Portable field hospital fed from solar system depends on interleaved boost converter (IBC)

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Abstract. In this paper we will suggest equipment for a portable field hospital that is electrically fed by solar panels. The solar panel is connected to the removable (Portable) field hospital via an interface, which is an Interleaved Boost Converter (IBC). The analytical study is carried out for the traditional Boost Converter (BC) and the Interleaved Boost Converter (IBC) using Matlab/Simulink To ensure the electric supply of the portable field hospital with suitable voltage values. The paper will explain what might happen if we doubled or tripled the main elements of the conventional boost converter. The expected results will reflect the implementation importance of the interleaved converter (IBC) in comparison with conventional converter. We will also compare the different types of interleaved converter (IBC), so that we get the best interior connection of the IBC, which achieves the suitable distribution of the total current between the coils, as well as the best size – weight specifications. The selected IBC will contain less ripple in the output voltage waveform, where we provide the portable field hospital feed without disturbances or breakdowns, which cause the IBC to be out of serves or fault occurring to any part of it.

Keywords: BC chopper, Interleaved Boost Converter (IBC), Portable Field Hospital (PFH), Hybrid Uninterruptible Power Supplies (HUPS), Intensive Care Unit (ICU).

1. Introduction:

The operating method of the conventional DC chopper and its internal construction was explained in [1],[2], the applications of the interleaved boost converters in PV systems and switched mode power supply are illustrated in [3]. In reference [5] the comparison of interleaved converter for battery charging of PHEV in production plants are studied, and from reference [6] how the magnetic coupling between two inductances in the converter, then we started with the design and simulation of 2-ph interleaved boost converters via MATLAB/Simulink in references [4],[8],[9] and from these references we concluded that the higher number of phases leads to better performance and output parameters, whereas the effect of magnetic coupling in three phase converters is established in reference [10], however the floating output in these converters with less THD% values which doesn’t exceed 5% is configured in reference [11], and from reference [12] we understood the equations configuring these converters and its operation methods.

In this paper, portable hospital is suggested which is fed from interleaved boost converter connected to solar system. The aim of the suggested system is to provide the devices and equipment of the portable field hospital by AC and DC required electrical power to prevent the interruption of electrical feeding. The essence of this paper focuses on suitable IBC, therefore the different types of IBC are discussed in this paper.
2. Conventional boost converter:

This study describes interleaved boost converters, within multiple cases. first to understand the conventional converter we must understand the DC choppers, DC choppers are semiconductor switching devices which convert the fixed DC voltage into controlled DC voltage, it is used to control the power of traction and propulsion like in electrical vehicles and subway metro, transportations in mines and hybrid uninterruptible power supplies (HUPS).

This type of choppers are allowed to obtain an output voltage higher than the input voltage value, $V_o > V_s$. We always have in this type of choppers induction coil $(L)$ at the input of the chopper circuit, as shown in figure (1).

2.1. Operation principle:

Within the switch-on period $0 < t < t_1$, the current of the induction coil increases to the maximum value at the end of this period, and during this period the coil will store electromagnetic power.

At the moment $t = t_1 = t_{on}$, the switch (MOSFET) is turned off for a period of time $t_2 = t_{off}$, the stored energy in the coil $(L)$ will be discharged, and the current starts to decrease passing through the diode D1 and the Load. [4],[12].

![Fig (1): a) the conventional chopper circuit diagram. b) the output waves of the conventional chopper.](image)

During the switch-on period the voltage value on the coil is expressed by the following equation:

$$U_L = L \frac{di}{dt} \ldots \ldots (1)$$

And the current varies between two values $i_2$&$i_1$:

$$\Delta I = i_2 - i_1 = \frac{V_s}{L} t_1 \ldots \ldots \ldots (2)$$

Through the switch-on period of SW, the load circuit is shorted, and $V_s = U_L$.

During the period $t_2$, the instant load voltage is given as following:

$$V_o = V_s + \frac{L \Delta I}{t_2} = V_s + L \frac{V_s}{L} \frac{t_1}{t_2} t_1 = V_s \left(1 + \frac{t_1}{t_2}\right) \ldots \ldots \ldots (3)$$

$$V_o = V_s \cdot \frac{1}{1 - k} \ldots \ldots \ldots (4)$$

Where:

$$k = \frac{t_1}{t_1 + t_2} = \frac{t_1}{T} \Rightarrow t_1 = kT, \quad t_2 = T - t_1 = T - kT = T(1 - k)$$

When a capacitive filter is connected to the load, we can presume that the output voltage is constant and $V_o = V_a$.

