DESIGN AND DEVELOPMENT OF A HYBRID SOLAR POWER TRAINER EQUIPMENT

Mustapha S. A.[1]*and Mahmud J. O.[1]
[1]NASENI Solar Energy Limited, Karshi, Abuja
Email: mustapha.sarafadeen@nsel.naseni.gov.ng*

ABSTRACT
The dearth of effective and indigenous manpower is a critical challenge facing the solar power industry in Nigeria. Several solar power training conducted lack well-structured hands-on practical scheme due to lack of appropriate equipment for the trainees. Therefore, this research work reports the design and development of a Hybrid Solar Power Trainer (HSPT) equipment using locally sourced materials. Double Diamond model was adopted where related research works were reviewed and then analyzed to have a well-defined goal leading to the design, development and implementation processes. The constructed HSPT equipment is detachable for ease of mobility. It also has the capability of simulating a typical household electrical wiring that is powered either by the grid supply/generator/solar power system or in their hybrid configuration for the purpose of teaching practical. The developed trainer was tested both on load and no load and generates stable outputs. The results of the tests show that the equipment can generate up to 894.6Wph, storage energy of 160Ah and can be used to conduct training for 12 hours at 65% depth of discharge before restoring state of charge. The quality of learning received by seventy-five trainees using the HSPT and assessed by five field expert was rated 90.55% and the quality and relevance of materials used was rated 92.25% making it to have high learning impact. This work will contribute to the improvement of the needed technical know-how in the solar power industry which will consequently increase confidence in the adoption of solar power technology in Nigeria.
Keywords: Solar Power Trainer, Electricity, Learning, Renewable energy

1.0 Introduction
Electricity is a very vital component for the development of socio-economic and technological activity of a nation. The epileptic electricity situation in Nigeria is such that the electricity demand far outweighs the supply which is causing hindrance to the nation's development[1]. Over the years, Nigeria has been very optimistic to solve the electricity challenge for the country which led to the drafting of various policies and strategies to achieve adequate and sustainable electricity for all through improvement in the energy mix [2][3]. Meanwhile, for the country to adequately match electricity supply to the rising demand there is need for investment in power generation infrastructure to attain 297,900MW by adding 11,686MW per year for 22 consecutive years [4]. Some of the realistic ways of achieving this feat is by decentralizing electricity generation, propagate the adoption of renewable energy for electricity generation and encourage distributed generation [5][6]. Researchers have proposed solar photovoltaic (PV) technology as a viable alternative source of electricity generation in Nigeria due to its abundance [7][8].
However, the dearth of adequate local human capacity in term of competence of the designers, installers, maintainers and other stakeholders of solar power systems in the solar energy industry in Nigeria is one of the identified challenges to the adoption of the technology [9].This calls for the need to develop capacity in the industry via qualitative training in orderfor Nigeria not to continuously rely on foreign technologies to ameliorate her challenges as seen in many sectors [10]. Although, several solar power training centers have sprung up, many of them lack well-structured practical scheme but rely more on theories. This calls for the need to adequately boost

the local human capacity required in the industry using locally developed infrastructures to conduct training tailored to follow the principles of instructional design as stated in [11][12].

This research work therefore aimed at further investigating the challenges to the adoption of solar power system relating to human capacity and reporting the design and development of a Hybrid Solar Power Trainer (HSPT) that is constructed with locally sourced materials for training purposes. The HSPT is a mobile and detachable equipment that consists of the basic components required for the design and installation of solar power system such as solar panels, charge controllers, inverters, storage batteries, electrical distribution board, electrical appliances and electrical tools used for a typical household electrical wiring. The HSPT is divided into three chambers. The load chamber contains the electrical loads such as bulbs and fans with their respective regulators as well as socket outlets. The power chamber is where the charge controllers, inverters, electrical distribution board and switch gear are fitted. The third chamber is the base chamber which houses the battery bank, electrical tools box, battery tester, a battery and inverter system to simulate hybrid connection to fuel powered generator. The HSPT affords learners to practically execute typical electrical wiring connections while learning off-grid and hybrid solar power systems. The use of the HSPT during training on solar power will improve the capacity to take jobs in the industry as well as improve the confidence in the adoption of solar power in Nigeria. The scope of this work is limited to trainer equipment.

