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DC grid for home applications

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Abstract. More than fifty percent Indian population do not have access to electricity in daily lives. The distance between the power generating stations and the distribution centers forms one of the main reasons for lack of electrification in rural and remote areas. Here lies the importance of decentralization of power generation through renewable energy resources. In the present world, electricity is predominantly powered by alternating current, but most day to day devices like LED lamps, computers and electrical vehicles, all run on DC power. By directly supplying DC to these loads, the number of power conversion stages was reduced, and overall system efficiency increases. Replacing existing AC network with DC is a humongous task, but with power electronic techniques, this project intends to implement DC grid at a household level in remote and rural areas. Proposed work was designed and simulated successfully for various loads amounting to 250 W through appropriate power electronic convertors. Maximum utilization of the renewable sources for domestic and commercial application was achieved with the proposed DC topology.

1. Introduction

According to World Energy Outlook 2015, almost 17% of the global population does not have access to electricity. Among them more than 300 million people belongs to the rural areas in India. However, over the past decade, with swift economic growth and many funded programs aiding energy access to these areas, thousands of people were able to electrify their homes. As of May 2016, 18452 villages in India are yet to be electrified. With fossil fuels rapidly losing its demand in the energy sector, economies are taking up more initiatives to harness maximum energy from renewable resources. For example by 2022, the Government of India aims at reaching 100 GW PV capacity from present statistics of 20 GW.

AC became the foundation of prevailing Power systems because of the ease with which it could be stepped up or stepped down during transmissions using transformers. Now, renewable energy is gaining more prominence in energy generation and revolutionizing the way electricity is being utilized in day-to-day lives. In this scenario, DC grid when implemented enjoys more advantages than an AC grid of same power rating such as reduced number of converters in every power conversion stages, constricted losses, easy merging with renewable energy sources and storage systems like batteries, less complexity etc.

Completely replacing the existing AC distribution grids with that of DC is unfeasible and expensive, but DC may become the ideal choice to power remote areas, also called "islands", which

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are not yet connected to the main power network[3]. These islands can be self-sufficient to meet their own power demands from renewable energy sources.

This work intends to implement a DC Grid that will enable a household in island areas to power commonly used household appliances using Solar PV. By this system, it is possible to eliminate unwanted power conversion stages and losses associated with it. This boasts of the overall system efficiency and reduces the complexity of the system. In addition, the performance and life of the devices will improve by this system [1,2]. The block diagram representation of the work is shown in Figure1.

