DESIGN AND SIMULATION OF SOLAR HYBRID POWER SOURCE FOR 1KW SMART DATA CABINET

Lemuel L. Duhaylungsod, and Lory Liza D. Bulay-og
College of Engineering and Architecture, University of Science and Technology of Southern Philippines, Cagayan de Oro City, 900 Philippines
For correspondence; *duhaylungsod.lemuel@gmail.com

ABSTRACT: *Data centers are voracious energy consumers, primarily housing IT infrastructure. Servers, the backbone of these centers, rely on uninterruptible power supplies (UPS) and precision cooling systems. However, this massive energy demand exacerbates fossil fuel usage and CO2 emissions. This research aims to integrate solar power into data centers through Smart Data Cabinets. These cabinets include built-in UPS and cooling, condensing data center functions into a single unit. The hybrid system leverages solar panels, rectifiers, inverters, and batteries. Simulation, using Matlab, and component selection based on the researcher's expertise guide the design. A 48VDC hybrid rectifier, battery, and inverter combo, common in telecommunications, forms the system's DC bus voltage. Sixteen 320W solar panels, arranged in series-parallel, provide a maximum input of 5,120W ((that can energize the 1kW ICT load and the Precision Cooling System), ensuring daytime operation. Grid power supplements solar during fluctuations, with batteries bridging power gaps until backup generators engage. This solar-powered approach reduces fossil fuel reliance, mitigating global warming and climate change concerns.*

Keywords: MatLab, Data Center, Uninterruptible Power Supply, Data Cabinet

1. INTRODUCTION

The world faces an undeniable crisis: the depletion of natural resources for energy production. This issue is exacerbated by the escalating energy demands of various components and devices, including Data Centers. Companies utilize enterprise data centers, cloud data centers, and managed data centers, all of which significantly contribute to the consumption of fossil fuels (such as oil, coal, and natural gas). The consequence is a surge in CO2 emissions, exacerbating global warming concerns [1]. The relentless growth of technology, particularly in the realm of the Internet of Things (IoT), further compounds this problem [2]. IoT connects countless devices to the internet, generating a massive digital information pool that necessitates extensive network storage. The rate at which data is stored and subsequently retrieved and processed directly correlates with the escalating power consumption of data centers. As technology advances, data centers' power demands will inevitably rise, posing a formidable challenge to our efforts to combat climate change [3][4].

Data centers have emerged as voracious consumers of electricity, strained global energy resources and exacerbated environmental concerns. The quest for sustainable alternatives to power these centers has gained prominence [5]. This study aligns with the proposal of Xingyu Bai [6], emphasizing the potential of solar power as a renewable energy source to energize data centers. Most data center implementations, as revealed by Schaefer and Dittmar [7], feature one or two server racks or data cabinets (see Figure 1).

These findings in figure 1 underscore the practicality of implementing renewable energy sources in standalone data centers, such as the development of smart data cabinets. Large data centers, due to spatial constraints, are typically ill-suited for renewable energy integration, relegating such efforts to auxiliary systems. The inclusion of renewable power sources in small-scale data centers can significantly contribute to natural resource conservation and greenhouse gas reduction.

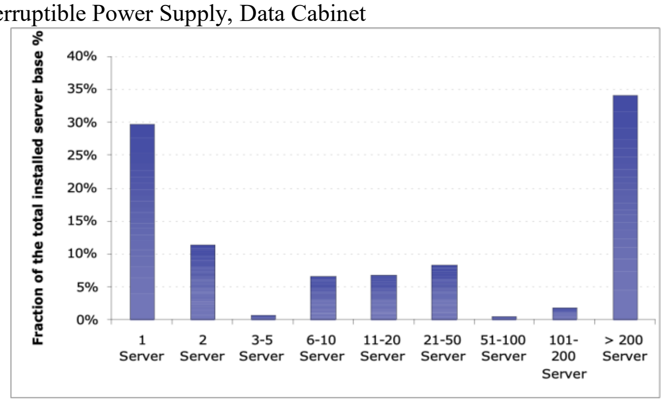

Figure 1. Breakdown of installed server base by server clusters in Germany 2007 (TechConsult 2008b) [7]

Currently, industry-manufactured smart data cabinets like Vertiv's SmartCabinet™ and Delta's Micro Data Center™ predominantly rely on commercial power sources. This study seeks to introduce an innovative solution to augment data center power sources, reduce grid dependency, and promote sustainability. The proposed modular Smart Data Cabinet, with an initial capacity of 1kW, harnesses solar energy through photovoltaic cells during daylight hours, supplying power to ICT loads, cooling systems, and auxiliary functions. This scalable solution ensures uninterrupted operation even during cloudy periods, seamlessly transitioning to commercial power when needed. Batteries serve as temporary backups during outages while backup generators start, avoiding extended battery usage, given their limited lifespan.

