JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-19, No.-11, November (2024) pp 1 - 08 ISSN (Print) 0973-8975

EFFECTIVELY CONNECTING BATTERIES TO ENERGY SYSTEMS FOR THE DIY ENTHUSIAST

P. E. Hertzog

Department of Electrical Engineering, Central University of Technology
South Africa

Email: phertzog@cut.ac.za

Corresponding Author: **P. E. Hertzog**

https://doi.org/10.26782/jmcms.2024.11.00001

(Received: August 30, 2024; Revised: October 20, 2024; Accepted: November 04, 2024)

Abstract

The proliferation of non-expensive commercially available renewable energy systems along with the regular interruption of electrical energy from local power producers has resulted in more DIY (do-it-yourself) enthusiasts. Many of these enthusiasts are from the lower to middle-income classes and thus seek to empower themselves to purchase and install a basic off-grid renewable energy system. It's crucial to emphasize the significance of acquiring a wiring certificate for the electrical setup. National standards, quality management, and human lives are all at risk, so this step cannot be overlooked. However, several components need to be connected in the most efficient and effective way, thereby promoting safety and efficiency. The purpose of this study is to evaluate different electrical connections between two of the main components, the battery (storage device) and the solar charger (or an inverter) to enable an informed decision regarding the optimal type of connection. An experimental setup is used to gather empirical data for seven different electrical connections. The worst type of connection is a solid 1,5 mm cable with battery clamps (or clips) that results in a higher voltage drop of 0,42 V when compared to the ideal type of connection that is a solid 2,5 mm cable with unsoldered crimped lugs. It is recommended that every DIY enthusiast working with electrical connections purchase a non-expensive crimping tool to effectively connect lugs to the correct wire diameter required for their application.

Keywords: Crimping-tool, DIY enthusiasts, Off-grid, Optimal, Solar charger

I. Introduction

"A battery by definition is a collection of cells. So, the cell is a little can of chemicals. And the challenge is taking a very high-energy cell, and a large number of them, and combining them safely into a large battery"[III]. These words, by Elon Musk, indicate that cells cannot reside in isolation, but need to be inter-connected to become a highly effective storage system. This connection of cells must be extended to the effective connection of a battery to an energy system to promote safety, effectiveness, efficiency, and reliability.

The effectiveness and dependability of a solar energy system are influenced by various elements, such as the robustness of the link between the batteries and the solar chargers/inverters. These connections play a crucial role in maximizing energy transfer from solar modules or voltage supplies to batteries, ensuring optimal energy storage and charging. The quality of these connections is influenced by several factors, which ultimately determine the effectiveness of the solar power setup. Loose, poor, or corroded connections can lead to voltage drops, heat generation, and decreased charging performance [II]. This can result in inefficient energy conversion, reduced battery lifespan, and potential system failures [V].

Although there is a lot of research available on the benefits of creating dependable electrical connections between batteries and solar chargers/inverters, there are limited practical examples for DIY enthusiasts who wish to make such connections. Vast online communities of DIY enthusiasts have sprung up about many different causes as a result of shared interests [VI], which include sharing experiences on setting up a basic off-grid renewable energy system. Assisting these enthusiasts is critical through the dissemination of knowledge and expertise gained through scientific research. Closing the gap between what a DIY enthusiast perceives to be correct and what is factually correct is critical to ensure the creation of a safe and effective environment. This may enable them to make informed decisions and optimize their electrical connections for efficiently charging and discharging their energy storage device.

The purpose of this study is to evaluate different electrical connections between a solar battery and charger to enable an informed decision regarding the optimal type of connection. By examining multiple options, the study seeks to highlight deficiencies that can arise from ineffective electrical connections. The next section involves a review of the methods utilized to evaluate solar battery connections. The methodology and practical setup follow, along with the results and conclusions.

