Study of DC electrification for future smart DC homes

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Abstract*– After decades of the traditional Distributed Grid, the microgrid are emerging as the new order on modern smart grids. However, due to the excessive use of DC to AC converters to allows the integration of renewable energy based on DC, as photovoltaic systems, researchers are now focus in studying the feasibility of implementing DC distribution on a given application, by involving DC microgrids in the future smart grids. These DC microgrids have control system advantages and their easy integration with IoT technology, makes it a real alternative in applications as future smart homes. This project aims to apply all the DC microgrids advantages to explore DC residential grid schemes for future smart DC homes. This work in progress paper is focus in the designing and implementation of a benchtop DC microgrid for testing proposes. The benchtop includes a 400W microturbine, PV generation, AC source and batteries for storage. A monitoring system was developed to visualize the power generation of the micro wind turbine as part of the development of the home energy management system. Preliminary results demonstrate the feasibility of DC electrification for future DC homes.

Keywords—DC Microgrid; Micro wind turbine; DC bus; DC homes; home energy management module.

I. Introduction

The amount of energy consumed in residential sectors in recent times is a serious concern to both utility providers and consumers. The United State Energy Information Administration (EIA) report for 2018 that about 1,464,373 million kWh of electricity was sold to residential consumers in 2018, the value amounts to about 50% of the total electricity sales to the four major sectors (residential, commercial, industrial and transport) considered [1]. Furthermore, according to [2], about 30% of global total energy consumption is currently being consumed within the home. One of the methods to achieve low expenditure on electricity bills without compromising electricity needs in the home is via home energy management systems (HEMS) schemes. HEMS schemes allow consumers to monitor, control and efficiently manage various household appliances energy consumption in response to Demand Response (DR). By effectively scheduling major household appliances, residents can spend less on electricity bills [3].

Energy consumption pattern of home appliances vary depending on properties such as operating periods, power rating and the specific duties of the appliances. However, some appliances exhibit similar patterns and hence can be grouped together. In recent years, authors have been focused on HEMS with and without Renewable Energy Sources (RES) to get system efficient and better management of energy. Different research works divide into three main categories: i) conventional system with no DSM; ii) DSM, smart grid and HEMS with RES; iii) DMS, smart grid, HEMS without RES. Results summarized in Table I reveal that HEMS with renewable energy gives more reduction in bills and peak to average ratio as compared to HEMS without RES. If we compare HEMS with and without RES to conventional approach, it shows significant difference in both systems. Self-generation makes users to purchase less grid power in high pricing peak hours. User can reduce bills and peak demand by using their own solar, wind and storage electricity without any discomfort [4].

TABLE I. Comparison of HEMS with and without RES

Proposed energy management scheme	Algorithm	HEMS, RES and storage results	HEMS, smart grid without RES results
Utility maximization with dynamic game behavior [5]	Fast distributed dual gradient	N/A	N/A
HEMS system with state of charge [6]	SOC based	28% reduction in bills	25% reduction in bills
Optimization ILP-based HEMS [7]	ILPHEM	55% bill reduction in one day with conventional system	40% bill reduction in one day with conventional system
HEMS with micro generation system [8]	MINLP-based architecture	Energy management 63% in summer and 38% in winter	Conventional approach
HEM with RES [9]	Incentive-based demand response	5kW reduce out of 14.8 grid power consumption in 6-9pm	6.7kW reduce out of 14.8 grid power consumption in 6-9pm
DSM and micro grid [10]	Stackelberg game and genetic algorithm	13% reduction in bills and 12% in PAR	N/A
HEMS with load-based pricing [11]	Energy tariff model	1.0504 $ per kWh	2.20221 $ per kWh

Actually, researchers are now focus in studying the feasibility of implementing DC distribution on a given application, by involving DC microgrids in the future smart grids. These DC microgrids could be a real alternative for future smart DC homes and in combination with HEMS, a significative reduction in bills will be expected. This work in progress paper presents a DC microgrid test bench that includes three sources (wind generation, PV, and AC source), DC and AC loads, and batteries. All elements are connected by a common DC bus. Preliminary results of the DC microgrid test bench and the monitoring system are presented as well.

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II. Experimental Procedure

There is no standard for the voltage bus of DC houses, but ones of the typical values are 24V and 48V. Preliminary studies were performed using a 12V DC bus as is shown in Figure 1:

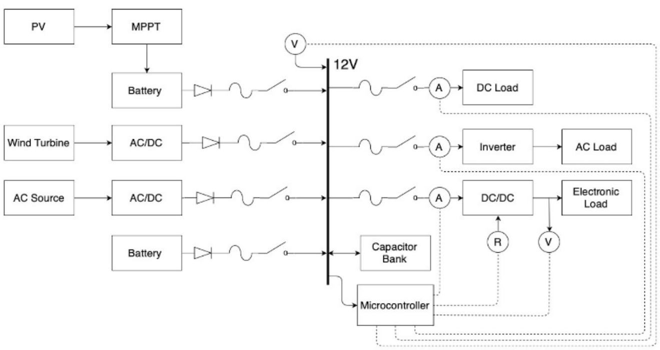

Fig. 1 Scheme of the proposed test bench.