This paper is divided into six sections; section one introduces the work while sections two and three present the literature review and material and methods respectively. Section four highlights the tests carried out as well as the discussion of the obtained results. Section five presents the conclusion.

2.0 Literature Review

In this section, review of related literatures is presented. Several research works by the authors in [13][14][15] highlighted numerous motivating factors that encourage the adoption of solar power system such as: stability of electricity supply, cost effectiveness in the long run as well as convenience in usage when compared to fossil fuel powered generators. However, some other factors have been serving as barrier factors hindering the adoption of solar power systems. Some of these barrier factors are presented in the research works by authors in[16][17][18] such as: high initial cost of installation of solar power systems, unregulated influx of substandard solar power products and inadequate required technical know-how in the industry. Meanwhile, in order to improve the solar power industry, one of the major areas in the solar PV value chain is training for improved required technical know-how [19]. Although, on the issue of technical know-how, different capacity building activities have sprung up in the solar power industry both online and physical organized by different organizations and training centres, the practical sessions however require upgrade [20]. Quality training is regarded as vital because human capital development is an inevitable needed tool if Nigeria must succeed in its effort to boost her citizens and the nation's laid down National Development Plan (NDP)[21][22].

In order to improve the needed technical know-how in the solar power system industry, researchers have designed and developed trainer kits and equipment of different operation conditions and limitations. In a research work by the authors in [23], sun simulator is used to direct light rays towards a 10Wp solar panel output from which measurement and data evaluation can be taken to study the current-voltage characteristics at various solar radiation. The development of solar educational training kit by the authors in [24] is designed for elementary studies on the use of solar cells as the basis for solar energy conversion to electricity. In a research presentation by [25], a solar PV power trainer was developed to be used as educational instrument in laboratory. It was designed for the purpose of investigating performance evaluation of balance of systems (BOS) and effects of environmental factors on solar PV modules at different tilt angles. The instrument will improve knowledge of trainees on the characteristics of BOS at different climatic conditions. In a critical review of commercially available trainer and experimental kits meant for teaching renewable energies by [26], products used by universities to teach solar energy and designed by solar energy trainers producers such as EDIBON, Lab-Volt, De Lorenzo and Hampden were reviewed. In a related work by authors in [27], learning kit was designed for training on solar power system with power generating capacity of 22.74W and estimated energy of 136WH. After the tests, the system was rated 89.59% for the quality training acquired using the kit used while it was scored 87.5% for the quality and relevance of materials used.

The review indicated that many of the trainers are for experimental purposes which are used to investigate balance of system (BOS) responses to solar radiation intensity. Others who are used to study the electrical wiring and configurations of solar panels and BOS are plug and play which are short of physical real life wiring and components experience for trainees.Also, they did not consider the use of the instrument to train on practical installations of solar PV power system for residential or commercial applications. Hence the need for a trainer which has the capability of being used for real life connections of solar power system and electrical wiring. This therefore led to this research work.

3.0 Material and Methods

In order to address the problems discovered in the reviewed literature, the Double Diamond Model (or the 4Ds model) of design thinking as presented in Figure 1 was used as the adopted methodology.

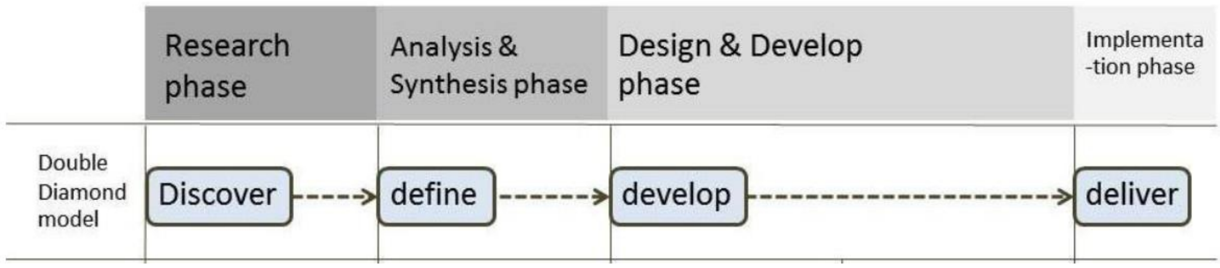

Figure 1: TheDouble Diamond Model Methodology [28]