II. Battery connections

It's crucial to make sure that the battery cables are securely fastened [XIII]. Loose connections can degrade over time because of vibrations or movement, potentially causing poor electrical contact and resulting in intermittent power supply or total power loss. Loose connections and insulation faults are two common types of arc faults [X] that can cause electrical fires [IX]. This is because the loose connection will heat up substantially more than a tight connection, thereby leading to a possible fire hazard, especially when flammable or combustible materials are in proximity.

Another aspect to consider is proper cable sizing, which is essential to the functionality and safety of high-demand electrical systems. Using the wrong cables, such as those that are too small or not compatible with the system, can lead to unwanted voltage drops and increased resistance [VIII]. These conditions can lead to insufficient power supply to the other connected components and in extreme cases, cause damage to the cables themselves [IV]. It's important to choose the right cables for the task to guarantee safety and effectiveness during operation. Excessive heat may also be generated when a large current is passed through a thin-sized cable (e.g., 10 A flows through a 1 mm diameter cable), which may also cause a possible fire hazard when near flammable or combustible material.

A further potential concern that may arise with battery cables and terminals is the occurrence of corrosion [XV]. If these parts come into contact with moisture, it can start a corrosion process. This can then block the flow of electricity by creating resistance [XI]. Corrosion may further result in poor charging [XIV] or intermittent electrical problems. One of the primary mechanisms involved in corrosion is oxidation. Oxidation on battery terminals can prevent good electrical contact [XVI] between the terminal and the cable.

To ensure the safety and optimal performance of electrical systems, it is essential to conduct thorough testing of battery cables to detect any potential defects. Testing procedures are crucial in promoting proper power distribution, minimizing downtime, improving system efficiency, and ensuring electrical safety. First off, it's crucial to visually inspect the cables for any signs of damage, rust, loose connections, or physical injury. After visual examination, electrical testing can be done. Electrical testing encompasses a diverse array of techniques, which includes measuring voltage loss while under load to evaluate resistance and power loss [VII]. In the field of cable testing, advanced techniques are constantly being developed and utilized to ensure optimal performance and safety of cables and their connections. One such technique is thermal imaging, which involves the use of infrared cameras [I] to detect temperature variations along battery cables. By analyzing the heat signatures, potential hotspots, loose connections, or faulty cable segments can be identified, thus preventing energy losses or overheating that could lead to potentially dangerous situations. By utilizing these methods, technicians can identify and address any potential issues before they become critical, ensuring the safe and efficient operation of the cables and their connections.

It's important for DIY enthusiasts in Electrical Engineering to have a reliable digital multimeter and crimping tool, along with the necessary standard hand tools, to support their projects. DIY enthusiasts would essentially make use of visual inspection and voltage drop testing to evaluate the effectiveness of a cable connection, thereby confirming its compliance with quality and safety standards.

III. Practical setup

An experimental setup has been created to assess various electrical connections between the battery and solar charger. Figure 1 displays the components of the setup.

The components include:

1. a PicoLog 1012 data logger (to automatically record voltage values for different loads and cables);
2. a login interface circuit (measurement interfacing circuit to limit the input voltage to the PicoLog data logger to below 5V);
3. ACDC CML-20 solar charger (to control the charging and discharging cycles);
4. ACDC 30W LED spotlights (to provide three different load currents);
5. Fluke 115 multimeters (to observe and confirm voltage values for manual recording);
6. IPS303A DC power supply (charging power source);
7. Valve-regulated sealed GEL battery (GE120-12 energy storage device); and

8. cables under test (also called lead cables).