Moreover, this research advocates the utilization of the well-established 48VDC power supply system, widely adopted in the telecommunications industry. The 48VDC technology boasts high efficiency, exceeding 90%, encompassing solar converters and 48VDC inverters [8-10]. The researcher's certification and expertise in Unipower products underscore the feasibility of implementing a hybrid power source for the Smart Data Cabinet. The Smart Data Cabinet, powered by a hybrid source, holds tremendous potential for industry adoption. Given the prevalence of small to medium-scale data centers, this research project promises to positively impact economic development and environmental preservation. In the quest for sustainable data center operations, this study represents a pioneering step towards a greener, more energy-efficient future.

2. METHODOLOGY

The proposed hybrid solar power source is a multifaceted system comprising solar panels, rectifiers, and hybrid rectifiers. This integrated system not only acts as an uninterruptible power supply for servers and network equipment but also powers the precision cooling system and auxiliary components responsible for system monitoring and protection. The selection of these components draws heavily on the researcher's extensive industry experience, where similar hybrid power systems have been successfully employed to energize communication equipment at repeater or relay stations. While the specific customer and project details remain confidential due to non-disclosure agreements, the brand and model of the chosen components will be transparently disclosed in this research.

To comprehensively understand and evaluate the behavior of this hybrid power source, a detailed simulation will be conducted using the Matlab Simulink program. This simulation will allow for a dynamic assessment of the system's performance under various conditions and loads. Additionally, the capacity computation of the power supply components will be meticulously calculated based on their individual equipment specifications, ensuring optimal performance and reliability. By leveraging both practical industry experience and advanced simulation tools, this research aims to provide a robust and efficient hybrid solar power source solution for data centers, contributing to sustainable energy practices and reducing the environmental footprint of data center operations.

2.1 The Circuit Simulation

The simulation of the hybrid power supply for the Smart Data Cabinet is executed using the sophisticated Matlab Simulink simulation software [11].

To create a comprehensive Solar Hybrid Power Source within a 48VDC system circuit simulation, multiple concepts and techniques from these tutorials were seamlessly integrated. Please refer to Figure 2 for a detailed depiction of the complete circuit layout, while Figure 3 provides a visual representation of the circuit's intricacies using subsystems. This simulation framework not only reflects the depth of research and innovation but also underscores the commitment to developing a robust and efficient hybrid power solution for the Smart Data Cabinet.

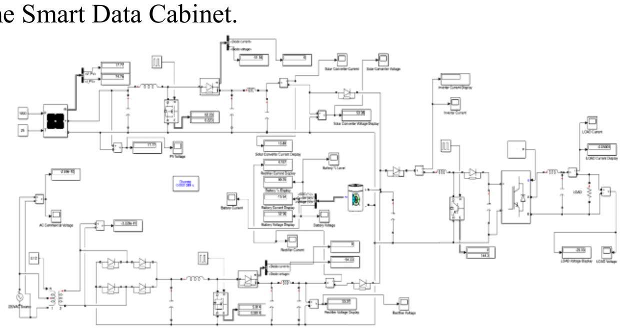

Figure 2. Complete circuit simulation of the Solar Hybrid Power Supply for the Smart Data Cabinet using 48VDC System.

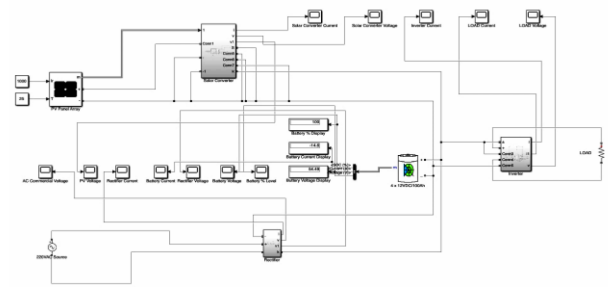

Figure 3. Subsystem Illustration of the Solar Hybrid Power Supply for the Smart Data Cabinet using 48VDC System.