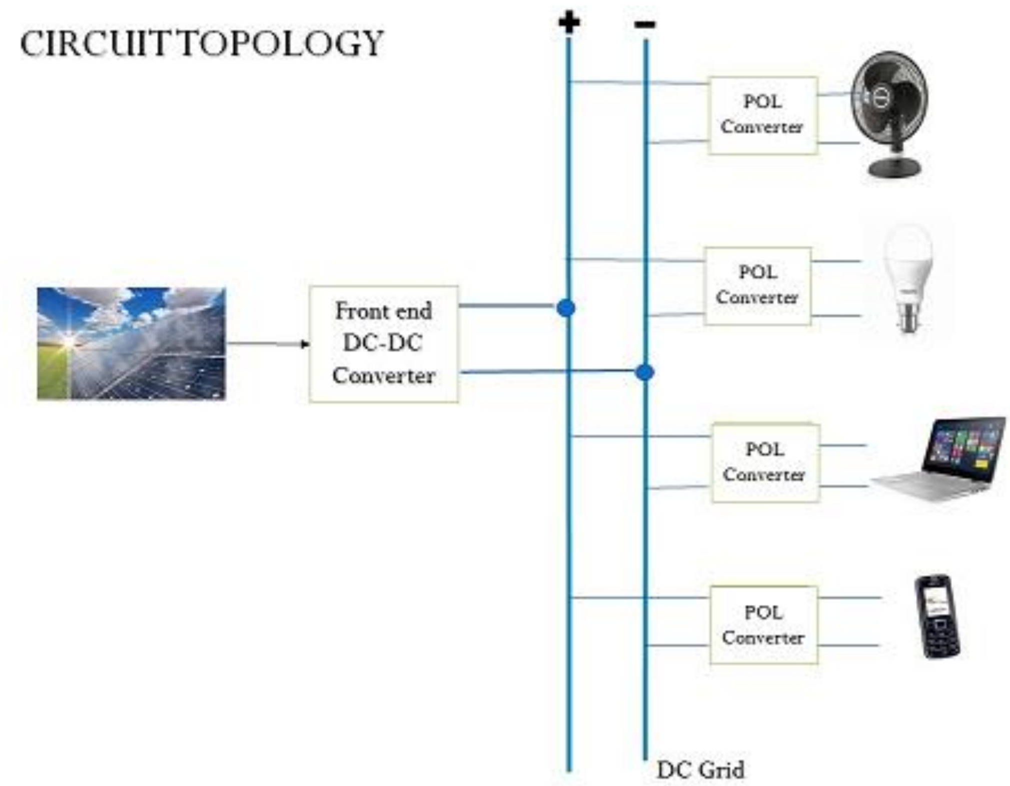

Figure 1. Proposed Model for Rural Home Electrification

2. Selection of bus voltage

Most of the household electrical equipment requires only low voltage DC that is conventionally obtained by stepping down and rectifying the AC supply [6]. Whereas the power produced by the renewable energy sources are generally low voltage DC [4,5]. A standard bus voltage is not specified for a typical DC micro grid. The loads chosen in this work has voltage ratings ranging from 5 V to 230 V. An optimum grid voltage of 72 V is fixed such that coherent conversion from the grid voltage to the rated voltage of the load is achieved [8].

The voltage expected from the solar panel is 24 V. An equivalent DC source of 24 V is used for simulation. The proposed system acknowledges the transmission losses of a low voltage (24 V DC) system by stepping up it to a 72 V DC using front end flyback converter. The 72 V grid voltage is then fed into assorted loads through Point of Load (POL) converters. The point of load converter can be a Buck or boost converter depending on the voltage specification of the load. The proposed model utilizes the loads as mentioned in the Table 1.

Table 1. Selection of loads for the proposed converter

Load	Power (w)	Voltage (v)	Duty ratio (%)	Point of load converter
DC Fan	90	48	66.7	Buck
Mobile charger	5	5	6.9	Buck
Laptop	65	19	26.38	Buck
Led 1	9	240	70	Boost
Led 2	9	240	70	Boost

3. Front end DC to DC Converter

As the solar panel output is expected around 24 V, we need to boost the voltage level to 72 V to connect to grid. Flyback topology that can provide galvanic isolation between input and grid is used as front-end convertor for the proposed work. It is based on primary buck- boost convertor topology. The overall circuit topology of flyback convertor is simpler than other SMPS circuits [7]. As this convertor has the least number of components and lower cost, this topology is very popular. The circuit can operate for a wide range of variations in input voltage and can offer single or multiple isolated voltage outputs. For a flyback convertor, for an input of 24 V and output of 72 V, Duty cycle ratio is 0.428. The front-end convertor can drive a total load of 250 W. An isolation transformer of 1:4 turns ratio is used for the proposed work. The supply side inductor for the flyback convertor having 10% tolerance in inductor current was designed to be100 µH. For a switching frequency of 50 kHz, and 1% voltage ripple, the grid side capacitor is designed as 500 µF.

4. High voltage loads

The voltage requirement of a high voltage load is supplied through a simple boost converter that is cost effective and simplifies the network. For the rural lightening a 9 W Syska B22 LED lamp having voltage rating of 240 V DC is chosen to be supplied through a boost converter designed for a maximum voltage ripple of 1% of specified voltage and current ripple of 10% of rated current output.. Figure2 below shows the proposed schematic for the high voltage loads. The Table 2 shows the calculated values of inductance and capacitance.

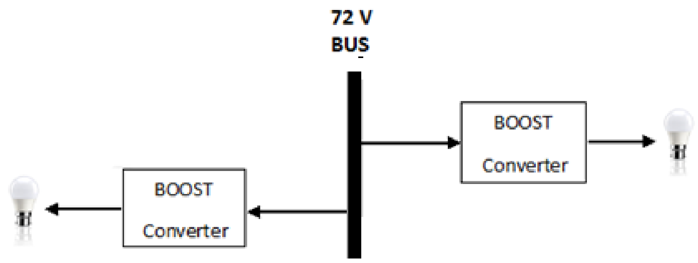

Figure 2. Proposed Schematic for High Voltage Loads

5. Low voltage loads

The load taken here includes a Mobile charger, DC fan and Laptop. These loads inherently require a ripple free DC voltage that is conventionally obtained by high quality rectification stages and boost power factor correction circuitry, makes the whole system bulky and costly[5]. By using a buck converter to interface the high voltage DC in the proposed topology, it is possible to obtain a high quality DC output, which reduces the manufacturing cost, size and improves the life of the equipment [4].