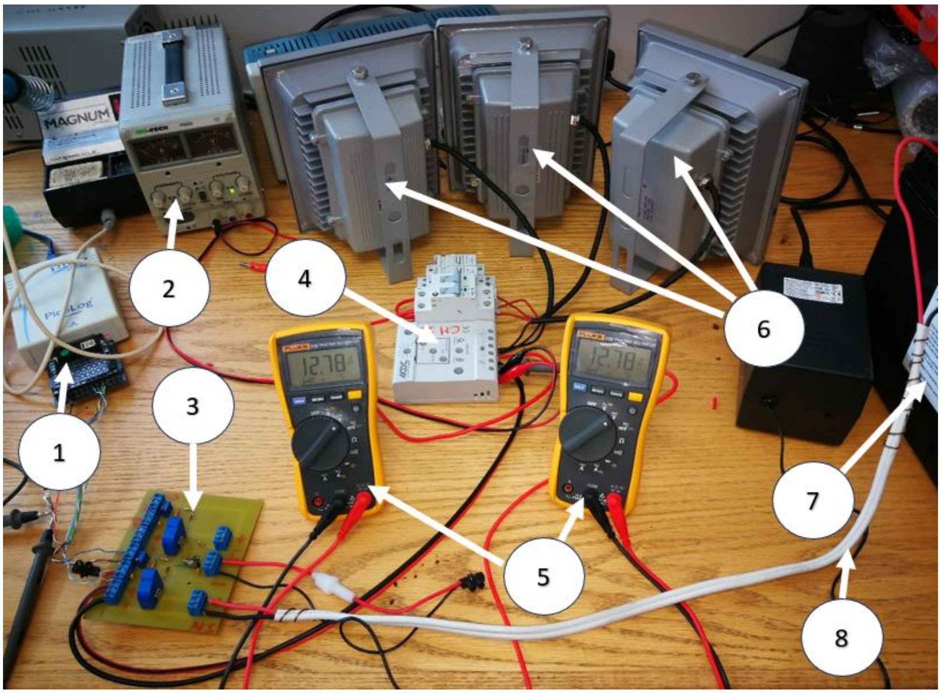


Fig. 1. Practical setup showing a, PicoLog (1), DC power supply (2) the logging interface (3), a solar charger (4), two multimeters (5), LED spotlights (6), a battery (7), and cable connection (8)

IV. Methodology

Seven different cable connections were made and then evaluated using the experimental setup. Two primary cable thicknesses were used, 1,5 mm and 2,5 mm as the solar charger is limited to 10 A. These cables had either a stranded or solid core. A crimping tool was used to connect lugs to six of these cables, while the seventh one was uncrimped (standard pliers being used to connect the lug to the cable). Some of these connections were soldering using a Weller Soldering iron.

Each cable was then connected between the logging interface (2) and the battery (6) and tested during the charging and discharging cycles of the battery. These cycles were controlled by the ACDC Solar Charger. The battery was considered fully charged when the charging current fell below 1 A, and the battery was disconnected from the load by the solar charger when its voltage fell below 11,2 V. This lower limit of the battery was then used to compare the seven different cables for three different load conditions.

The load consisted of three LED spotlights, that were individually switched into the circuit after 4 minutes had elapsed. This means that the first load was 2,45 A for the first 4 minutes, then it was increased to 5,49 A for the next 4 minutes, and finally to 8,94 A for the last 4 minutes. This helps to illustrate that the higher the load current, the higher the voltage drop, which impacts the operation of the system. During each period (4 minutes in duration), readings from a digital multimeter and PicoLog were recorded. The PicoLog reading would be lower than the multimeter reading, as it considers the voltage drop across the cable. The multimeter would be connected directly to the terminals of the battery, thereby not being influenced by the resistance of the cable or its connection.

V. Results

Table 1 compares the lower voltage limits of the seven different lead types for three specified load currents. The battery voltage entry was obtained using a Fluke Digital multimeter that was connected directly to the battery terminals. The SC Battery Voltage was obtained using a second Fluke Digital multimeter that was connected directly to the battery input channel of the solar charger. This value would always be lower than the other stated voltages, as it requires another cable connection between the logging interface circuit and the solar charger. The PicoLog voltage represents the voltage at the logging interface, which is primarily influenced by the voltage drop of the given lead. The Diff value indicates the difference between the battery terminals and the Pico-logger (this takes into account the different leads).