From the equation (4) we can observe that the load voltage is configured by the duty cycle $(k)$, where the voltage increases with the increase of $(k=D \text{ [duty cycle]})$, however when $k = 0$ the voltage will be minimum and $V_o = V_s$.

From equation (4), the output voltage is changing by varying of $(k=D)$ value.
2.2. Simulation of conventional interleaved boost converters using Matlab/Simulink:

Table (1) parameters for BC

| Parameter               | Value                           |
|-------------------------|---------------------------------|
| Input voltage           | 12 [V]                          |
| L (Inductive)           | $76.8 \times 10^{-6}$ [H]       |
| Switching frequency     | $\frac{1}{100000}$ [Hz]         |
| Duty Cycle              | 82%                             |

Fig (2) the simulation diagram of BC

Fig (3) the output voltage of BC

Fig (4) : - pink color the inductor (coil) current  
- yellow color the inductor (coil) voltage

3. Double Boost Converters:
In this case we doubled the number of coils, diodes and MOSFETs(chopper), however we decreased the values of the coils to half, to observe the advantages of this change by simulating the circuit using MATLAB\Simulink.

Table (2) parameters for 2-ph IBC.

| Parameter               | Value                           |
|-------------------------|---------------------------------|
| Input voltage           | 12 [V]                          |
| L (Inductive)           | $38.4 \times 10^{-6}$ [H]       |
| Switching frequency     | $\frac{1}{100000}$ [Hz]         |
| Duty Cycle              | 82%                             |

Fig (5) the simulation diagram of 2-ph IBC
Fig (6) the output voltage of 2-ph IBC

As we can observe the change was obvious, the output voltage value increased almost up to 25% more than the conventional boost converter. We must keep in mind that the switching frequency has to be high so the voltage ripple can be as low as possible, in our case we chose switching frequency of 100 kHz, as the switching chopper is a MOSFET, it can hold up to 1 MHz, but unfortunately the MOSFET with these mentioned parameters is commercially unavailable.

3.1. Voltage ripple comparison:

In case of double boost interleaved converter if we changed the switching frequency of the MOSFET we would decrease the voltage ripple:[5],[6],[7]

![Fig (8) the simulation of the comparison](image)

Table (3) comparison parameters

| Switching Frequency | 25 [kHz] | 100 [kHz] | 1 [MHz] |
|---------------------|----------|-----------|---------|
| $V_{in}$            | 12       | 12        | 12      |
| $V_{out}$           | 50.46    | 50.1      | 49.99   |
| THD %               | 3.939    | 3.933     | 3.932   |

3.2. The effect of the duty cycle:

If the switching frequency is maintained at a constant value of 100 kHz and the duty cycle D is varied of 67, 75 and 82 % we get how the average value of the voltage increases with the increasing of D in limited range up to 82% :[2],[9]

Fig (7) - pink color the inductor (coil) current  
- yellow color the inductor (coil) voltage

Fig (9) reducing ripple in the output voltage versus to higher switching frequency
Table (4) comparison parameters

| Duty cycle % | 82 | 75 | 67 |
|--------------|----|----|----|
| $V_{in}$     | 12 | 12 | 12 |
| $V_{out}$    | 50.1 | 49.44 | 48.76 |
| THD %        | 3.933 | 4.076 | 4.224 |

Fig (10) the output voltage versus to duty cycle values.

a. Black line: 82%
b. Pink line: 75%
c. Blue line: 67%

4. 3-ph IBC:

Fig (11) the simulation diagram for 3-ph IBC.

Fig (12) the output voltage of 3-ph IBC

So if we compared between the conventional boost converter and the double converter and the 3ph converter, with the same switching frequency of 100 kHz, and the same duty cycle of 82% [1], we would notice the increase of the average voltage value:

Fig (13) comparison between BC and 2-ph & 3-ph IBC

5. Study case:
After the analysing of the IBC operation of different topologies, we have to apply the previous study on the portable field hospital supplied via solar panel.

The box diagram of our study case is illustrated below:

![Flow chart of the study case.](image)

The general overview of the portable field hospital contains all devices and equipments is shown below, which is designed by DIALux

![General overview of portable field hospital.](image)

Fig (15) shows: (a) the general overview of portable field hospital
(b) the designed practical structure of the portable field hospital.

![Plan view of the portable field hospital.](image)

Fig (16): (a) actual portable field hospital in real location.
(b) plan view of the portable field hospital.