In the test bench a micro-wind turbine (MWT) of 400W is used as a source. This turbine has been tested with a wind speed around 7.5m/s. An anemometer was previously located to verify the wind speed at the same place were the wind turbine will be installed. An electronic load was connected and adjusted from 3W to 12W, which indicates that the turbine could give enough power to small devices like a led and cellphone charger. In addition, four 24V/100W PV with MPPT are used as a source, and two deep cycle batteries of 12V/75Ah are connected for storage purposes.

To build the monitoring system, an Arduino microcontroller was programmed to read sensors connected to the control system and transmit this data to a Raspberry Pi via wireless through an xBee module. The Raspberry Pi also has an xBee module connected via the USB port to receive this data. Two python scripts were written. One of them which reads those values and stores them in a database written in sqlite3. The second script is an API written in the Flask microframework that will provide a JSON object with the latest information read from the database. To visualize those values, an open source web application named Freeboard will be used as a dashboard. This dashboard includes different types of graphs and will be automatically refreshed every minute. Figure 2 shows a block diagram of the preliminary monitoring system.

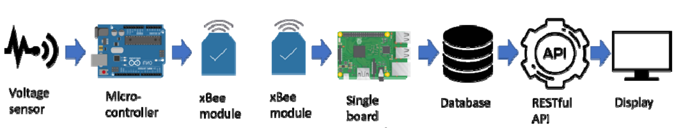

Fig. 2 Monitoring System Scheme

III. Preliminary Results

Figure 3 shows the test bench implemented [12]. An Arduino microcontroller will operate as the control system and will take decision based on the battery State of Charge (SOC). Voltage and current sensor will be continuously monitoring the voltage and current flowing in the whole system. An AC/DC converter was used to emulate the AC source.

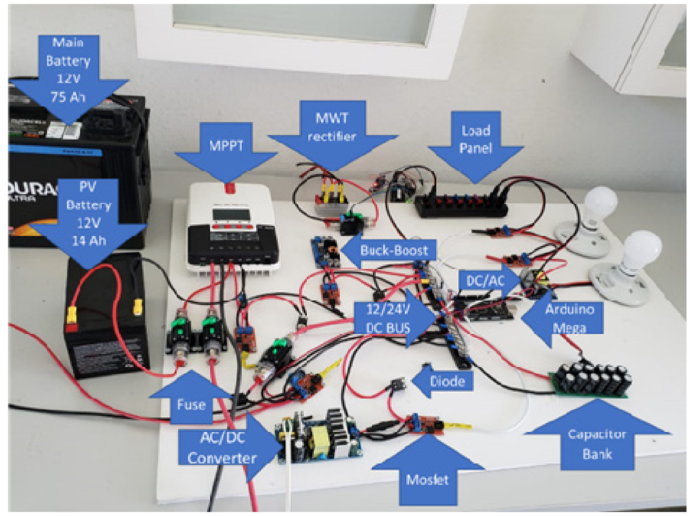

Fig. 3 Test bench implemented

Battery was discharged at different rates in order to study its behavior. Results demonstrate that each battery can supply during 6 hours a constant load demand of 7.5A (see Figure 4).

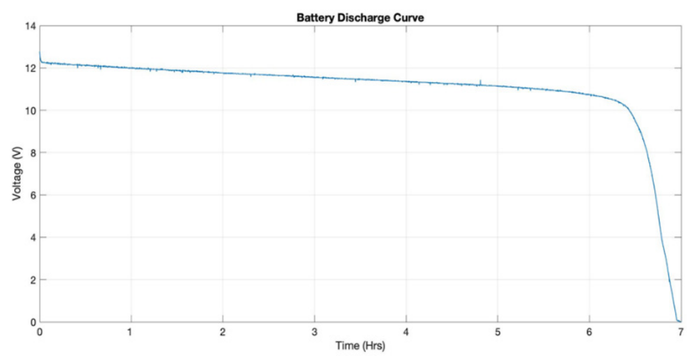

Fig. 4 Deep-cycle battery discharge curve at 0.1C

Wind data was collected by an anemometer in the same place where the MWT was located. Results show the good winds between 9am and 5pm, which represents around 7h of effective daily generation, approximately (see Figure 5).

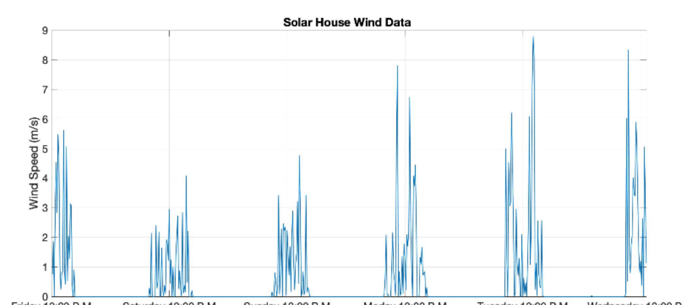

Fig. 5 On-site Wind data

Results demonstrate a good PV generation between 9am and 5pm, which represents around 8h of effective daily generation, approximately (see Figure 6).

