Hybrid Renewable Energy Sources based Mobile Charging Unit for Public Usage

Kandi Bhanu Prakash[1], *Suresh Kakinatla*[2], *Sankara Rao Burada*[3], *and Siva Ganesh Malla*[4*]

[1,2,3] Research and Development unit, ERG Foundation, Anakapalli, Andhra Pradesh, India.
[4]Director, ERG Foundation, Anakapalli, Andhra Pradesh, India.
[1]kandibhanu@erg.org.in; ORCID: 0009-0006-1531-4151.
[2]suresh@erg.org.in; ORCID: 0009-0003-5903-9591.
[3]sankararao@erg.org.in; ORCID:0009-0005-5205-0709.
[4*]mallasivaganesh@gmail.com; ORCID: 0000-0002-8145-511.

Abstract: Mobiles are becoming a part of our daily life and the usages of mobile phones are increasing day by day to simplify our lifestyle. The charging in the battery is very important to operate the mobile. However, the availability of charging points is very difficult to find in public places including bus stands, railway stations, most populated areas etc. Hence installing a charging device to charge various mobiles effectively is needed at many places in the society. Moreover, unlimited power supply is required to such a device for an effective operation. Further the utilizing of renewable energy sources to provide sufficient power supply to the charging device will be more effective. Renewable energy sources such as Photovoltaic (PV) and wind based hybrid power supply systemsare incorporated into the charging device to supply required reliable power. However, different voltage levels are required to charge batteries of various mobiles. Hence, a multi-output dc to dc converter along with a master control unit is implemented in this paper. OPAL RT modules are utilized to create a Hardware-in-the-Loop (HIL) system, which showcases outcomes across different operational modes.

Keywords: Mobile Charging Unit, Photovoltaic (PV), Wind Energy, Multi-output dc to dc Converter, HIL.

[*] Corresponding Author: mallasivaganesh@gmail.com

1. INTRODUCTION

Mobile phones are becoming a part of every human's daily life for every action. Since, the majority of work is done through the mobiles including daily communications, payments, gaming, using many apps, etc. The battery is only the power source in most of the mobiles [1]. Frequent charging process is required to make mobiles in operating condition every time. However, this process may not be possible every time, especially during a journey or traveling period. Electrical plugged based many charging points are available in bus stations, railway stations etc. unfortunately, chargers must be carried out to put charging for mobile batteries which may not be possible every time and every place. Hence, many points with an intelligent operating control system must be placed at various required locations. In general, many mobiles with their own rating of battery systems are available in the market for many people. Hence an innovative device should be designed with an appropriate working principle to provide the facility to charge various mobiles.

Generally mobile phones required voltage ratings in between 3.0V to 5.5V depending on various models [1]. Hence, the designed device for providing charging for mobiles must have a facility to provide various voltage ratings at their output terminals. Therefore a multi-output dc to dc converter is employed in the charging unit to have multiple outputs from a single dc-link. This configuration can be able to provide charging points for various mobiles as per their charging ratings. Therefore, the mobile batteries do not damage from charging. In order to provide charging facility throughout the day, an appropriately designed battery bank will be also used in the charging unit.Output ports of the charging unit device are connected with respective of various charging pins, hence no need to use separate plugged in chargers. This kind of design will be also used by many people including thosewho don't carry their chargers during their travel or journey.

The procedure of electric supply to the charging unit is a very important aspect to provide reliable service. Hence, a renewable energy based power supply unit is used for supplying required electricity [2-3]. In order to provide a reliable supply, Photovoltaic (PV) and Wind energy based hybrid standalone power supply units are designed based on the capacity of the device which depends on the number of charging ports. A boost converter is used to extract maximum power from a wind turbine and a bidirectional dc to dc converter is incorporated with battery bank [4-5]. To avoid the multiple devices, the bidirectional dc to dc converter which is employed with a battery bank is also used as maximum power point tracking (MPPT) device for the PV system. Hence, there is no need to use an extra converter for a PV system to extract maximum power under various operating conditions. This kind of configuration can reduce the system cost as well as size of the charging unit without decreasing the efficiency and working nature.