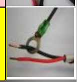
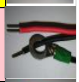
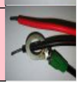
Considering the 2,45 A load, one realizes that the cable does not significantly introduce a high voltage drop, with the highest value (0,09 V) being for the unsoldered crimped lug with a 1,5 mm stranded cable. However, the voltage drop will increase with the load current increase, as can be observed when the load is increased to 5,49 A (0,2 V drop) and 8,94 A (0,33 V drop). This confirms published research [XII].

Lead 5 (2,5 mm solid core cable with an unsoldered crimped lug) is considered the best performer, as it provides the lowest voltage drop difference (0,16 V for an 8,94 A load current) between the multimeter connected to the battery terminals and the PicoLog. Comparing the PicoLog values of the other cables with this value provides the final Diff value shown on the right-hand side of the table. This then helps to rank the different leads (cables and connections) in terms of efficiency and effectiveness.

The 1,5 mm solid cable with soldered battery clamps (clips) is the worst performer. The reason for this is that the clamp does not securely tighten around the battery terminal, resulting in increased resistance at this connection. As a result, there is a higher voltage drop. Another notable conclusion is that a stranded cable provides a higher voltage drop than a solid cable (compare Lead 7 and 2). Therefore, DIY enthusiasts in Electrical Engineering should be encouraged to use solid cables rather than stranded cables when considering the same cable thickness.

What is further noteworthy is that the lowest difference is observed between Lead 5 and 6. The primary distinction between these two cables is that the connector of Lead 6 was soldered, whereas the connector of Lead 5 was not soldered. This suggests that the DIY enthusiast only requires a good crimping tool to connect the cable to the lug, and not a soldering iron to improve the connection with solder.

Table 1: Cable lead results where the key difference between the PicoLog voltages for an 8,94 A load are shown on the right-hand side (called Final Diff.)

Lead number	Lead type	Load = 2,45 A				Load = 5,49 A				Load = 8,94 A				Lead 5 as std.	Lead picture
		Battery Voltage	SC Battery Voltage	PicoLog	Diff.	Battery Voltage	SC Battery Voltage	PicoLog	Diff.	Battery Voltage	SC Battery Voltage	PicoLog	Diff.	Final Diff.	
1	Soldered Battery Clips - Solid 1,5 mm	12,33	12,21	12,28	0,05	11,93	11,67	11,81	0,12	11,56	11,14	11,34	0,22	0,42	
2	Soldered Crimped Lugs - Solid 1,5 mm	12,45	12,33	12,4	0,05	12,15	11,89	12,03	0,12	11,86	11,42	11,64	0,22	0,12	
3	Unsoldered Uncrimped Lugs - Solid 1,5 mm	12,45	12,32	12,37	0,08	12,15	11,89	12	0,15	11,88	11,43	11,63	0,25	0,13	
4	Unsoldered Crimped Lugs - Stranded 1,5 mm	12,45	12,3	12,36	0,09	12,15	11,83	11,95	0,2	11,85	11,32	11,52	0,33	0,24	
5	Unsoldered Crimped Lugs - Solid 2,5 mm	12,45	12,34	12,41	0,04	12,18	11,95	12,07	0,11	11,92	11,55	11,76	0,16	NA	
6	Soldered Crimped Lugs - Solid 2,5 mm	12,45	12,34	12,39	0,06	12,18	11,95	12,07	0,11	11,94	11,56	11,75	0,19	0,01	
7	Soldered Crimped Lugs - Stranded 1,5 mm	12,45	12,3	12,36	0,09	12,1	11,77	11,9	0,2	11,78	11,23	11,43	0,35	0,33	

VI. Conclusions

The purpose of this study was to evaluate different electrical connections between two of the main components, the battery (storage device) and the solar charger (or an inverter) to enable an informed decision regarding the optimal type of connection. The worst type of connection is a solid 1,5 mm cable with battery clamps (or clips) that results in a higher voltage drop of 0,42 V when compared to the ideal type of connection, which is a solid 2,5 mm cable with unsoldered crimped lugs. It is recommended that every DIY enthusiast working with electrical connections purchase a non-expensive crimping tool to effectively connect lugs to the correct wire diameter required for their application.

