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Estimation of Loss and Cost of Characteristic Solar DC Distribution for Residential Household

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Abstract

DC networks for residential consumers have gained attraction in recent years, primarily due to building-integrated photovoltaics and increasing electronic loads coupled with the decreasing prices of DC appliances. The purpose of this project is to construct a prototype DC electrified house that can be usable in rural electrifications. More specifically, this project focuses on the development and construction of an efficient DC powered house by minimizing the losses in the conductor, cable length and total cost of the system and also to verify that both the cost and losses can be minimized with respect to conventional type solar powered AC system, as the inverter loss is omitted in the above system. In this project both simulation and hardware implementation both AC and DC powered houses are done. The results of this project serves as a proof that, the solar powered DC electrification is economically feasible compared to the conventional AC solar powered houses.

Keywords: *DC Network, Alternate current, Electrified house, Conductor, Solar power..*

1. Introduction

Energy is the basic need for people’s living standard for the development of socio- economic and enhancement. The energy consumption increased day by day due to became more developed. But the conventional energy system has a negative impact in our environment and which is also in the verge of exhaustion. The conventional distribution system for rural electrification is not that much fruitful to satisfy the electricity consumption for rural areas because rural villages are more far from the grid system [1-2]. In addition, the DISCOMS (corporations who is responsible for the distribution of electricity) do not give a priority for rural electrification since it does not directly lead to economic regeneration or increased productivity [3-4]. As per the census data of 2011 of the state of Odisha, 50.00 Lakh households are yet to electricity, mostly in the rural areas. The only way to provide electricity to these areas by renewable sources. Among the available renewable sources like wind energy, solar energy, fuel cells, geothermal energy; solar energy is easily available and less costly than others. The output of the solar cells are DC, which is an advantage as it can be easily integrate to the storage elements (batteries)without any power conversion [5-7].These storage power used to compensate the energy deficiency or store the extra energy whenever it required.

We know that most of the household appliances are internally operated on DC like led bulb, television, computer; so by converting DC to AC by inverter which are again internally converted to DC there are some unwanted loss occur. The energy generated by these photovoltaic cells can supply DC power directly to the DC appliances without converting to AC. By this method the wanted losses are avoided which provide a better power quality [8-9]. In this project, we envisage an energy-efficient house model which uses low-DC voltage Generated from PV sources to run household appliances. A novel scheme is proposed for efficient generation of power (<500 W) for home appliances with low voltage DC (24 V) for creation of an energy-efficient home for the future. In conventional solar powered AC system there are two stages of energy conversion occur from source to load (i.e. 1st stage DC to 230 v AC and then again 230 V ac to low voltage DC inside the equipment), which can be easily neglected by providing low voltage DC (24 V, 12 V) to the equipment, in this manner both losses and safety can be checked.

The feasibility of “low-voltage DC house for rural electrification” set within predefined boundary conditions is the subject of this report. The first part of the research has focused on simulation of a house with different types of load. The second part of the project concentrates on the hardware implementation of the above models.

2. Literature Review

- Thadani and Yun Ii Go [10] integrate clean energy into low-cost housing development for sustainable cities in Uganda and Indonesia. We propose an optimal energy system and examine the most significant design parameters that exhibit a desirable performance ratio and energy yield. This project was undertaken in two stages: energy yield estimation and detailed energy system design using two different software programs. Stage 1 aimed to estimate the energy yield based on the available roof area considering existing homes in Uganda and Indonesia. A photovoltaic (PV) array was designed with suitable inverters, tilt angles, and orientations. Stage 2 was intended to determine the optimal tilt angles. Five different PV systems were developed and tested using the optimal tilt angle determined earlier. Finally, an optimizer was integrated into the PV system to investigate potential improvements in the energy yield. The inclusion of an optimizer significantly increased the energy yield from 0.5% to 5.3%. For Uganda, the levelized cost of electricity (LCOE) with and without an optimizer ranged from $0.25/kWh to $0.36/kWh, whereas for Indonesia, the LCOE ranged from $0.25/kWh to $0.3/kWh. The amounts of carbon dioxide reduction were 173.894 t and 122.742 t in Indonesia and Uganda, respectively. The techno-economic outcome of this study serves as a reference model for other developing countries planning similar initiatives that can be replicated with local contextualization and assistive schemes