2.2 Subsystem Components and Description

The core components of the hybrid solar power source for the Smart Data Cabinet are strategically configured to ensure efficient energy generation and utilization. Here's a breakdown of these vital components:

- **Solar Panels**: The system employs high-efficiency 320W solar panels with the model number Advance Power API-320. These panels are arranged in a series-parallel configuration, consisting of eight parallel sets, each comprising two panels connected in series. This arrangement results in a maximum input voltage of 73.2VDC from the solar panels.
- **Solar Converter (Controller):** The solar converter plays a crucial role in optimizing energy capture from the solar panels. Its primary objective is to maintain an output of approximately 54VDC from the solar panel power, which is ideal for charging four 12VDC / 100Ah lead-acid batteries connected in series. The solar converter output is designed to be slightly higher than the rectifier output, prioritizing solar power utilization whenever it's available.
- **Rectifier**: The rectifier complements the solar converter by converting 220VAC to a voltage slightly below 54VDC to efficiently charge the series-connected lead-acid batteries. To ensure seamless operation, the outputs of the solar converter and rectifier are connected in parallel, with the assistance of two blocking diodes.
- **Inverter**: The inverter takes the output from the solar converter and/or rectifier and converts it into clean, sinusoidal 220VAC voltage. This output is what powers the Smart Data Cabinet, providing a stable and reliable source of electricity.

The intelligent configuration and synchronization of these components demonstrate a well-designed hybrid solar power source system. This system not only maximizes the utilization of solar energy but also ensures the continuous operation of the Smart Data Cabinet, contributing to sustainable and eco-friendly data center practices.

2.3 Calculations

There are two computations or calculations involved in this research project, the calculation of the crucial electrical components used in the simulation circuit to attain the 48VDC bus system, and the capacity calculation in the selection of product model to be used in the prototype.

2.3.1 Model Circuit Components

The required ratings of inductor and capacitor were calculated through the given equations 1 and 2 shared from the video of Tech Simulator [12]:

Given:

- Rated Power = UPS + Cooling = 1,000W + 2,700W = 3,700W;
- Vinput = 36.6V x 2 = 73.2;
- Fsw = 5kHz;
- Voutput = 48V;
- Iripple = 10%
- Vripple = 1%
- Output Current = rated power / Voutput = 3,700W / 48V = 77A
- Current ripple (*Iripple*) = 10% of Output Current = 0.1 x 77A = 7.7A
- Voltage ripple *(Vripple)* = 1% of Output Voutput = 48V x 0.01 = 0.48V
- Inductance, L = $Voutput\ x\ (Vinput\ -\ Voutput)\ /\ (Fsw\ x\ Iripple\ x\ Vinput)$

Inductance, L = 48V (73.2V - 48V) / (5000 x 7.7A x 73.5V) = 429.2uH

- Capacitance, C = $Iripple\ /(8\ x\ Fsw\ x\ Vripple)$

Capacitance, C = 7.7A / (8 x 5000 x 0.48V) = 401uF

Other values and settings in the simulated circuit were just achieved due to experimental tuning to achieve the desired behavior and have an illustration pertaining to Solar Hybrid Power Source using 48VDC bus voltage.

2.3.2 Actual Equipment Capacity Sizing

Solar Hybrid Power Source is already available in the market and has been in the industry powering several telecommunication equipment. The actual component selection is done through capacity sizing to identify the specific model to cater the entire power requirement of a 1kW Smart Data Cabinet. The specific brand for the hybrid 48VDC power system is Unipower, a Singaporean company with over 30 years' experience in manufacturing DC power systems and is operating globally [13].

The prototype of the Smart Data Cabinet, along with its subcomponents and critical design features, are visually represented in the following figures:

- Figure 4: This illustration provides an overview of the Smart Data Cabinet prototype, showcasing its physical structure and key elements.
- Figure 5: In this detailed depiction, the subcomponents of the Smart Data Cabinet are highlighted, offering a closer look at the internal setup and arrangement.
- Figure 6: This figure offers insight into the control system and mechanical design of the Smart Data Cabinet, emphasizing the control interfaces and structural elements.
- Figure 7: The cooling system design inside the Smart Data Cabinet is elucidated in this illustration. It leverages the hot and cold aisle principle to optimize cooling efficiency and maintain ideal operating temperatures.