The research paper is developed to fulfill below objectives.

a. Design best rating of PV, wind system and battery bank for providing continuous power supply to the charging unit for desired time span.
b. Establish a hybrid dc power supply system by connecting PV, wind and battery bank with respective their respective converters.
c. 24V dc-link is established by integrating PV, wind and battery bank.
d. Connected dc multi-outputconverter to dc-link for achieving various outputs for charging different mobile batteries through proper charging cables.
e. Established Hardware – in the – Loop (HIL) setup by using two OPAL-RT devices to present extensive results under various operating conditions.

Further the paper is prepared by providing the description in Section-2, controlling unit in Section-3, various selected ratings in Section-4, results based on HIL in Section-5 and conclusion is presented in Section-6. Valuable key references are listed at the end of the paper.

2. System Description

The proposed charging unit consists of PV panels, wind based power generation system, battery bank, MPPT converter, bidirectional dc to dc converter, multi-output c to dc converter and mobiles for charging. The proposed system layout is shown in Figure 1. A 24V strong dc-bus system is established by integrating PV panels, wind power generation unit and battery bank with their respective converters. The bidirectional dc to dc circuit can be able to regulate the voltage at dc-bus (i.e., 24V). A MPPT converter (i.e., boost circuit) is employed between dc-bus and wind power generation systems for obtaining the best response during conditions of variable wind speed. In order to make the system more cost effective as well as optimizing size, a dc-generator based wind power conversion system is considered in this research paper. A separate MPPT converter is not considered for PV system, the existed bidirectional dc to dc converter which employed between dc bus and battery bank is also making to working as a MPPT converter of the PV system by proposed control unit of bidirectional dc to dc converter. Generally mobile batteries are charged based on their rated voltage and there are many different mobiles used in society. Hence, a single and common dc-output based converter may not be safe (i.e., effect on mobile batter's life time) to charge all mobiles in safe mode. Hence, single input multi-output terminal dc to dc converter is incorporated to 24V dc-bus to obtain various ranges of dc-outputs which can be used to charge various mobiles based on the customer's choice. A 12V battery bank is considered and will be charged from both PV panels and wind power systems through a 24V dc-bus system. Similarly this battery bank can also discharge required current into 24V dc-bus through bidirectional dc to dc circuit. Hence, the bidirectional converter can be able to manage both charging and discharging current of the battery bank depending on the power mismatch between generation (i.e., wind and solar) and load (various mobile phones). Proper controlling units of various converters are employed in master controlling units to make the system more effective. This device can be installed at public places to be utilized by the public at any time. The battery bank is designed to work for 3 days continuously even if there is no power available from both PV and wind systems.

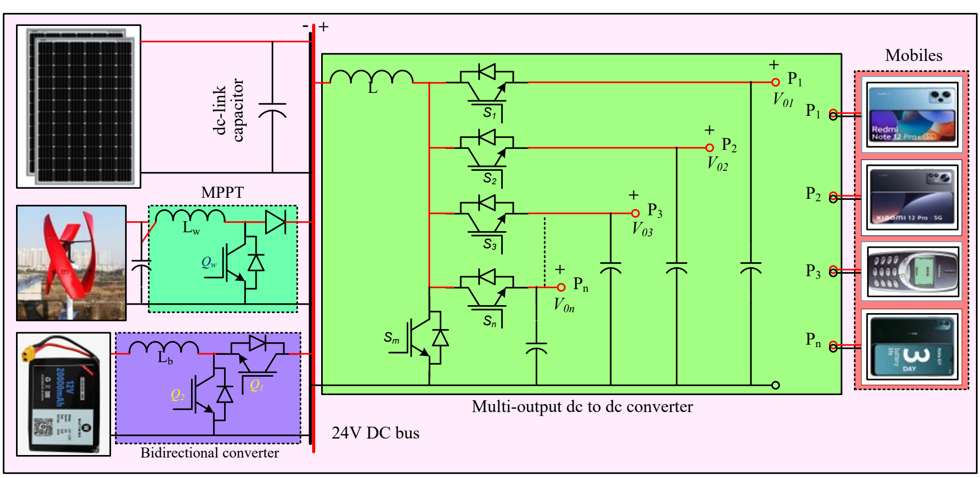

Figure 1: Layout of proposed charging unit for public usage.