- Siraj, Hassan and Abbas [11] Khan Formulate a framework to analyze the impact of various voltages on residential system losses incorporating both distribution losses and power electronic conversion losses. Subsequently, we evaluate the system efficiency for a typical DC home at 48 V, 220 V, and 380 V DC and compare it with the 220 V AC using the developed analytical framework as well as through simulation. Results show that for a medium scale solar integrated house, the DC system at 220 V and 380 V is 4% and 10% more efficient than the AC 220 V system, respectively. Further, for 48 V DC, the system efficiency is higher than 380 V DC for wire size AWG-6 and beyond. While the efficiency depends on several factors such as conductor size, voltage selection, loads connected, and the solar capacity, the framework presented is the key in the quantification of losses and selection of suitable system components for DC home
- Y. Arafat et al [2] have worked on “Feasibility Study of Low-Voltage DC House and Compatible Home Appliance Design”. The research area is focused on the design of efficient kitchen appliances for a low-voltage DC supply. The outcome of this investigation is that, the 48V DC system with optimized cable area most economical and viable as compared with the 230V AC system and also save energy.
- N. Soorian et al [3] have worked on “Appliances in a low-voltage DC house - Low power solutions in the kitchen area”. The research concluded that, Low voltage DC can certainly save money for their users, cables of optimized thickness will guarantee that the losses due to high currents are kept low in the kitchen.
- H. Kakigano et al [12] has proposed The losses in the ac and dc micro grid systems for residential complex with PV system . The analysis results show that the whole losses of the dc system are around 15 % lower than that of the ac system for a year. Any electrical energy storages are not considered in both systems. If the energy storage is included, the loss reduction effect of dc distribution becomes higher than this result.
- Kuei-Hsiang Chao et al [13] have proposed a stand-alone photovoltaic power generation system framework for small-scale air-conditioners, and formulated a DC link voltage regulation strategy based on a bidirectional buck-boost converter combined with the charge and discharge functions of a battery. The DC link voltage not only maintains its set command value, but also supplies sufficient power for small-scale air-conditioners under insufficient irradiation through the charge and discharge functions of the battery. When higher levels of solar irradiation are provided, the excess energy is stored in the battery.
- Mark Cabaj [14] has experimented the parallel DC-DC converters, were assembled and tested to verify that they function properly for this purpose. Once all main components were selected, each one was tested to verify their functionality for the DC House model. Some of these other tests included testing the solar panel, DC drives, Motors, Generators, charge controller with battery, DC power distribution panel, buck converter, and appliances.

3. Overview of PV based AC and DC system

PV based AC system

Now-a-days most of the solar based house electrifications are AC based. In this system the power generated by solar panels are feed to DC-DC converters through MPPT algorithms and then the regulated DC voltage was further converted to 230 V AC which are feed to the household appliances [15]. But in this process there is unnecessary losses occurred in the inverting stage from DC to AC. As we know that the efficiency of the inverter is nearly equal to 80% at full load and even more at partially loaded condition [16]. So by this process there is unnecessary loses are occurred inside the inverter. Below figure 1 shows the power flow diagram of a PV based house electrification.

