorithm then traverse through the V-I curve and determine the current at which the 12V is the output. The current is then used with the voltage to determine the power produced by the PV-panel.

```
void Panel_Simulator::Direct_Charging ()
{
    double power = 0, V(0), I;
    int counter(0);

    ofstream outfile ("V-I characteristics.txt");
    ofstream outfile2 ("Average Power per
         hour.txt");

    for (int number = 0; number <
         input_list.size(); number++)
    {
        double iter_p(0);

        if (input_list[number].Isc > 0)
        {
            for (double I = 0; I <
                 input_list[number].Isc; I =
                 I+0.00001)
            {

                V = input_list[number].Voc
                +input_list[number].V_T
                *valueE(1-(I/input_list[number].Isc))-Rs*I;

                if (V>=11.9 && V<=12.2)
                {
                    if (V*I > iter_p)
                        iter_p = V*I;
                }

                if (I + 0.00001 >=
                     input_list[number].Isc)
                {
                    while (true)
                    {
                        V -= 0.1;
                        if (V>=11.9 && V<=12.2)
                        {
                            if
                                (V*input_list[number].Isc
                                > iter_p)
                               iter_p = V*I;
                        }

                        if (V <= 0)
                            break;
                    }
                }

                outfile << V << " " << I << endl;
            } outfile << endl << endl << endl;

            power+= iter_p;
            outfile2 << counter << " " << iter_p <<
                 endl;
        }
        else
            outfile2 << counter << " " << 0 << endl;

        counter++;
    }

    cout << power << endl;
    outfile2 << power << endl;
}
    outfile.close();
    outfile2.close();
}
```

3. MPPT Charging

The MPPT charging always try to operate the PV-panel at the maximum power point. The algorithm shown in the code listing below uses the same parameters as the direct charging algorithm. This algorithm also also generate the V-I characteristic of the panel and traverse through it to determine the voltage current point giving maximum power.

```
void Panel_Simulator::MPPT_Charging ()
{
        double power = 0, V(0), I;
```

```
        ofstream outfile2 ("Average Power per
            hour.txt", ios::out | ios::app);

    for (int number = 0; number <
        input_list.size(); number++)
    {
        double iter_p(0);

        if (input_list[number].Isc > 0)
        {

            for (double I = 0; I <
                input_list[number].Isc; I =
                I+0.00001)
            {

                V = input_list[number].Voc
                +input_list[number].V_T
        *valueE(1-(I/input_list[number].Isc))-Rs*I;

                if (V*I > iter_p)
                    iter_p = V*I;
            }

            power+= iter_p;
        }
    }

    cout << power << endl;
    outfile2 << power << endl;
}
```

4. 40W PV-Panel Energy Profiling

Table 1: Parameter values from the manufacturers data sheet [1]

Parameter	Value	SI unit
V_{mp0}	18	V
I_{mp0}	2.22	A
V_{oc0}	21.6	V
I_{sc0}	2.42	A
β	-0.34	$\%/K$
α	0.04	$\%/K$

4.1 Direct Charging

Using the 40W panel, the maximum energy that can be harnessed from the panel by direct charging is simulated to be 133.041Wh. The minimum energy harnessed reaches 81.1205Wh, this results are observed on the blue curve in Figure 3 below.

4.2 MPPT Charging

The maximum energy that harnessed using the solar panel with MPPT efficiency consider is simulated to have the maximum of 155Wh and the minimum of 95Wh. In most cases the energy harnessed remain below 150Wh.

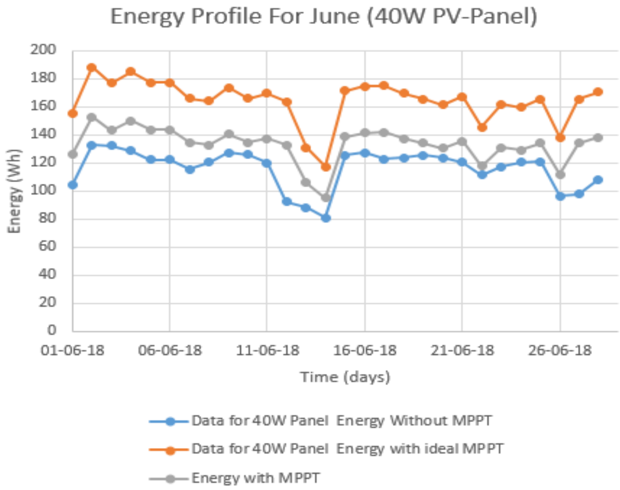

Figure 1: Plotted daily average GHI for 2017 and 2018 using SAURAN data for Pretoria with 40W PV-panel.

5. 50W PV-Panel Energy Profiling

This section simulates the energy that can be harnessed using the 50W solar panel under direct charging and charging using the MPPT method. Table 2 below provides the PV-panel parameters provided by the manufacturer which are useful for modelling of the PV-panel.

Table 2: Parameter values from the manufacturers data sheet for 50W PV-panel [2]

Parameter	Value	SI unit
V_{mp0}	18.2	V
I_{mp0}	2.75	A
V_{oc0}	21.6	V
I_{sc0}	2.95	A
β	-0.34	$\%/K$
α	0.034	$\%/K$

5.1 Direct Charging

With direct charging the energy that can be harness using the panel reaches 150Wh in most instances as seen by the curve on Figure 2, but there are also some days when the harnessed energy goes below 100Wh, this is the case when there is no full clear day.