VII. Acknowledgements

The author gratefully acknowledges the support of the Department of Electrical Engineering, Central University of Technology, South Africa, in this study.

Conflict of interest:

There is no conflict of interest regarding this paper.

References

I. Bakır, Hale. "Detection of Faults in Photovoltaic Modules of Spps in Turkey; Infrared Thermographic Diagnosis and Recommendations." Journal of Electrical Engineering & Technology, vol. 18, no. 3, 2023, pp. 1945-57.

II. Beszédes, Bertalan et al. "The Practice of Troubleshooting and Maintenance in a Small-Scale Off-Grid Industrial Environment." 2023 IEEE 21st World Symposium on Applied Machine Intelligence and Informatics (SAMI), IEEE, 2023, pp. 000213-18.

III. Brainy Quote. "Homepage." http://www.brainyquote.com/quotes/. Accessed 10 March 2020.

IV. Desai, Alpesh et al. "Temperature Effects on Dc Cable Voltage Drop in Utility Scale Rooftop Solar Pv Plant Based on Empirical Model." 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), IEEE, 2020, pp. 2397-2402.

V. Du, Pin et al. "Research Progress Towards the Corrosion and Protection of Electrodes in Energy-Storage Batteries." Energy Storage Materials, 2023.

VI. Fidai, Aamir et al. "Internet of Things (Iot) Instructional Devices in Stem Classrooms: Past, Present and Future Directions." 2019 IEEE Frontiers in Education Conference (FIE), IEEE, 2019, pp. 1-9.

VII. Generation, Dispersed and Energy Storage. "Ieee Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (Pv) Systems."

VIII. Iderus, Samat et al. "Optimization and Design of a Sustainable Industrial Grid System." Mathematical Problems in Engineering, vol. 2022, 2022.

IX. John, Obukoeroro and HE Uguru. "Appraisal of Electrical Wiring and Installations Status in Isoko Area of Delta State, Nigeria." Journal of Physical Science and Environmental Studies, vol. 7, no. 1, 2021, pp. 1-8.

X. Paul, Kamal Chandra et al. "Series Ac Arc Fault Detection Using Decision Tree-Based Machine Learning Algorithm and Raw Current." 2022 IEEE Energy Conversion Congress and Exposition (ECCE), IEEE, 2022, pp. 1-8.

XI. Ramay, Muhammad Bin Zubaid et al. "Corrosion Effect in Underground Lv Distribution Networks in Domestic and Commercial Buildings." Engineering Proceedings, vol. 22, no. 1, 2022, p. 16.

XII. Sun, RL et al. "A New Method for Charging and Repairing Lead-Acid Batteries." IOP Conference Series: Earth and Environmental Science, vol. 461, IOP Publishing, 2020, p. 012031.

XIII. Szabó, Gabriella-Stefánia et al. "A Review of the Mitigating Methods against the Energy Conversion Decrease in Solar Panels." Energies, vol. 15, no. 18, 2022, p. 6558.

XIV. Vaideeswaran, V et al. "Battery Management Systems for Electric Vehicles Using Lithium Ion Batteries." 2019 Innovations in Power and Advanced Computing Technologies (i-PACT), vol. 1, 2019, pp. 1-9.

XV. Wang, Yang-Yang et al. "Mechanism, Quantitative Characterization, and Inhibition of Corrosion in Lithium Batteries." Nano Research Energy, vol. 2, no. 1, 2023, p. e9120046.

XVI. Yao, Xing-Yan and Michael G Pecht. "Tab Design and Failures in Cylindrical Li-Ion Batteries." IEEE Access, vol. 7, 2019, pp. 24082-95.