![Plan view of the operating room.](image)

Fig (17): (a) plan view of the operating room.
(b) plan view of the intensive care unit (ICU).
The portable field hospital contains various loads (AC & DC), therefore we have to provide these loads by a suitable feeding. DC loads can be resourced directly from the output of IBC, while the AC loads must be supplied via inverter, and the output voltage of the inverter will be applied to the various AC loads, such as: operating room; ICU; and radiology room, as shown in figure (18).

The presence of inverter requires to make a simulation of this inverter to insure the waveform required by the mentioned previously AC loads.[3],[10],[11].

5.1. The simulation process of the portable field hospital using MATLAB \ Simulink:

The simulation for the diagram shown in figure (14) using MATLAB \ Simulink:

![Simulation Diagram](image1)

Fig (18) simulation of the portable field hospital. Fig (19) output voltage waveform of the inverter. From figure (20) the suggested system consists of many components:
- Solar panels.
- Charger unit.
- Set of batteries.
- IBC (boost converter).
- Inverter.

6. Result discussion:

- The study had been carried out using conventional boost converter and various topologies of IBC.
- From dedicated previous figures (2) and (5) the comparison shows that from double IBC, we can obtain higher voltage value, and less distortion (THD% = 3.933%).
- The total current in IBC is divided equally between the coils, therefore the power dissipation will be less than conventional BC.
- Figure (8) and (9) shows the reflection of increasing the duty cycle (D%) and varying the switching frequency on the total harmonic distortion (THD), since the output voltage will contain less harmonics with the increasing of D% and switching frequency.
- The simulation of the portable field hospital had been done by using MATLAB \ Simulink to provide to all loads to avoid the interruption of the electrical supply from any part of this hospital.

7. Recommendations and conclusions:

- The higher number of phases of IBC will lead to enhancing the output voltage of boost converter. But we have to consider the increasing of volume – weight of the converter cascade.
- There is no doubt, that increasing the number of phases of the boost converter in these systems will certainly improve the specifications and values of output voltage suitable for feeding different loads. In order to feed some of the proposed AC field facilities, it is necessary to introduce an appropriate inverter to convert the DC voltage into an appropriate AC voltage for these loads.
- The increasing of the IBC links (number of phases) leads to complexity of control circuit of the used switches related to their high number, therefore the future suggestion is to reduce the number of these switches and simplify the control circuit of the used switches.
MPPT Algorithm can be discussed to obtain maximum efficiency from solar system in the future, might be a good recommendation to meet the reliable expectations.

8. References
[1] Steady-state Characterization of Multi-phase, Interleaved Dc-Dc converters for Photovoltaic Applications. Sairaj V. Dhople, Ali Davoudi and Patrick L. Chapman – 2009.
[2] Power Electronics Handbook 3rd ed. M. Rashid (B-H, 2011).
[3] High Voltage Gain Interleaved DC Boost Converter Application for Photovoltaic Generation System. Weerachat Khadmun, Wanchai Subsingha – 2012.
[4] Simple And Efficient Implementation Of Two-Phase Interleaved Boost Converter For Renewable Energy Source. Mounica Ganta, Pallam reddy Nirupa, Thimmadi Akshitha, Dr.R.Seyezhai – 2012.
[5] Comparison of Interleaved Boost Converter Topologies with Voltage Multiplier for Battery Charging Of PHEV. R. Seyezhai, V. Aarthi – 2014.
[6] Analysis of non-isolated two phase interleaved high voltage gain boost converter for PV application. A. Ramesh Babu, T.A.Raghavendiran – 2014.
[7] Basic Design and Review of Two Phase and Three Phase Interleaved Boost Converter for Renewable Energy Systems. Chitra.P, Seyezhai.R – 2014.
[8] Simulation of Incremental Conductance MPPT based Two phase Interleaved Boost Converter using MATLAB/Simulink. Sheik Mohammed, D. Devaraj – 2015.
[9] Modeling and simulation of choppers switching via MATLAB/SIMULINK. Ehsan Hosseini 2015.
[10] Review of Coupled Two and Three Phase Interleaved Boost Converter (IBC) and Investigation of Four Phase IBC for Renewable Application. P.Abishri, Umashankar S, Sudha Ramasamy – 2016.
[11] A floating-output interleaved boost DC–DC converter with high step-up gain. Ardavan Kianpour, Ghazanfar Shahgholian – 2017.
[12] Power electronics /1/ Carlo J. Makdisie – Tishreen university publication – 2017A reference This reference has two entries but the second one is not numbered (it uses the ‘Reference (no number)’ style.