3. Controlling Unit

Controlling unit is the main part in the system since it must control power production from renewable energy sources, discharging and charging process of the battery bank, and output terminal voltages of multi-output dc to dc converter where mobile phones are connected for the process of charging. The master controlling unit is further divided into three parts which are: 1. MPPT of wind system, 2. Control of bidirectional dc to dc circuit, 3. Control of multi-output dc to dc converter. In this paper, a dc-generator based wind power conversion system is considered, hence the output of the wind power generation system is directly coupled with a boost converter to work as MPPT converter. A constant torque based MPPT of the wind turbine is considered in this paper which as shown in Figure 2. The boost converter can be able to work even during low wind speed by pumping generated current into a 24V dc-bus by adjusting its duty cycle with the help of a proposed control method. In order to reduce one more MPPT converter of PV, the PV module is directly connected to 24V dc-bus by selecting a proper specification which is suitable to associate the control method of the bidirectional dc to dc converter of the battery. Therefore, by integrating Perturb and Observe (P&O) method to control mechanism of bidirectional dc to dc converter which is integrated between battery bank and 24V dc-bus as shown in Figure 1. Usually sliding mode control (SMC) is one of the best as compared with other control methods to regulate dc-current effectively. Hence, the reference signal of dc-bus voltage obtained from P&O method (i.e., V_{mpp}) will be treated as a reference signal of SMC to generate reference battery current (i_{bref}). Further the i_{bref} is compared with actual battery current (i_{bat}) to produce required pulses for Q_1 and Q_2 through hysteresis loop.
The multi-output dc to dc converter is used to provide facilities for charging many mobiles in safe mode. The voltage rating is very important to charge the mobile battery without any damage by over voltage rating. Lower voltage will take longer time to charge, sometimes mobile may not get charge if the voltage is not supported by the mobile. Hence, charging ports with various ranges of voltages must be required to charge different mobile batteries effectively. To get this facility, a multi-output dc to dc converter is incorporated to the dc-bus in the charging unit. Figure 4 illustrates the control unit of the multi-output DC to DC converter. The individual control blocks can give the best performance as well as accurate output voltages at their respective terminals to provide charging for respective mobiles.

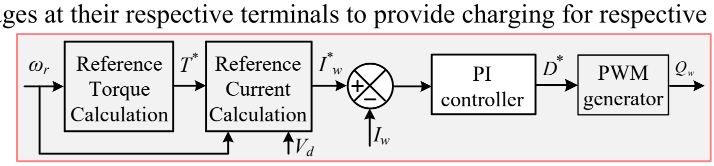

Figure 2: Control method of wind MPPT.

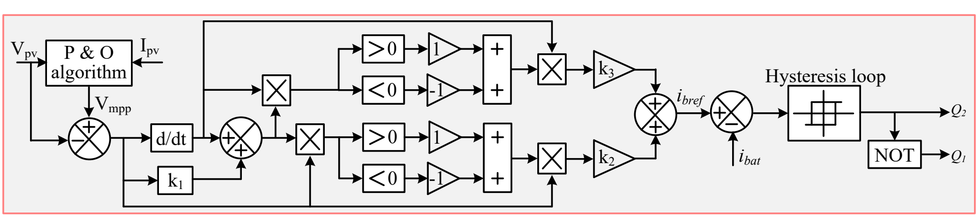

Figure 3: Control method of bidirectional dc to dc converter integrated with P&O method.

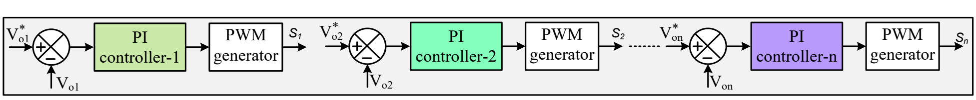

Figure 4: Control unit of multi-output dc to dc circuit.

4. Ratings of Various Components

The ratings of various components are depending on the number of ports provided for charging the mobile. In this paper assume20 mobiles are charging continuously and ratings of components are designed accordingly. A 200 watt PV panel is considered in this model where parameters mentioned in Table-1. A 100W dc generator based wind power conversion system is considered in this paper. Various parameters of wind power generation systems are listed in Table-2. However, the battery bank is designed by considering both generation as well as required hours to manage loads without any generation. Let's consider the battery backup is for 72 hours (3 days), which means there is no power from PV and wind continuously for 3 days. Under this situation, four battery banks of each 12V, 20000mah are considered. The battery bank is formed by connecting all four batteries in parallel. The key specifications of an individual battery can be found in Table-3.