It is often observed in rural areas that due to long distance between nearest distribution transformer to the load end, the voltage obtained is 20-25% lower than the national standards. Operating Induction

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motors generally used in fans at such a huge difference from the standard voltage causes more iron losses and possibility of thermal breakdown in motor [6]. The Induction motor when replaced by a BLDC motor in the DC Fan and supplied by a buck converter with a voltage fluctuation of 1% gives higher power density, higher torque, extended operating life due to absence of brushes, reduced electromagnetic emission and simple control. Figure3 below shows the proposed schematic for the high voltage loads. The Table 2. shows the calculated values of inductance and capacitance for each of the converters.

Table 2. Calculted Values of Duty Cycle Ratio, Inductance, Capacitance, for Various Convertors that Power loads

LOAD	Rating	Duty cycle	Type of converter	Inductance value in the converter	Capacitance value in the converter
DC FAN	90W, 48V	66.7	BUCK	1.69mH	$1\mu F$
MOBILE CHARGER	5W, 5V	6.9	BUCK	1mH	$5\mu F$
LAPTOP	65W, 19V	28.38	BUCK	1mH	$5\mu F$
LED1, LED2	9W, 240V	70	BOOST	80mH	$0.5\mu F$
LOAD	Rating	Duty cycle	Type of converter	Inductance value in the converter	Capacitance value in the converter

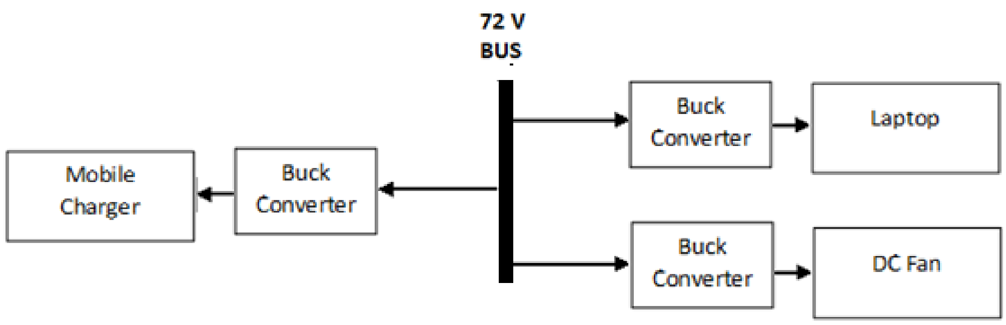

Figure 3. Proposed Schematic for Low Voltage Loads

6. Gate Pulses

Gate pulses are generated using d Space 1104 kit at a frequency of 50 KHz for all the converters. Pulse for the converters was generated by using PWM technique from d Space.Four ports of the dSPACE PWM output were used to get four pulses of the DC micro grid system, with the calculated Duty cycle as in the table. Required gate pulses are shown in the Figure 4.