The model consists of four steps which correspond to four phases of design thinking process as follows:

i. Discover (Research phase): The first step carried out was to identify the challenges in the solar power system industry through literature review in order to set research problem. This step afforded the opportunity to better discover variety of challenges demanding solutions while understanding them through various research opinions.
ii. Define (Analysis and Synthesis phase): The second step carried out in the methodology was to analyze the reviewed literature for the purpose of streamlining the investigation to a well-defined problem and precise goal. In this case, the development of a robust solar power trainer equipment to improve quality of technical know-how in the solar power industry.
iii. Develop (Design and Develop phase): In this step, brainstorming was done via discussions with five experienced solar power trainers on the needs assessment and different challenges being faced during training for effective training activities. This informed the design considerations: components availability in local market, compactness, detachability for mobility and use of mini modified

inverters, mini 12V/40Ah batteries, NSEL 80W solar panels as well as using locally available aluminum and light wood for the framework. In the design of the solar power trainer, the following were also carried out:

- The electrical load consist of two numbers of 12W bulbs and two numbers of 30W mini fans while socket outlets only indicate via LED making it to consume negligible power making the total load of 84W. It was estimated that the HSPT should be able to have battery backup time up to 12 training hours on full load at 0.8% efficiency and 65% depth of discharge (DOD). Also, the number of 80W solar panels is expected to restore the state of charge of the used batteries in 6 solar hours. This information was used as inputs to form the basis for sizing the HSPT as follows.
- The HSPT system sizing was calculated using equations (i) – (v) as stated in [29]:

$$System\ Energy = Total\ load\ x\ Usage\ hours \quad \text{(i)}$$
$$= 84W\ x\ 12h$$
$$= 1{,}008Wh$$

$$Number\ of\ batteries = \frac{System\ energy}{\text{Battery voltage x Battery capacity x DOD x Battery efficiency}} \quad \text{(ii)}$$
$$= \frac{1{,}008Wh}{\text{12V x 40Ah x 0.65 x 0.8}}$$
$$= \mathbf{4.03} \approx \text{ 4 batteries of 40Ah each are required}$$

The fifth battery is only used to demonstrate the connection of a fossil fuel generator in hybrid configuration.

$$Number\ of\ solar\ panels = \frac{System\ energy}{\text{Solar hours x solar panel power rating}} \quad \text{(iii)}$$
$$= \frac{1{,}008Wh}{\text{6h x 80W}}$$
$$= \mathbf{2.1} \approx \text{ 2 solar panels of 80W are required}$$

Considering 25% added tolerance;

$$Inverter\ capacity = Total\ load\ x\ 1.25 \quad \text{(iv)}$$
$$= 84W\ x\ 1.25$$
$$= \text{105W inverter capacity is required}$$

However, due to availability, 1000W mini modified inverter was chosen
Similarly, considering 25% added tolerance;

$$Charge\ controller\ capacity = Total\ solar\ panel\ short\ circuit\ current\ x\ 1.25 \quad \text{(v)}$$
$$= 5\ x\ 2\ x\ 1.25$$
$$= \text{12.5A charge controller current capacity is required}$$

Due to availability, 20A charge controller current capacity was considered.

- Using the sizing of each component in terms of space and after each component have been positioned in sketch, the HSPT was then drawn in 3D using AutoCAD as presented in Figure 2 with its dimensions as shown in Table 1.