Table-1: Parameters of a 200W PV panel [6].

S. No	Parameter	Value
1	Brand	Bluebird
2	Connector type	USB
3	Maximum power	200 W
4	Maximum voltage V_{mpp}	23.56
5	Maximum current I_{mpp}	8.49
6	Open circuit voltage V_{oc}	27.76
7	Short circuit current I_{sc}	9.0
8	Module efficiency	18.97
9	Model number	BBS12MF200
10	Cells	36 – 5BB cut cells
11	Product dimensions (cm)	149 x 66.5 x 3
12	Performance warranty	25 years
13	Weight	11.5 g

Table-2: Parameters of a 100W Turbine and Generator

S. No	Parameter	Value
1	Model	ATO-WT-NE-100S5
2	Rated Power	100W
3	Maximum Power	130W
4	Rated Voltage	12V/24V
5	Operating speed	10 m/s
6	Start up wind speed	2.0 m/s
7	Survival wind speed	55 m/s
8	Type of generator	PMDC
9	Rated RPM	500
10	Rated current	7.2A

Table-3: Parameters of a battery [7].

S. No	Parameter	Value
1	Battery chemistry	NMC
2	Battery case	PVC wrapped
3	Voltage	12V

4	Capacity	20Ah
5	Energy storage	240 W-h
6	Weight	1.4kg
7	Dimension (in x in x in)	6.4 x 2.9 x 3.0
8	Normal charged voltage	12.60V
9	Normal charging current	5.0A
10	Normal battery cutoff voltage	8.40V
11	Maximum discharge current	20.0A
12	Normal discharge current	10.0A
13	Recommend charging	12.6V, 5A, 4hrs

5. HIL BASED RESULTS

For a best visualization, various results under different operating conditions are included in this section. By using two OPAL-RT modules, an HIL is established to test the performance of the proposed system under various operating conditions. Similar to real time performance can be executed by using OPAL-RT modules since they are designed to work in real time behavior [8-9]. The establishment of the HIL configuration involves the connection of two OPAL-RT modules that can host the MATLAB model via a computer. These modules are then connected in a loop using appropriate channels. The OPAL-RT unit-1 houses the plant through a computer, while the proposed master control model is stored in OPAL-RT unit 2. Figure 5 illustrates the entire laboratory setup of the HIL model. The control unit (OPAL RT2) is receiving multiple analog signals from the dynamic model of the plant (OPAL RT1). However, the control unit of the proposed system receives the digital signals from the plant. The detailed block diagram illustrating the HIL setup of the proposed method can be seen in Figure 6, complete with the appropriate connecting configuration. Various scenarios are being examined in order to showcase the efficiency and validate the performance of the controller being suggested. Other parameters of mobile devices are adopted from [10-11].

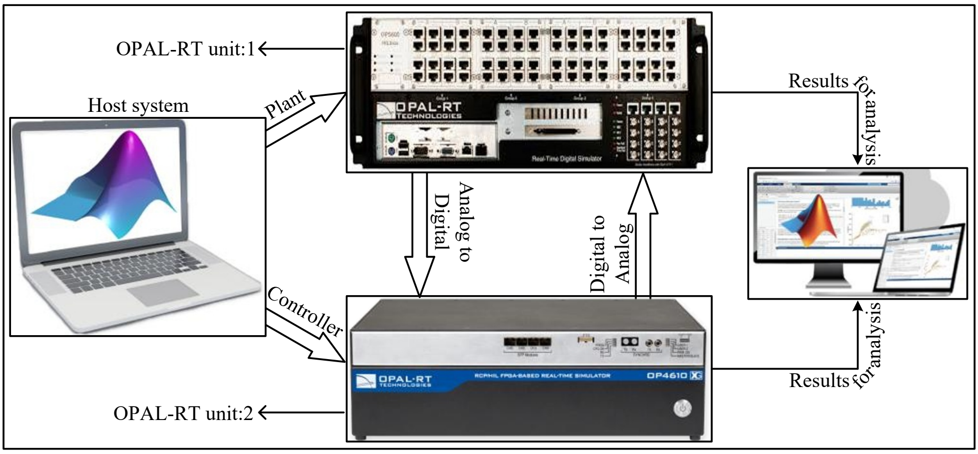

Figure 5: HIL establishment in laboratory using OPAL-RTs.