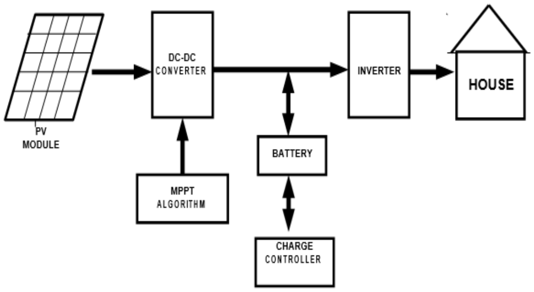

Figure 1: PV integrated AC house layout diagram

Advantages of AC house electrification

There are certain advantages of autonomous PV based AC houses; which are listed below [17]:

1. Due to high voltage i.e. 230 V the current carries by the conductors are less; which leads to lesser I2R losses and cost saving.
2. More familiar with the AC system.
3. Easily available of the AC household appliances.

Disadvantages of AC house electrification

There are certain disadvantages of using AC for house electrification. These are [18]:

1. Complexity in power calculation.
2. Have to maintain 50 Hz frequency across all equipment's.
3. We have to take care of the reactive power.
4. Due to skin effect the conductor size may increases.
5. Due to inverter the total system efficiency decreases and cost increases.
6. Due to reactance comes into account; there is unnecessary voltage drop occur.

Overview of PV based DC system

The DC House is designed to power a house in a village where there is no access to electricity. DC house allows unfortunate villages to improve their style of living. The DC power house will include various types of components like PV array, Battery charge controller with MPPT, Tubular battery and DC appliances. This autonomous DC house will be grid independent also called stand-alone system . Figure 2 mentioned below suggest the power flow through different stages of a DC house.

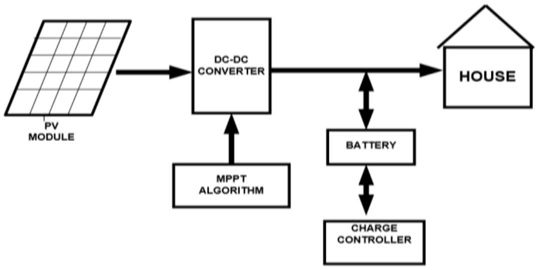

Figure 2: DC house layout diagram

The improvement in the area of power electronics have made a huge impact on DC powered rural electrification. There are many advantages for DC electrification; some of these are simple integration with the PV system (both operate on DC voltage), simple coupling with storage elements (i.e. Battery) and high power density. Many authors have investigated the feasibility of the implementation of DC in low and medium voltage systems. It can be concluded that if the if losses in DC-DC converter reduced, then the total system efficiency can be increased significantly. Generally the efficiency of the converter is varies between 80%-95% depends upon the manufacture.

Advantages of DC house electrification

There are many advantages of PV based DC house with respect to AC electrification .some of these are [6]:

1. Easily integration with the renewable sources of like solar energy.
2. Easily integration with the storage devices without any further energy conversion.
3. High power density.
4. Safety; Due to lesser voltage operation i.e. 24 V, 12 V.
5. No skin effect and no need to maintain frequency constant.
6. Less value of appliances rating than of AC appliances.
7. No need to convert voltage from one level to another i.e. DC-AC. So inverter loss omitted.

Disadvantages of DC house electrification

Although DC electrification have some disadvantages, these are not major ones. Which are listed below [6]:

1. DC appliances are not as much familiar as AC appliances.
2. Conductor size increases due to high current carrying compared to AC system, As in house electrification we use low voltage i.e. 24 V, 12 V.
3. Losses in the conductor increases.
4. DC transient occur during switching.

4. Methodology

To design a DC house the major components used are photovoltaic array, battery, battery charge controller and DC-DC converter with MPPT algorithm. Whereas in inverter used in the AC house model which is omitted in this case [19].

Photovoltaic array

The output of the PV array depends upon the irradiance level, environmental temperature and characteristic of the respective module. Before calculating the hourly output of PV module, the average hourly light intensity on horizontal surface should be converted to that on the PV module. Generally, Hay's model is used for this purpose.

In figure 6 the electrical model of a PV module shown with a current source connected across a diode. Where Rsh is the shunt resistance of the module and Rs is the series resistance.