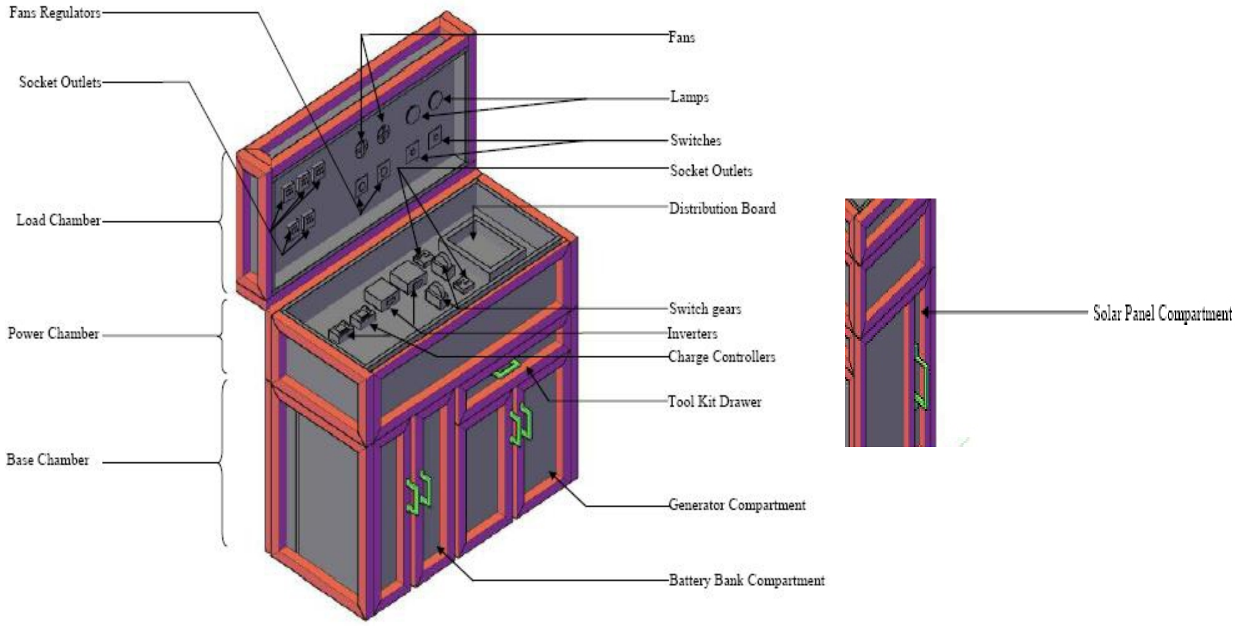

Figure 2: 3D Diagram of the HSPT

Table 1: Dimensions of the HSPT

Compartment	Length (m)	Breadth (m)	Height (m)
Load chamber	1.25	0.6	0.15
Power chamber	1.25	0.6	0.25
Base chamber	1.25	0.6	0.6

- The circuit diagram on how the electrical wiring will be carried out was then developed as shown in Figure 3. This shows how the solar panels are connected to the battery bank via the charge controllers, the inverter connection to the battery bank and supplying the electrical loads through the electrical distribution board. It also shows how the electricity supplies from mains and fossil fuel generator are hybridized to power the loads via a switch gear.

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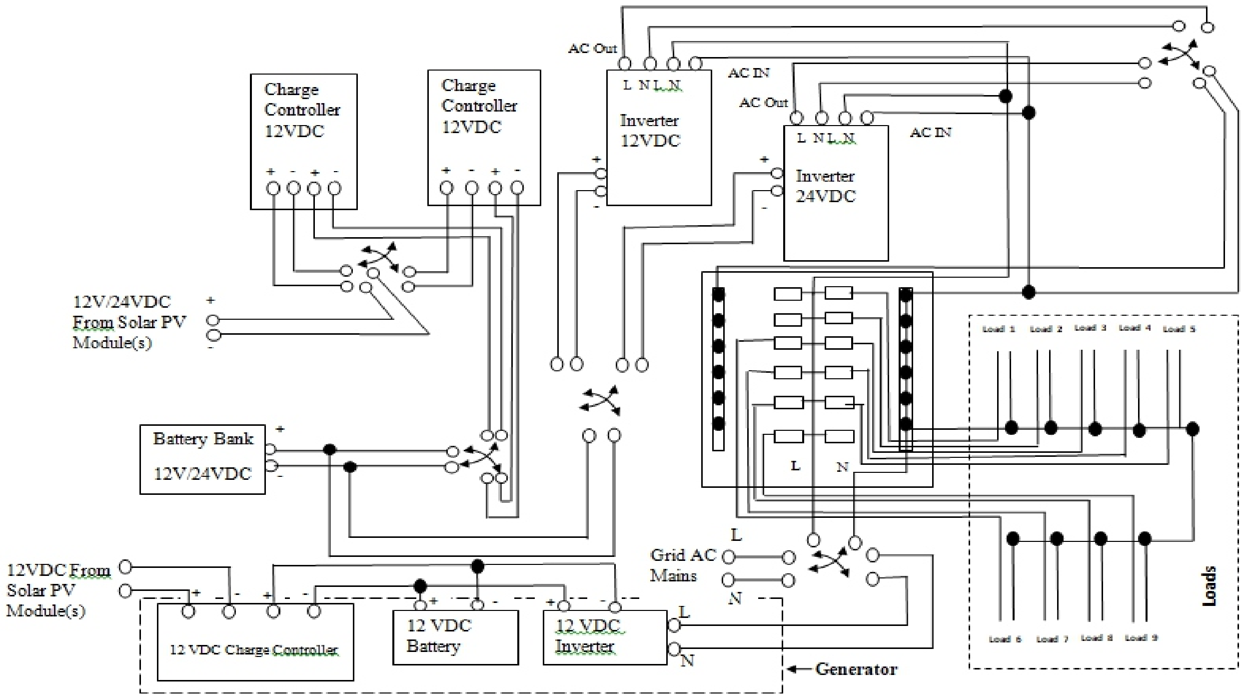