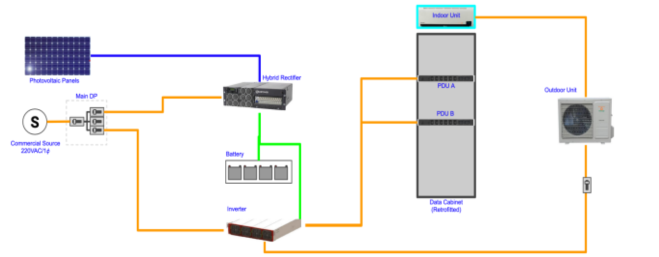

Figure 4. Solar Hybrid Power Source for Smart Data Cabinet

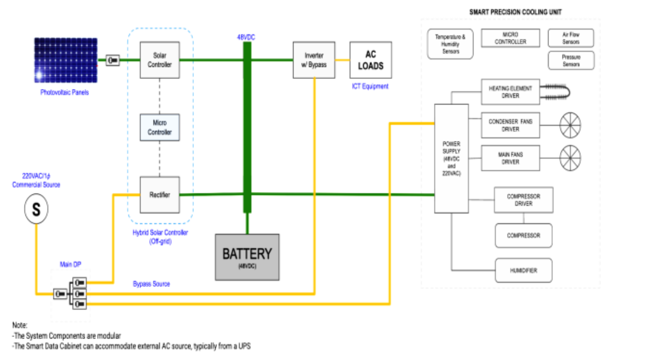

Figure 5. Illustration of the Solar Hybrid Power Source and the subcomponent of the Smart Data Cabinet

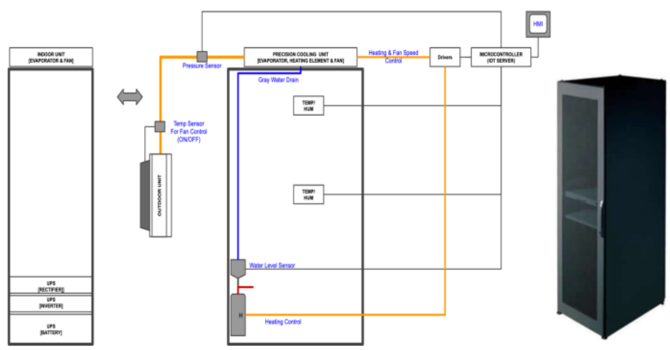

Figure 6. Control System and Mechanical Design illustration of the Smart Data Cabinet

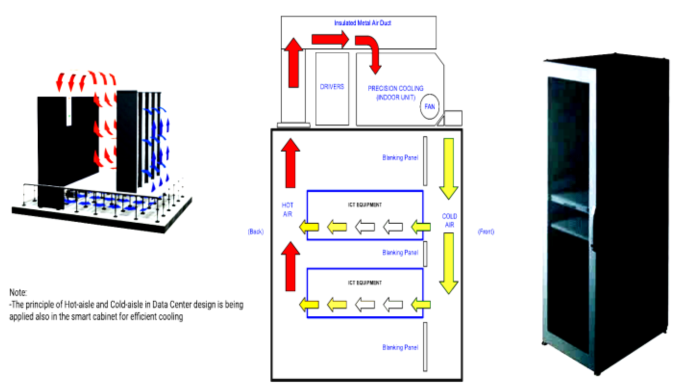

Figure 7. Cooling System Design | Airflow

Total Required Power is 3,700W from the capacity of the Information and Communication Technology (ICT) equipment which was pre-defined in this research up to 1kW and the precision cooling unit (PACU) will reach up to maximum of 2,700W, although non-continuous but the capacity is required to be included to avoid the current in-ruch effect during startups of compressors and heaters. The capacity of the rectifier will be based on the maximum total load: 3,700 multiplied with 1.25 (safety factor) resulting to 4,625W. At the Unipower website [8], since the available module has 62.5A or 3000W, we need 3 modules for an N+1 redundancy as shown in the computation below.

Total Module Capacity = Total Power requirement x 1.25 (safety factor)

Total Module Capacity = 3,700W x 1.25 = 4,625W;

4,625W / 3000W (per module) =

1.5417 units ≅ 2 units

Since we need redundancy, we will add another module with a model number: FMPe30.48J. Hence, there will be three (3) units of FMPe30.48J at 3000W/module.

In calculating the quantity of the solar panels, we will first choose a model with 320W similar to what we have used in Matlab simulation [14]. In the search for the solar panel, there is this product from Renogy, a Canadian company based in Ontario, that can be browsed through www.renogy.com. The capacity of the solar panel is 320W with output operating voltage at maximum power of 33.7VDC. Since the total power requirement is 4,625W, there is a need first to check the solar converter's input range required for the system to operate. The voltage operating range is 130V-300V and the solar panel operating voltage is 33.7V, hence, from the Equation 4, the quantity of RNG-320G solar panel is computed.