To get the required output voltage and power we have to connected connect number of PV cells in series or parallel manner.to enhance the voltage rating cells should be connected in series and for current rating it should be in parallel.in this project we connected four number of PV modules in parallel to fulfill our requirement.

Below equation (1) and (2) shows the voltage rating and power rating of PV array:

$$V_{PVA} = N_{PVS} . V_{PV} \quad (1)$$

$$P_{PV} = N_{PVP} . N_{PVS} . V_{PV} . I_{PV} \quad (2)$$

Where N_{PVS} is total number of series connected PV modules and N_{PVP} is the total number of parallel connected PV module.

Figure 3: Front view of TP-280 PV panels

Figure 4: Four panels connected in parallel

To conduct the experiment, we used four number of PV panels in parallel to provide the load demand. The practical value of all the parameters are given in a tabular form below:

Nominal power output (W)	280
Power tolerance (W)	0-5
Module efficiency (ŋ%)	14.1
Voltage at PMAX VMPP (V)	36.1
Current at PMAX IMPP (A)	7.78
Open-circuit voltage VOC (V)	44.5
Short-circuit current ISC (A)	8.33
Actual Power output PMAX (W)	201.6
Actual Voltage at PMAX VMPP (V)	31.8
Actual Current at PMAX IMPP (A)	6.35
Actual Open-circuit voltage VOC (V)	39.2
Actual Short-circuit current ISC (A)	7.03
Number of cells & size	72 cell and 156 mm
Operating temperature range (ºC)	-40 to+85

MPPT Algorithm

The output current-voltage characteristics of solar arrays are nonlinear, and the operating conditions of the optimum PV power gained from the PV array is affected by solar irradiation, cell temperature and loading conditions. Therefore, a maximum power point tracking control is needed to continually match the PV internal resistance with the loading effect, hence ensuring that maximum power is transferred to the load].

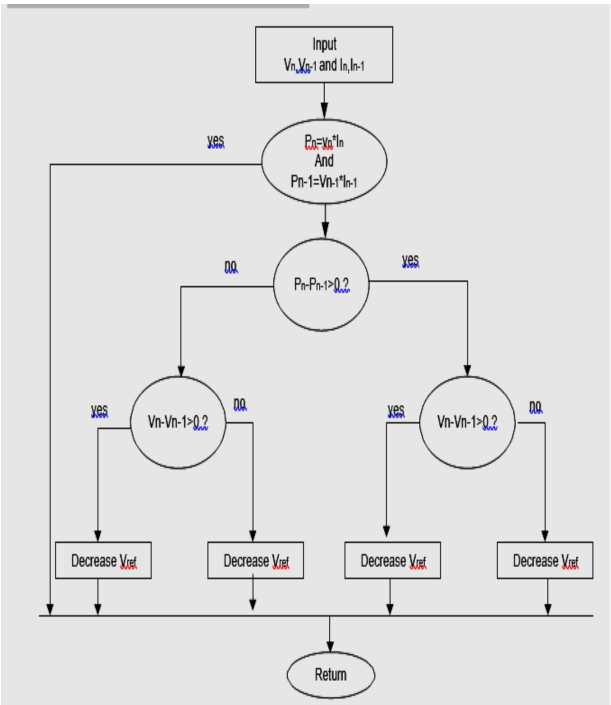

Figure 5: Flow chart for P and O MPPT algorithm [24]

To extract the maximum power from the PV panel, in this algorithm power at the two points of P-V curve compared and according to that, the reference voltage adjusted.

5. Experimental Setup and Result Analysis

Experimental Setup

In order to select the loads needed for the DC house it is important to consider the needs of the people living there and the humanitarian goals of the DC house project and weigh them against the constraints that an isolated generation system provides. First we should accurately define the limitations of our generation system, then develop a strategy to select the loads that can fit in those constraints. The following subsections discuss this issue.