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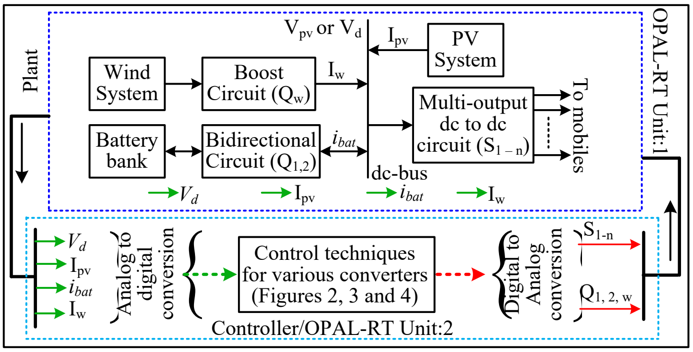

Figure 6: HIL establishment of the Figure 1.

Case-A: Under charging of battery bank

Considering no mobile phone is charging from the device and there are some changes in both speed of the wind and solar irradiance. Changes of solar irradiance and wind speed are depicted in Figure 7. Respective voltage of the dc-bus is shown in Figure 8. The voltage of the dc-link is stable according to V_{mpp} of the PV system. This kind of response represents the energy balance in the system which occurs by charging the battery bank from both PV and wind power conversion systems. Under this situation, various powers are depicted in Figure 9. The battery bank gets more charge when increasing irradiance and wind speed. Small power is consumed by the device to operate the control unit and considered some LED lights which are also represented by device power in Figure 9.

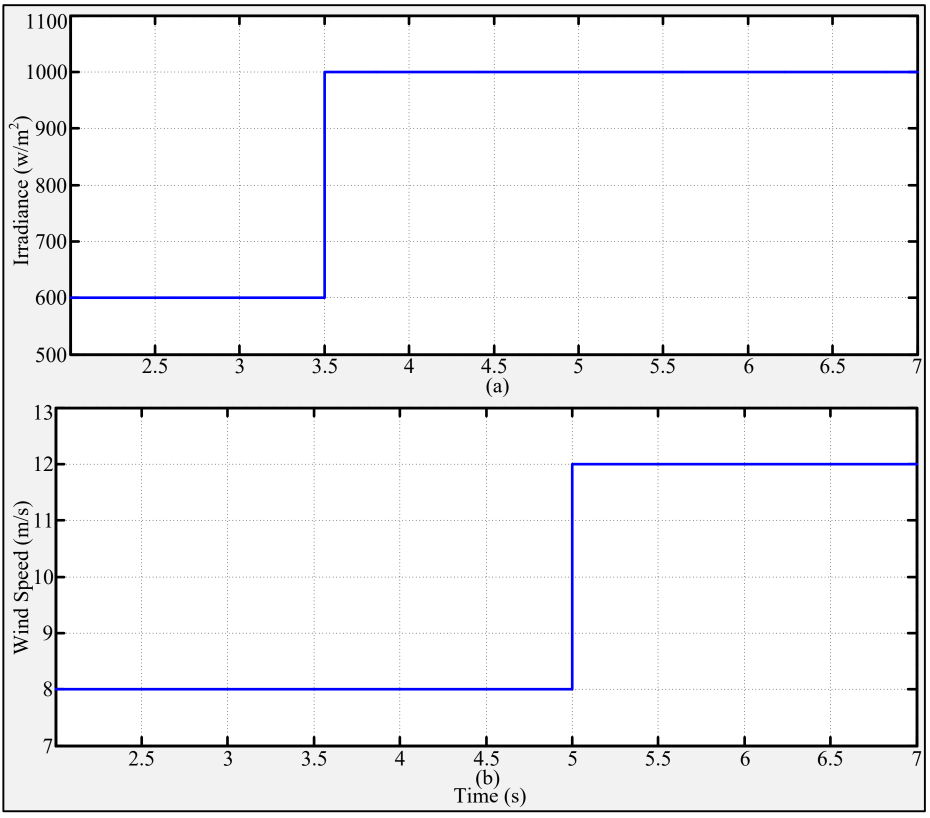

Figure 7: Change in (a) solar irradiance, (b) wind speed.