Operating voltage range/solar panel
operating voltage = Quantity of PV

300V / 33.7V = 8.9 pcs to provide allowance, the value is rounded down to 8 pcs.

The capacity of the inverter is calculated through the given capacity of the inverter module plus one redundant module. The capacity of the Bravo Inverter model is 2,400W since we need to energize 4,625W of loads, we need 3 units including the N+1 redundancy configuration.

3. RESULTS and DISCUSSION

In this section, we present two pivotal outcomes of our research:

(1) Simulation Results Using Matlab: The first outcome pertains to the simulation results obtained through the utilization of Matlab. This simulation serves as a crucial validation of the project's viability. It demonstrates the feasibility and performance of the proposed hybrid solar power source and its integration into the Smart Data Cabinet. Through Matlab's advanced modeling capabilities, we have assessed the system's behavior under various conditions, verifying its capability to efficiently harness solar energy, charge batteries, and deliver clean power to the Smart Data Cabinet.

(2) Bill of Quantities for Major Components: The second outcome is the comprehensive bill of quantities, (3) detailing the major components necessary for the actual implementation of the Smart Data Cabinet with its hybrid power source. This document includes specific models and capacities of the components required for the project's construction. By meticulously itemizing the essential equipment, such as solar panels, solar converters, rectifiers, inverters, and batteries, this bill of quantities offers transparency and clarity regarding the project's resource requirements.

3.1 Power System Simulation

With irradiance of 1000 and 220VAC input voltage at 80% battery level:

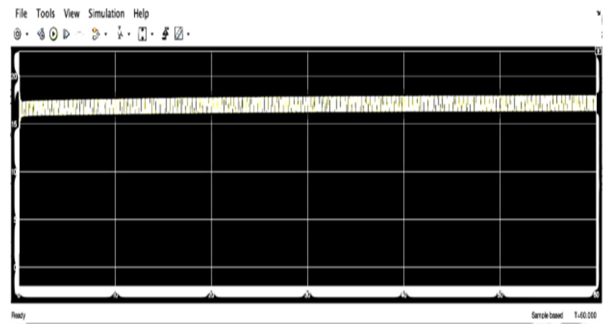

Figure 8. PV Voltage waveform at irradiance=1000, AC Input Voltage=220VAC, and battery level at 80%

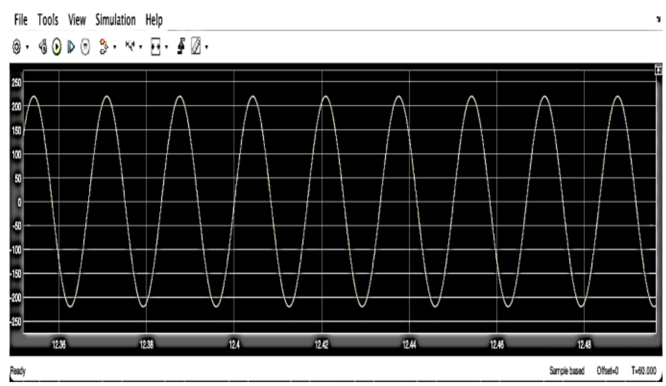

Figure 9. AC Input Voltage=220VAC

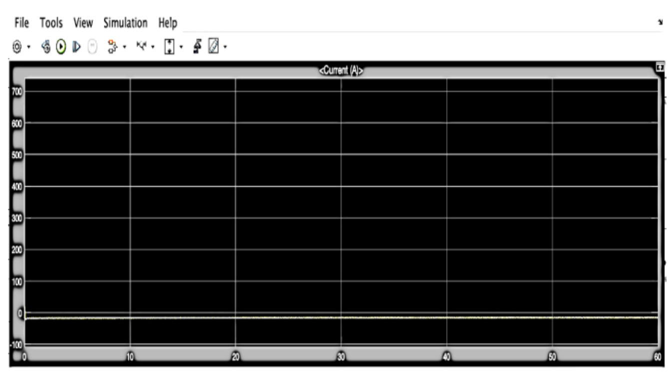

Figure 10. Battery Current waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

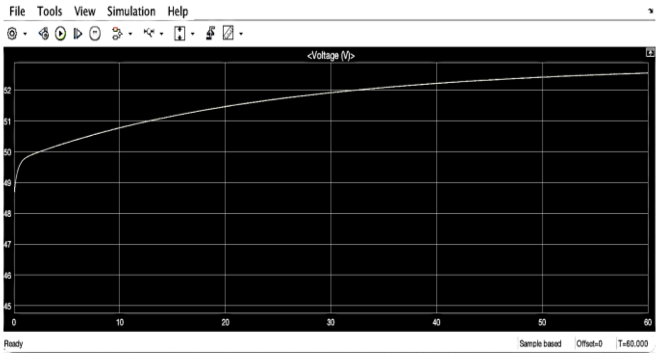

Figure 11. Battery Voltage waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