House model

These models are classified according to their load rating (depends on the total no of equipment used).MM_1 model has 5 LED bulbs, 3 fans a television and a mixer. The total load demand is under 500 watts

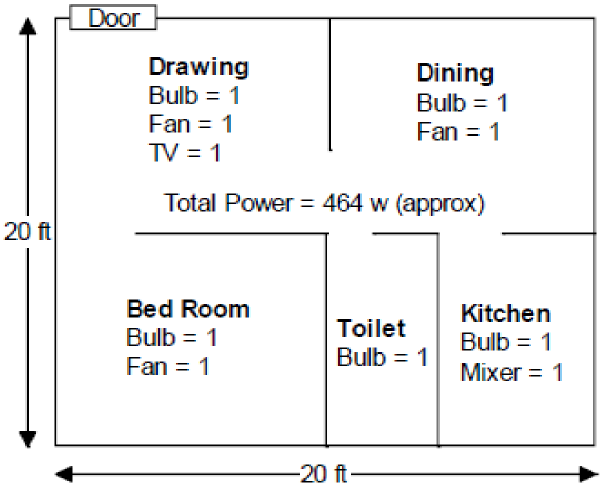

Figure 6: All loads for house model

Table 1: Rating of each load house

EQUIPMENT	QUANTITY	RATING
BULB	5	14
FAN	3	20
TELEVISION	1	25
MIXER	1	90

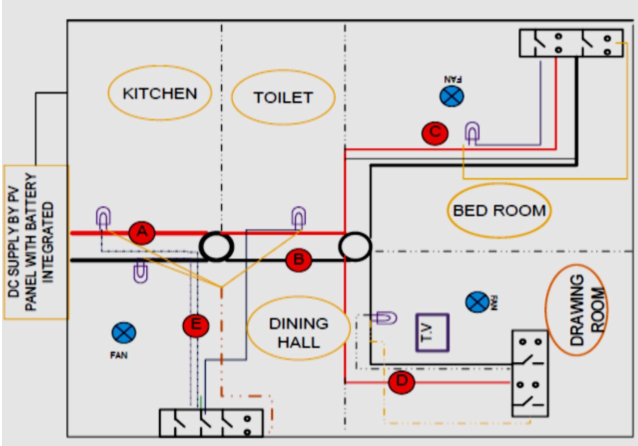

Figure 7: Total wiring diagram for house model

Figure 8: Hardware implementation of the DC house

Result Analysis

In this section we are going to discuss about the various aspects of DC electrification i.e. with PV and battery integration and with battery backup power only. First we are going to calculate the losses in the various section of the conductor in both the cases and compare it with the traditional standalone AC system. This experiment is conducted with and without solar power for six hours to study the case.

DC electrification with PV and Battery

To provide required power to the all the DC load of MM-1 model PN panel and battery circuit are provide power parallel. The six hour experimental data are given in tabular format in table 2.
From the data the losses in the charge controller circuit is only 23.19 watt. Whereas the line losses are increased due to high current rating as voltage level is very lesser than AC supply.

Table 2: Power delivered by all equipment's with both PV and Battery on

TIME (Hour)	PV			BATTERY			LOAD			LOSS IN CHARGE CONTROLLER (WATT)
	V (Volt)	I (amp)	P (watt)	V (Volt)	I (amp)	P (watt)	V (Volt)	I (amp)	P (watt)	
1	27.54	19.3	531.52	26.53	10.9	289.177	26.5	8.2	217.30	25.04
1.5	28.75	16.9	485.87	27.66	8.6	237.876	27.62	8.2	226.48	21.51
2	29.17	16.5	481.30	28.27	7.9	223.333	28.23	8.2	231.48	26.48
2.5	31.75	12.1	384.17	29.06	4.1	119.146	28.88	8.2	236.81	28.21
3	33.9	9.2	311.88	29.11	1.6	46.576	28.67	8.2	235.09	30.21
3.5	35.48	7.1	251.90	27.33	0.4	10.932	27.27	8.2	223.61	17.36
4	35.41	7.1	251.41	27.28	0.2	5.456	27.22	8.2	223.20	22.75
4.5	28.9	5.5	158.95	25.98	3.2	83.136	25.8	8.3	214.14	27.94
5	28.6	5.4	154.44	25.57	2.9	74.153	25.46	8.3	211.31	17.27
5.5	28.8	4.8	138.24	26.16	3.8	99.408	26.06	8.2	213.69	23.95
6	27.7	3.1	85.87	25.05	5.6	140.28	24.96	8.3	207.16	18.98
6.5	27.27	2.3	62.72	24.91	6.6	164.406	24.82	8.4	208.48	18.63
AVG									220.73	23.19