5.2 MPPT Charging

With MPPT charging the energy that is harnessed from the panel considering the efficiency of the buck-boost converter is shown to have the maximum of 200Wh and minimum of 125Wh.

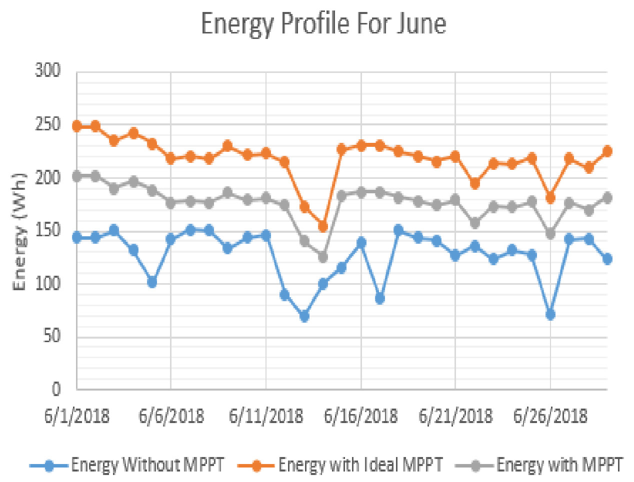

Figure 2: Plotted daily average GHI for 2017 and 2018 using SAURAN data for Pretoria with 40W PV-panel.

6. Inverter cost of production

Table 3: Cost of production for the inverter

Component	Cost	Store
Step-up Transformer (12V-220V, 150W)	R678.75	Builders
Half bridge driver (IRS2184)	R56.31	Mantech
Comparator (LM324N)	R4.20	Mantech
2× MOSFET (IRFz44N)	R19.38	Mantech
Total cost		R758.64

7. Transformer load/ambient temperature curve

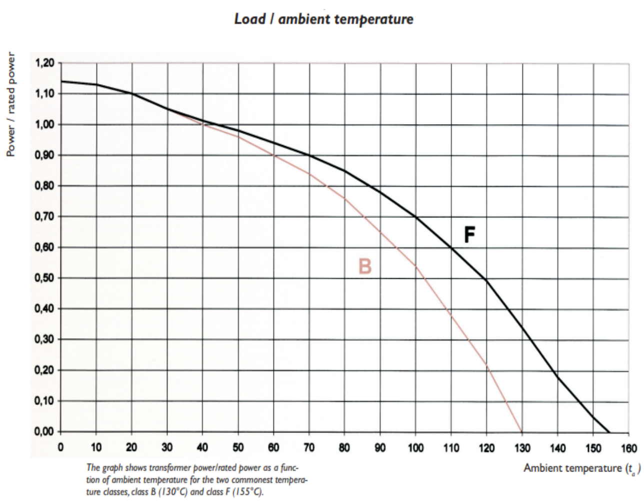

Figure 3: The graph shows transformer power/rated power as a function of ambient temperature for the two commonest temperature classes, class B (130C) and class F (155C)[3].

8. Protection

8.1 *Reverse current and polarity protection*

9. System cost and Return of Investment

9.1 *System cost*

Table 4 shows the cost of components used for the implementation of the off-grid solution. The total cost of production is also calculated on the table.

Table 4: Cost for the overall electrification system

Product	Quantity	Price
Solar panel	1	R747.50
Battery	1	R890.16
MSW Inverter	1	R150.00
Arduino board	1	R294.52
Current sensor	2	R140.65
DC-DC Buck converter	1	R37.74
12 DC light	2	R40.00
Socket outlet	1	R79.00
Switches	1	R49.00
Kettle cord	1	R45.00
Storage container	1	R100.00
Bag trolley	1	R100.00
Panel mount male	1	R14.84
Total cost		R2726.71

9.2 *Return of investment*

The amount of money being saved by going off-grid can be calculated using equation 7 below.

$$G = E_{off-grid} \times R_r \tag{7}$$

$E_{off-grid}$ is the energy provided by the off-grid solution, R_r is the tariff changed by the supplier of electricity, which is currently R1.5992/kWh for homes that consume energy within the range of 350-500kWh a month [4]. G is the amount saved by going off-grid daily. The time it takes for return of investment is calculated using equation 8 below,

$$T = \frac{C_T}{365 \cdot G} \tag{8}$$

where C_T is the overall cost for electrification system and T is the time it takes for the return of investment. Table 5 below shows the amount saved with time assuming 150Wh is produced daily.

Table 5: Return of investment with time

Time (years)	Returns
2.5	R218.89
20	R1751.124
32	R2801.7984

References

[1] E. Ltd. "ENF Ltd." URL https://www.enfsolar.com/pv/panel-datasheet/crystalline/34395.

[2] "SW 50 poly RMA - la.solarworld.com.", May 2010. URL http://la.solarworld.com/~/media/www/files/datasheets/archive/sunmodule-off-grid/sunmodule-off-grid-solar-panel-50-poly-rma.pdf.

[3] URL http://www.noratel.com/fileadmin/content/downloads/school/Transformer.pdf.

[4] S. writer. "Electricity price shock for Joburg residents.", Jul 2019. URL https://businesstech.co.za/news/energy/327907/electricity-price-shock-for-joburg-residents/.