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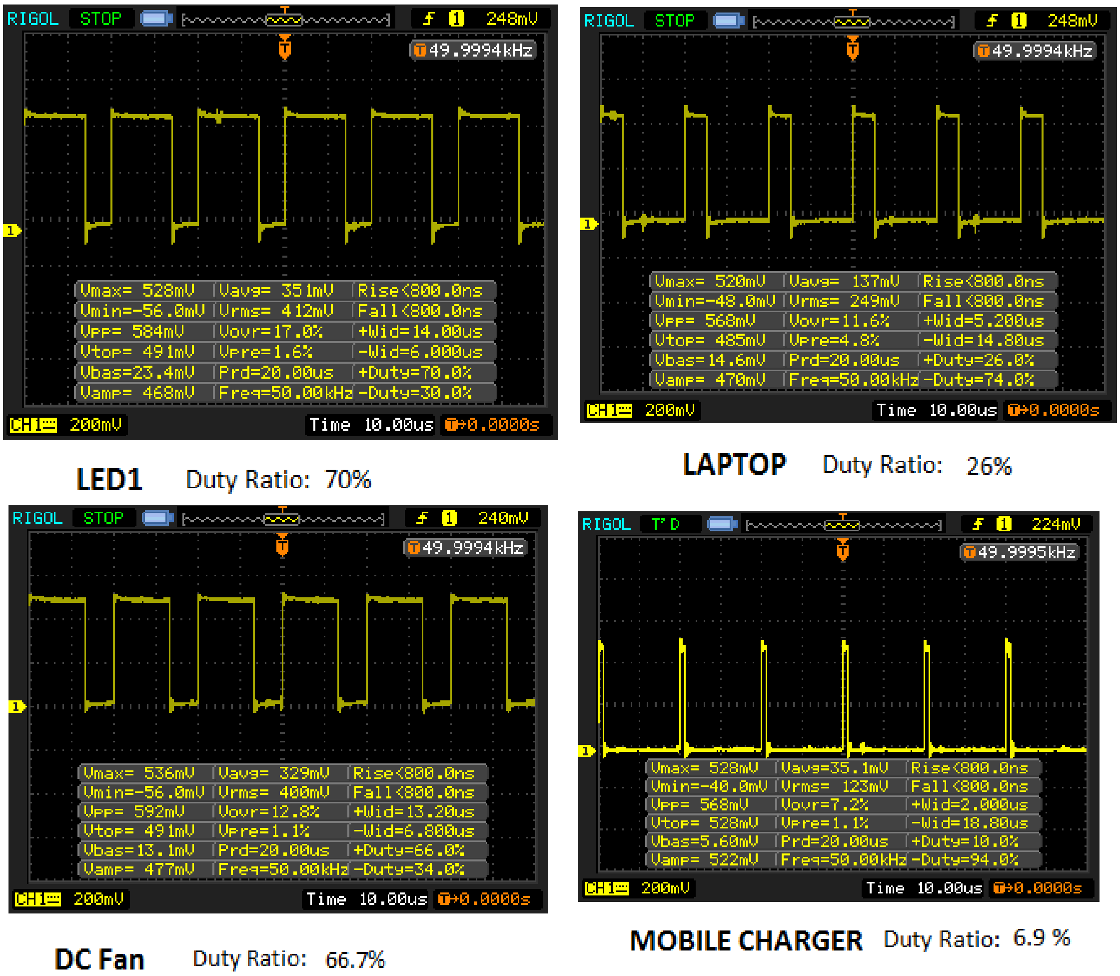

Figure 4. Duty cycle Ratios of Flyback Convertor and Respective Loads

7. Simulation Results

The proposed system was simulated using PSIM Professional Version 9.1.1.400. The system consists of six DC-DC converters in total. The proposed work uses a 72 V_{DC} bus for the electrifying grid. The complete system is designed such that it can power a maximum wattage of 250 W. Total loads of 178 W is connected to grid, and are powered by appropriate power convertor topologies.

The power conversion in the proposed topology starts with a flyback topology, which is selected as a front-end convertor that can step up 24 V to 72 V. The input of 24 V is fed from a DC voltage source. The flyback converter can feed a total load of 178 W as can be seen in Figure 5.

The Point of load convertors starts with two boost convertor that powers 9 W 240 V LED bulb each. The simulation results for the two boost convertor powering LED bulbs is seen in Figure 6. Figure 7 shows the simulation results for buck convertor powering a laptop of 65 W, 19 V. A buck convertor is also designed to energize a mobile charger of 5 V, 5 W and simulation results is as seen in Figure 8. Another buck convertor feeds a DC fan of 90 W, 48 V and Figure 9 shows the simulation results.