Figure 3: Electrical wiring of the HSPT

iv. Deliver (Implementation phase): This step in the methodology was the construction of the HSTP whereby the design stage was being implemented as shown in Figure 4. Figure 4A depicts the complete view of the outside structure of the HSPTwith the frames of the chambers made of aluminum bars embedded with plywood. Figure 4B shows the load chamber where the electrical loads and the power chamber where the charge controllers, inverters and electrical distribution board are fixed. Figure C shows the base chamber where the set of batteries are contained and the simulated generator system. Testing of the final equipment was carried out as presented in the following section.

B

A

C

Figure 4: Implemented HSPT

4.0 Results and Discussion

Upon completion of the construction, the HSPT was put to test and the result is presented in Table 2. The test was to determine the output functionality of the solar panels, inverter and the battery bank.

Table 2: Test results of the HSPT

	Solar panel			Inverter output					Battery	
				no load		on full load			on full load	
Temp. (°C)	Irradiance (W/m^2)	Short circuit current (A)	Open circuit voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Freq. (Hz)	Duration (H)	Voltage (V)
31	902	3.99	18	0	230	0.367	230	50	0	12.9
31	971	4	18.5	0	230	0.367	229	50	3	12.5
32	1001	4.2	18.5	0	230	0.367	229	50	6	12.42
32	1000	4.2	18.5	0	230	0.367	228.9	50	9	12.34
31	870	3.98	18	0	230	0.367	229	50	12	12.26

The result of the outdoor test of the solar panels in Table 2 shows that the two solar panels can generate up to an average of 149.1Wp (at 4.074A/18.3V each) and 894.6Wph in 6 hours/day at an average irradiance of 948.8W/m^2 and 31°C which is 93.2% of the solar panels power rating of a total 160Wp at standard test condition (STC). This indicates that the solar panels function optimally. Also, the inverter outputs were tested both on no load and on full load conditions. The result of the test shows that the output voltage, current and frequency of the inverter are averagely stable with only 0.43% in voltage drop on full load. Hence, the inverter system is appropriately functional. Similarly, the battery bank which has total energy storage of 160Ah was tested on full load for 12 hours as designed. The results show that after 12 hours, the battery still has 12.26V state of charge which is significantly good to elongate battery life.
Furthermore, the HSPT equipment was used to train seventy-five youth in Nigeria and assessed by five training experts. The HSPT equipment was rated an average of 90.55% in term of the quality of learning received and 92.25% in term of the quality and relevance of materials. The evaluation values shows that the learning outputs through the use of the HSPT are in the category of high feasibility with the capability of increasing trainees' learning significantly as in the work of [30]. This shows that based on the performance metrics above, the HSPT performs by 0.96% and 4.75% respectively better when compared to the work of the authors in [27].

5.0 Conclusion

Inadequate required skills for installers and designers of solar power systems as well as improperly structured practical sessions during training are some of the challenges facing the solar power industry in Nigeria. The design and development of a mobile and detachable solar power trainer that encompasses all basic components needed during installation of solar power systems to a typical residence and other related areas became imperative and executed in this work. The developed trainer equipment was tested and found to have daily outdoor generating capacity of 894.6Wph and storage energy of 104Ah at 65% depth of discharge when used to conduct training for 12 hours. The quality of learning received was rated 90.55% and the quality and relevance of materials used was rated 92.25%. This shows that the impact of the use of the equipment for training is highly significant which will improve the quality of human capacity in the solar power industry.

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