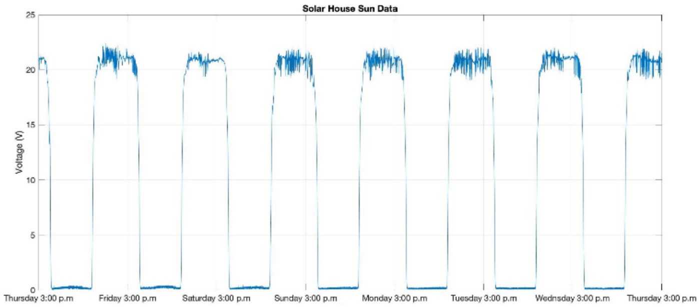

Fig. 6 PV generation measurements

Photos of the PV and MWT generation systems are presented in Photo 1 and Photo 2. PV was installed on the roof of an existing solar house in our institution while the MWT was installed at around 30 feet of height.

Photo 1. PV generation system

Photo 2. 400W micro wind turbine

To test the efficiency of a DC grid, we evaluated two popular cell phone chargers. Both cell phone chargers were connected to an AC outlet with a wattmeter and at the other end of the charger to an electronic load. The electronic load was adjusted until the wattmeter reaches the desired values. In the other hand, the electronic load displayed the actual used power in dc. Although the power loss of the chargers is small the test shows the expected efficiency for larger devices. Results are summarized in Table II and Table III.

TABLE II. Consumption analysis of Apple cellphone charger

AC	DC			
Power (W)	**Voltage (V)**	**Current (A)**	**Power (W)**	**Percent (%)**
1	5.0987	0.140	0.71	33.92
2	5.0548	0.290	1.47	30.55
3	5.008	0.445	2.23	29.45
4	4.96	0.602	3.99	28.9
5	4.91	0.755	3.71	29.62
6	4.87	0.902	4.39	30.99
Average difference percent = 30.57%				

TABLE III. Consumption analysis of Samsung cellphone charger

AC	DC			
Power (W)	**Voltage (V)**	**Current (A)**	**Power (W)**	**Percent (%)**
1	4.88	0.163	0.79	23.46
2	4.86	0.366	1.78	11.64
3	4.84	0.541	2.62	13.52
4	4.82	0.711	3.43	15.34
5	4.79	0.880	4.22	16.92
6	4.79	1.05	5.03	17.59
Average difference percent = 16.41%				

To test the monitoring system's voltage reading, we connected it to a power supply and provide it with a specific voltage and compare the values read by the monitoring system. The full system and test setup can be seen in figure 7. We tested various ranges for reading voltages. In this setup the power supply will provide a voltage that will be read by an Arduino. This micro-controller will read the voltage 10 times and will take an average and send the data via the xBee module. These values are received by the xBee module connected to the Raspberry Pi. On the Raspberry Pi the data is process by Python scripts that provide the latest data to an API which is called by the dashboard Freeboard. The ranges tested varied from 2.0V to 4.5V. After 15 minutes of taking measurements the largest difference of voltage readings was of 0.12V. We can see in Figure 7 that the display shows a timestamp for the last measurement taken the average voltage, the maximum voltage, a calculated wind speed and graphs of these values with respect to time.

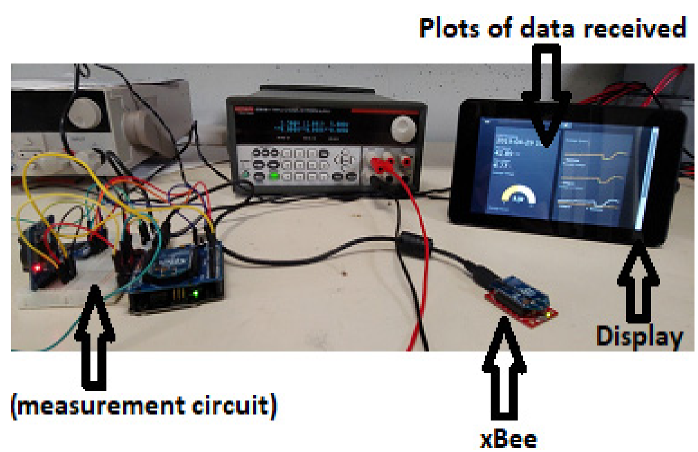

Fig. 7 Preliminary monitoring system

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IV. Conclusions and Future Work

A typical microgrid application focus on AC distribution although this method can be less efficient due to the excessive use of DC to AC conversion. While on DC microgrids are gaining popularity due to their expected efficiency gain. In this work in progress paper we propose a DC microgrid bench in which the behavior of a DC system is been tested. Preliminary results show improvements in efficiency and simpler integration of renewable sources. In addition, the integration of a monitoring system helps the user identify proper functionality as well as provide generation and consumption information, giving the user more control on his system.

As future work, the voltage on the bus bar will be increase to 24V to evaluate a more realistic scenario. More extensive tests that include the typical lighting of a home along with some fans will be included during the performance analysis. Real-time readings of the generation sources will bring to the system updated data which will allows to the control system take decisions based on more accurate information. In addition, a home energy management system will be implemented to the benchtop.

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