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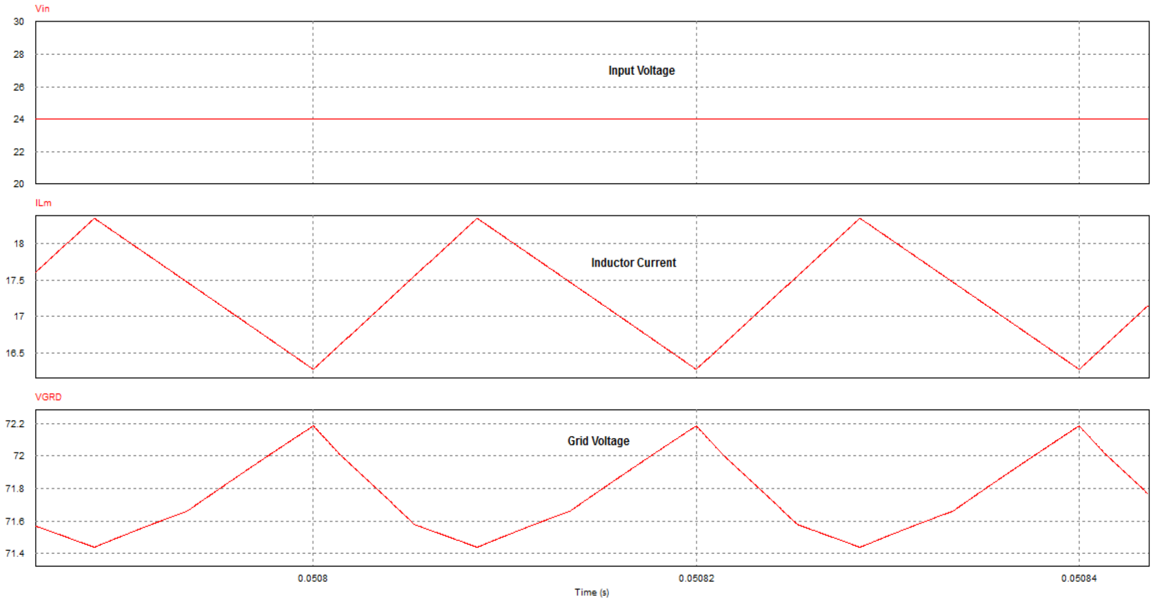