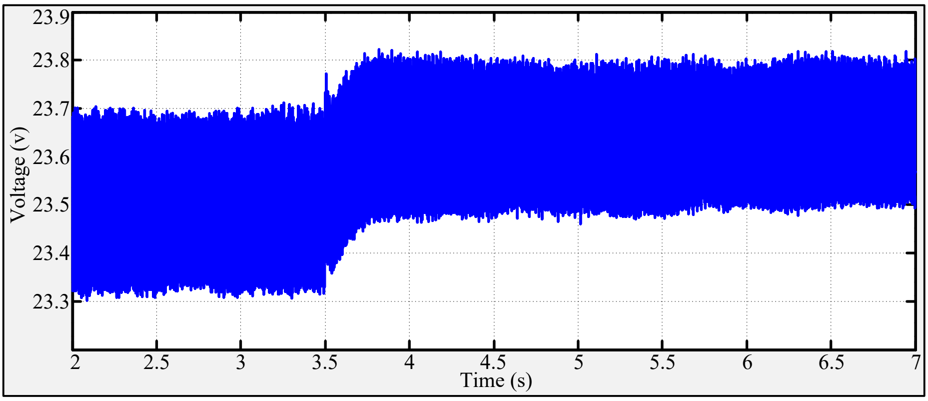

Figure 8: voltage at dc-bus (i.e., Vpv).

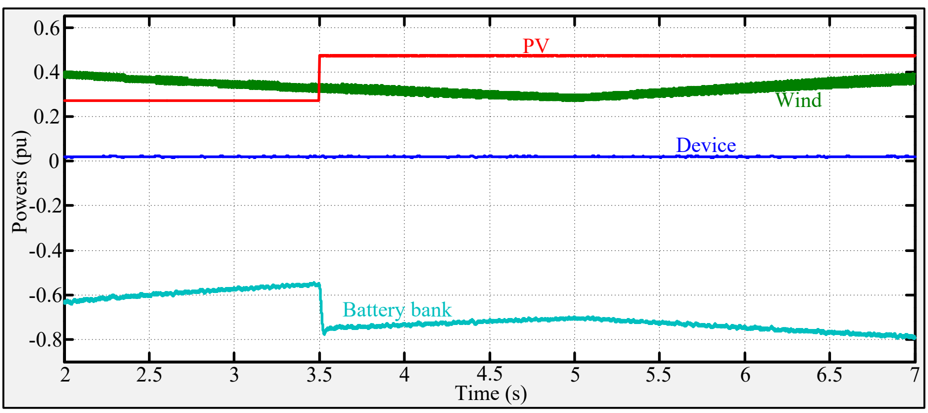

Figure 9: Various powers in per unit (pu).

Case-B: Under discharging mode of battery bank

Considering the power generated by both PV and wind is less as compared with power consumed by charging mobiles. Let's set the minimum values of solar irradiance at 400w/m^2 and wind speed at 5m/s continuously. Under this operation the load is changed two times by connecting new mobiles at charging ports. Corresponding powers and voltage at dc-bus are depicted in Figure 10(a) and (b) respectively. From Figure 10, it is observed that the battery bank is smoothly handling the load which is consumed by the mobiles during the charging process through a multi-output dc to dc converter.