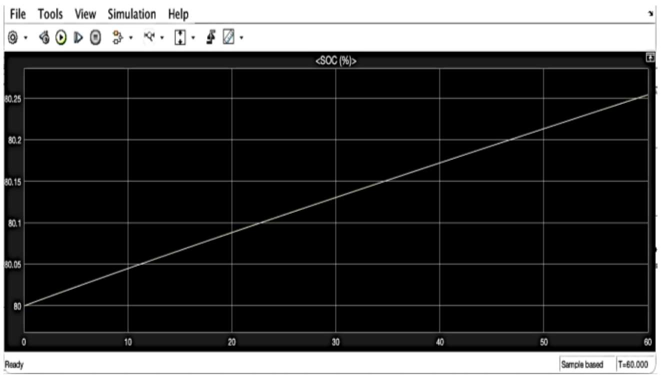

Figure 12. Battery Current waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

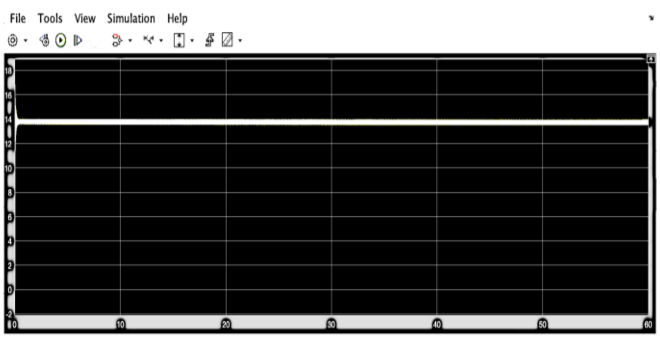

Figure 13. Solar Converter waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

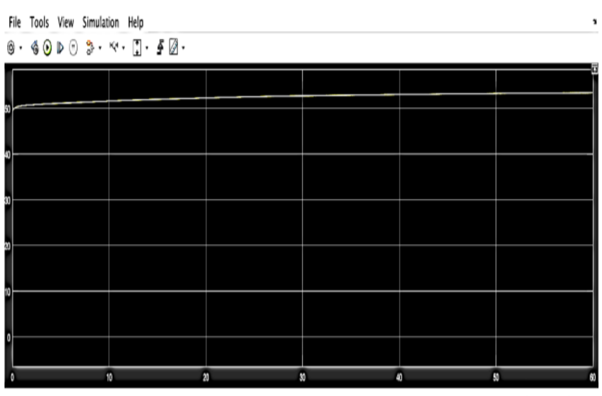

Figure 14. Solar converter waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

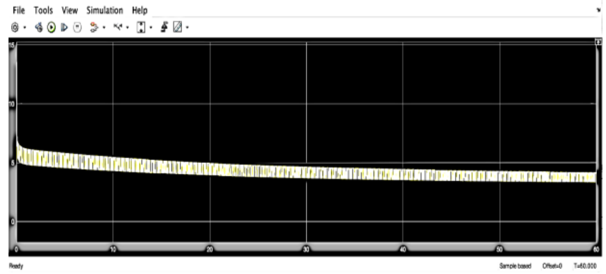

Figure 15. Rectifier Current waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

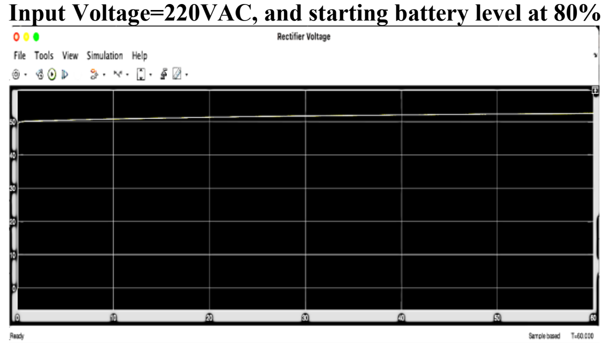

Figure 16. Rectifier Voltage waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