From the above experimental data it is shown that the average loss in the controller circuit when both the PV and battery power on is 23.19 watt. The power delivered/consumed curve for all the sections are given in the graphical format in figure.

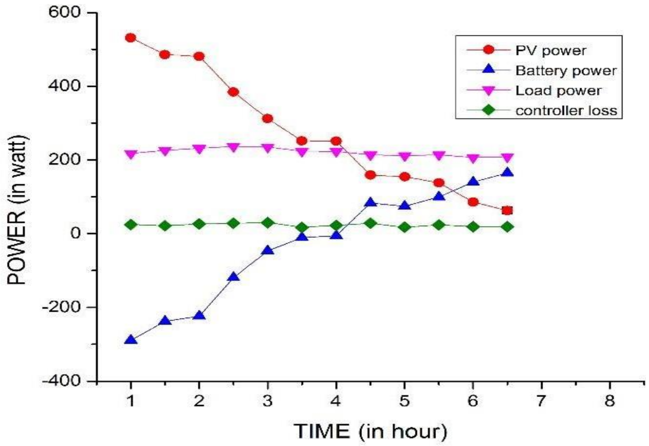

Figure 9: Power vs time curve for all the equipment's when both PV and Battery on

The simulation for the battery powered DC house with solar power are shown in figure 9. The load voltage wave form have some initial transients on it for some time which is later steady irrespective variation of PV array temperature and irradiance level shown in figure 9.

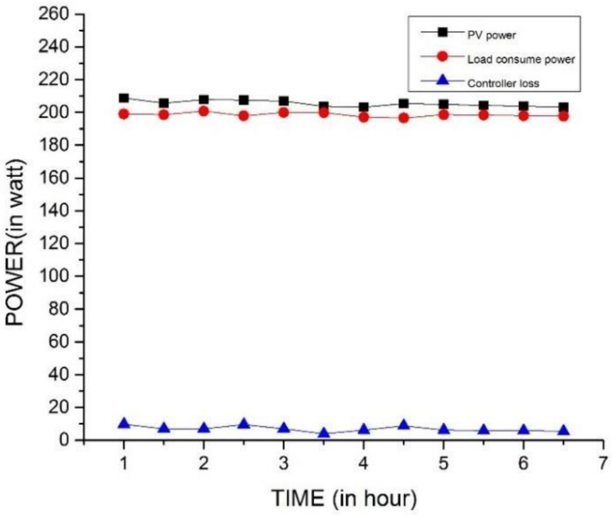

Figure 10: Power vs time curve for all the equipment's when only Battery on

5. Conclusion

This project demonstrated how a DC system was designed, modeled, and characterized steady state using the both hardware implementation and Simulink toolbox in MATLAB. This characterization provides a strong basis for future design decisions when the DC House is eventually constructed. This includes: the circuit configuration, and the bus voltage level (24 v) that produces the best efficiency for the best price. The Simulink model requires a relatively large initial investment in time to properly model all devices, however once complete can be easily tweaked to test for additional transient or steady state characterizations. The experimental setup is done using MATLAB toolbox and The proposed system is concluded that the initial cost involved for construct and design of DC house is slightly higher than that of AC system, although not much difference. However, the total loss involved in the DC system is less than that of conventional PV based AC system.

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