Figure 5. Input Voltage, Grid Voltage, Inductor current of Front End convertor

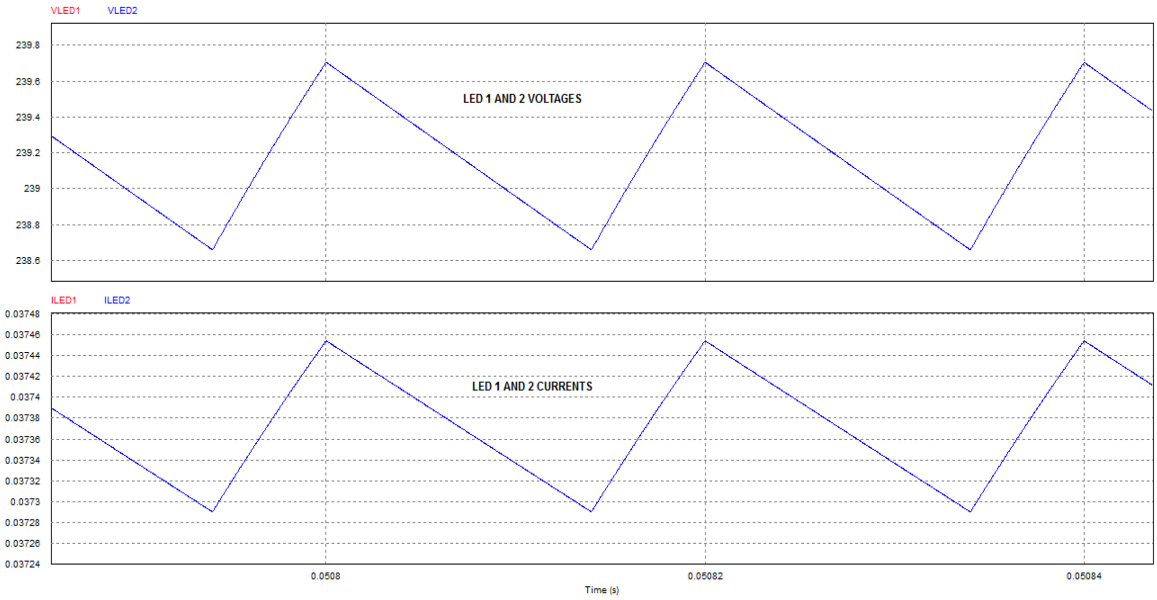

Figure6. Output Voltages, Output currents of Boost Convertors Feeding LED's

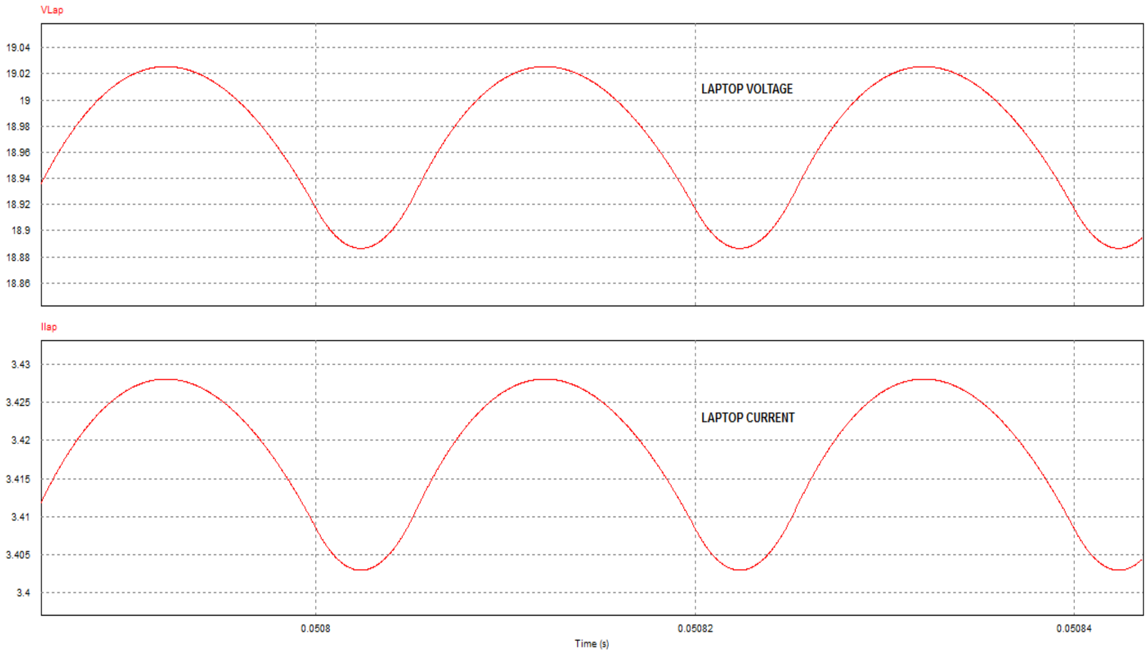

Figure7. Output Voltage, Output Current of Buck Convertors Feeding Laptop

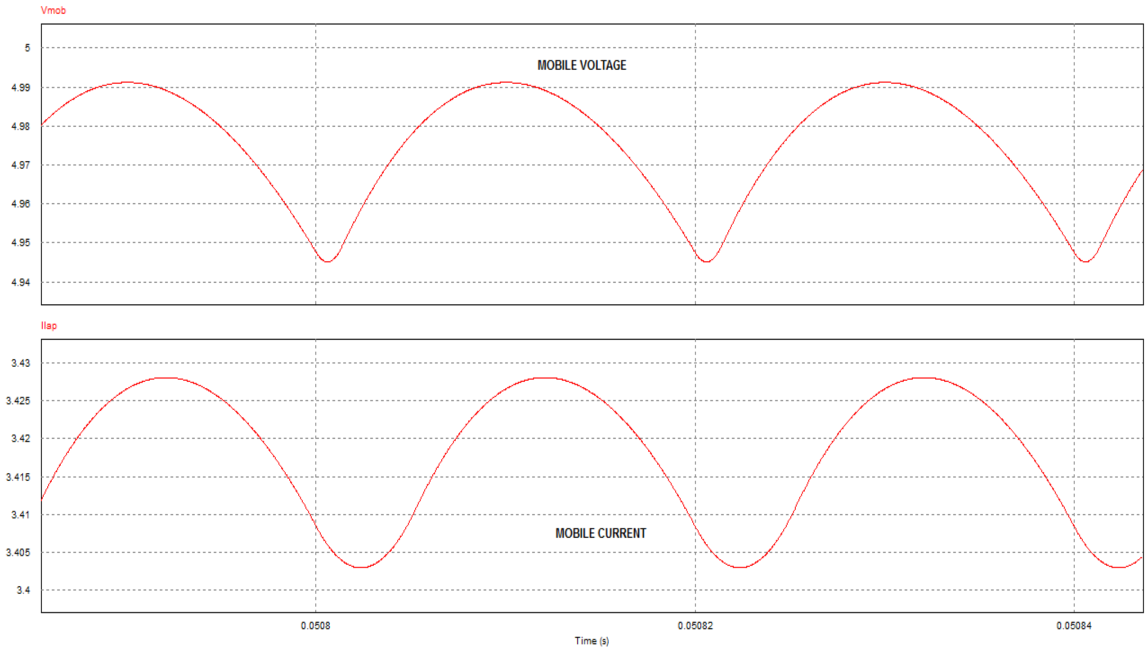

Figure8. Output Voltage, Output Current of Buck Convertors Feeding Mobile Charger

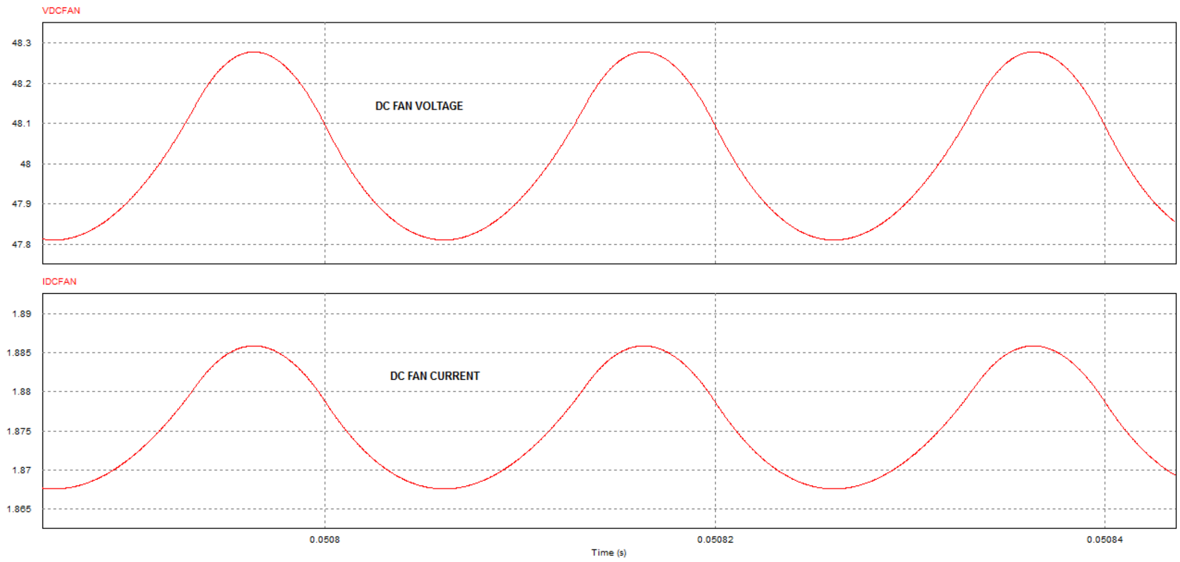

Figure9. Output Voltage, Output Current of Buck Convertors Feeding Mobile Charge

8. Conclusion

This paper presents the designing and simulation of a DC Grid that enables a rural household to power load less than 250 W on its own using a DC source. The DC-DC point of load converters were successfully integrated with the grid of 72 V. This grid is able to bring out the numerous advantages that a DC grid system enjoys over the conventional AC main grid, the important one being able to reduce the number of converters at the load side. DC grid is taken as 72 V since no particular standards. On simulating, the grid voltage was found to be 71.75 V. The converters at each stage were designed and the required voltage levels were obtained. From the simulation results, it can be concluded that the proposed model was able to achieve the power ratings required by each of the loads. The hardware implementation is in progress and the pulses required for the switches in each of the converters were obtained using dSPACE 1104 kit. The scope of this work can be extended on a commercial basis by implementing it on a large scale to power up individual houses in island areas there by facilitating 0% unpowered villages.

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