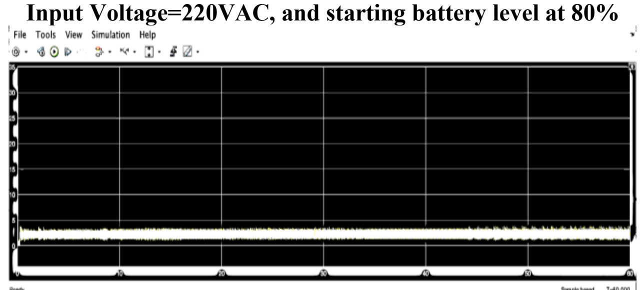

Figure 17. Battery Current waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

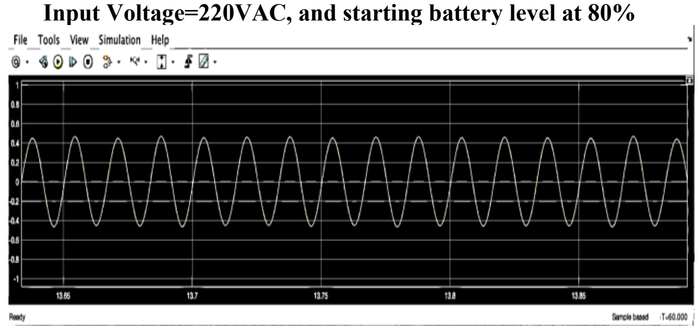

Figure 18. Load Current waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

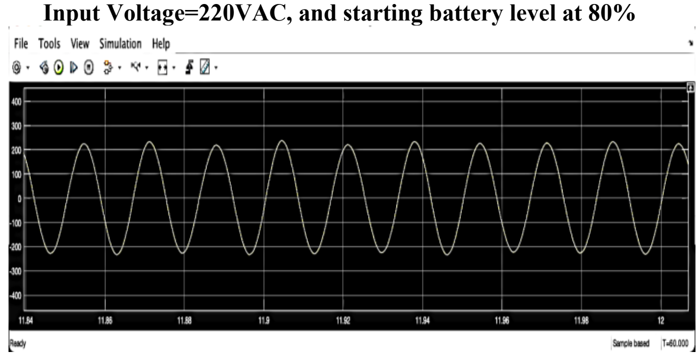

Figure 19. Load Voltage waveform at irradiance=1000, AC Input Voltage=220VAC, and starting battery level at 80%

Table 1: Simulation result summary

Irradiance	AC Input	Battery Level, %	Battery	Load Voltage	Dominant
1000	220VAC	80%	Charging	220VAC	Solar
500	220VAC	80%	Charging	220VAC	Solar
10	220VAC	80%	Charging	220VAC	Commercial
10	0VAC	80%	Dis charging	220VAC	Battery
500	0VAC	80%	Charging	220VAC	Solar
1000	0VAC	80%	Charging	220VAC	Solar
10	0VAC	5%	Dis charging	<220VAC	Battery

Table 2. Summary of Bill of Quantity

Item	Equipment	Capacity	Model	Quantity
1	Unipower Guardian Hybrid Subrack 19"/5U, 4-positions w/ ACX Controller		MS0031G*900059	1 set
2	Unipower Solar Converter	2900W	FPV30.48G	1 unit
3	Unipower Power Module	3000W	FMPe30.48G	1 unit
4	Inverter Subrack w/ Controller			1 set
5	Inverter	500VA	Bravo 4 – 48/230	2 units
6	Solar Panel	300W		14 units
7	Accessories			1 lot

The simulation results, as summarized in Table 1, unequivocally affirm the anticipated functionality of the system. It demonstrates a critical behavior: when there's ample sunlight, solar power takes precedence as the primary and dominant energy source, diligently supplying the load. It is noteworthy to mention that the simulation circuit currently lacks a Low Voltage Disconnect (LVD) circuit. The absence of an LVD circuit allows the simulation to continue supplying the load even when the battery is fully drained. In practice, an LVD circuit is essential as it safeguards the battery from complete depletion, thereby preventing potential damage. Fortunately, the actual Unipower rectifier subrack, which is slated for use in the Solar Hybrid Power Supply for the Smart Data Cabinet, incorporates this vital feature. The inclusion of the LVD circuit in the physical system will ensure that the battery is not excessively drained, thus preserving its health and longevity.

In essence, the simulation circuit effectively mirrors the expected behavior of the real-world component to be employed in the Solar Hybrid Power Supply for the Smart Data Cabinet, validating its reliability and adherence to best practices in battery management.