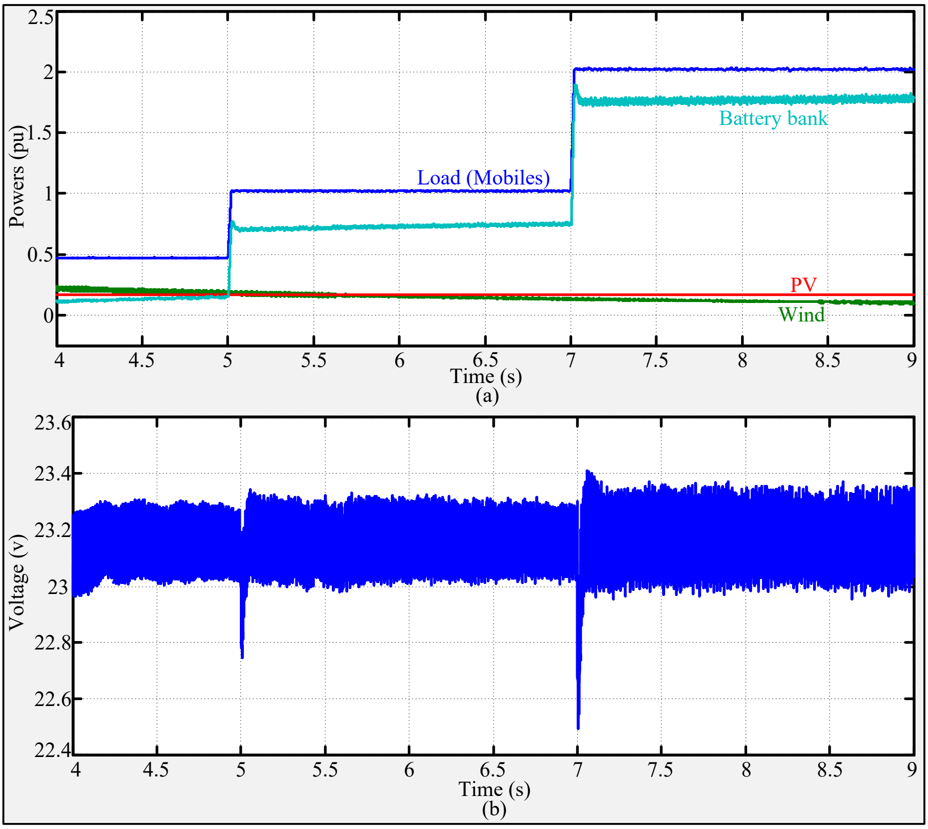

Figure 10: (a) various powers, (b) voltage t dc-bus.

Case-C: Performance of multi-output dc to dc converter

Mobiles are connecting at output terminals of multi-output dc to dc converter for their charging process. Hence, various output voltage levels must be obtained to charge different kinds of mobiles. In order to observe clearly, the initial voltage is kept at 1V and various reference voltages are considered to obtain output voltages. Reference signals of V_{o1}, V_{o2}, V_{o3}, and V_{o4} are considered as 4.4V, 4.75V, 5.0V and 5.5V respectively. Corresponding output voltages of a multi-output dc to dc converter is depicted in Figure 11. By using these ports, different voltage rating mobiles can be easily charged at the same time by connecting respective ports.

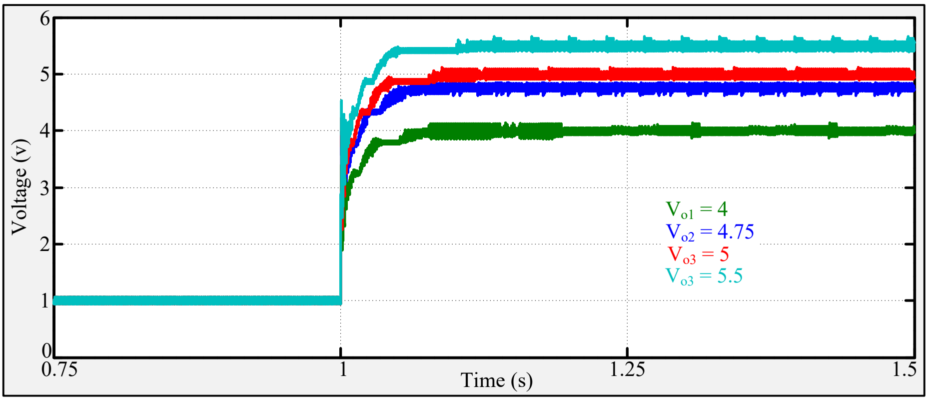

Figure 11: Voltages at multi-output ports.

6. Conclusion

An efficient mobile charger is designed for public usage which is powered by hybrid renewable energy sources. In order to obtain reliable power, a hybrid PV-Wind-battery bank based dc-bus system is developed and multi-output dc to dc converter is used to obtain various voltage levels at the output terminal to charge various mobiles safely. Sliding mode control associated P&O algorithm based MPPT controller is implemented on bidirectional dc to dc converter which is connected between dc-bus and battery bank to manage the charging and discharging process of the battery bank. Detailed system parameters are also included in this paper. Various results are presented under different operating conditions in this paper through the HIL process which is established by OPAL-RT modules. Satisfactory results are obtained and valid analysis is incorporated to them in the results section.

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