3.2 Bill of Quantity of the Components to be Used Based on Calculations

The proposed actual components that will be used for the system, which are already being used in the industry, have better performance and are already proven in terms of their efficiency and reliability.

4. CONCLUSION & RECOMMENDATIONS

This research represents a significant stride towards the advancement of data centers tailored for small to medium-scale applications, encompassing single cabinets to configurations of fewer than ten racks. It has made noteworthy contributions, particularly in terms of enhancing cooling efficiency. The distinct advantage lies in the dedicated cooling system tailored specifically for ICT equipment, excluding additional room-based heat loads. A standout characteristic of this system is its inherent modularity. This feature stands to streamline corrective maintenance processes during breakdowns, as system components are designed to be hot-swappable. This not only reduces downtime but also augments the overall reliability and availability of the Smart Data Cabinet, which is paramount for uninterrupted data center operations.

Moving forward, we recommend the implementation of this innovative project on a broader scale, with a focus on local production to stimulate economic growth. By fostering the development of these solar-powered Smart Data Cabinets within local communities, job creation opportunities can be realized, contributing to both regional and national economic expansion. Moreover, the primary ecological benefit of this project cannot be overstated. The integration of renewable energy sources and the reduction of greenhouse gas emissions align with global environmental conservation objectives. Embracing and supporting projects like this is not only a step towards sustainable data center practices but also a significant stride towards safeguarding our environment for future generations. We encourage further research and investment in similar initiatives to amplify the positive impact on both the economy and the environment.

5. ACKNOWLEDGEMENT

I thank the following individuals and organizations that assisted me accomplish this project research. To Dr. Ambrosio Cultura, the President of University of Science and Technology of Southern Philippines, for the visionary suggestion of utilizing solar power for Smart Data Cabinets, paving the way for this groundbreaking research; to Engr. Clark Darwin Gozon or generously sharing his expertise in microcontrollers and simulations, Engr. Gladdy Christine Compasan for assistance, to Dr. Lory Liza D. Bulay-og, my ever-supportive adviser, whose guidance and encouragement were instrumental throughout this research journey; to my InfiniteCare Technology Solutions, Inc. (iTSi) family; and also to Unipower for their products. Their unwavering support, guidance, and expertise have been pivotal in bringing this research to fruition, and for that, I am sincerely grateful.

6. REFERENCES

[1] Schaefer, M. and Dittmar, L. (2009, January). Electricity demand modeling of German data centers: Dealing with uncertainties. ISBN. 2-5. DOI:10.14279/depositonce-2296

[2] Wang, Y. (2020). Evaluating and modeling the energy impacts of data centers, in terms of hardware / software architecture and associated environment. https://tel.archives-ouvertes.fr/tel-02948725

[3] Childs, M. (2021, July). Reducing greenhouse gasses: our position. Friends of earth. https://policy.friendsoftheearth.uk/policy-positions/reducing-greenhouse-gases-our-position

[4] Center for Science Education. (2020). How do we reduce greenhouse gases? https://scied.ucar.edu/learning-zone/climate-solutions/reduce-greenhouse-gases

[5] Physics Today. (2021). The cost of solar energy production has plunged, but it needs to fall further. 74(6). 27. https://doi.org/10.1063/PT.3.4769

[6] Xingyu Bai (2021). Research on the application of renewable energy in dc data centers. Journal of Physics: Conference Series 2108 012054

[7] TechConsult (2008a). Installierte Serverbasis nach Branchen und Mitarbeitergrößenklassen. Kassel.

[8] 48VDC Rectifier Module Brochure, Unipower Corporation, https://unipowerco.com/pdf/fmpe3048j-ds.pdf

[9] 48VDC Solar Converter Brochure, Unipower Corporation, https://unipowerco.com/pdf/fpv3048-ds.pdf

[10] 48VDC Inverter Brochure, Unipower Corporation, https://unipowerco.com/pdf/eci48230-man.pdf

[11] Tech Simulator. (2020). Demonstration of maximum power point tracking using boost converter using Matlab. https://www.youtube.com/watch?v=o9BOrAHH5E4

[12] Urban School. (2021). Battery Charger using solar PV | boost converter | Matlab Simulink. https://www.youtube.com/watch?v=8JzP7Hf5NiA

[13] Unipower. https://unipowerco.com/company/

[14] All About EEE. (2022). Solar power generation for home using Matlab Simulink. https://www.youtube.com/watch?v=RQcMuLC8_DE

[15] Renogy multicrystalline solar panel brochure. https://m.media-amazon.com/images/I/B1IUTxlZXOS.pdf