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IMPLEMENTATION OF MULTIPHASE BIDIRECTIONAL NONISOLATED DC – DC CONVERTER FOR HIGH POWER APPLICATIONS

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ABSTRACT

The converter has high efficiency due to soft-switching operation in all Multi bridges. Steady-state analysis of the converter is presented to determine the power flow equations, tank currents and soft-switching region. Dynamic analysis is performed to design a closed-loop controller that will regulate the load-side port voltage and source-side port current. Compared to the traditional full and half bridge bidirectional dc–dc converters for the similar applications, the new topology has the advantages of simple circuit topology with no total device rating (TDR) penalty, soft-switching implementation without additional devices, high efficiency and simple control. These advantages make the new converter promising for medium and high power applications especially for auxiliary power supply in fuel cells and power generation where the high power density, low cost, lightweight and high reliability power converters are required. The operating principle, theoretical analysis, and design guidelines are provided in this thesis. The simulation and the experimental verifications are also presented.

Key words: Battery charger, DC-DC converter, Multi-port converter, Virtual isolation.

INTRODUCTION

In recent years, with the rapid increase in the growth of the population, the electrical energy utilization has been increased. The most of production of energy is from the fossil fuels like coal, oil and natural gas. However these sources are limited and face number of challenges which include rising prices, security concerns over dependence on import of fossil fuels from limited countries in number and also had created environmental problem leading to the change in climatic conditions (Global warming) because of the release of green house gases on its combustion. Because of the limited in nature, fossil fuels they are decreasing very rapidly with high utilization. Also in last few decades the petroleum prices have shown large hike in price and the pollution caused by the nontraditional resources of energy had seek the interest of scientific research scholars towards traditional energy sources. So in order to overcome these problems and reduce the change in climatic conditions, the renewable energy sources are likely to be used for energy generation and storage that have emerged as potential alternatives.

MATERIALS AND METHODS

PV Module

PV cells which connected in series/parallel combination to form the PV Module, in order to come up for higher ratings. Because of the variation in illumination and temperature the power varies. So for that we use MPPT, accomplished by DC-DC boost converter and is connected in between the DC load and solar panel. A small capacitor at the input side of boost converter reduces the ripples of the solar panel voltage. The PV panel could not track the optimum voltage at terminals at the fast rate, if the capacitance value is large.

For the module circuit modeled as single diode circuit, as shown in figure 1. Relationships for current and voltage of mentioned PV module are given below[1,2].

$$I_{LG} - I_D - \frac{V_D}{R_{Sh}} - I_{PV} = 0 \qquad (1)$$

$$V_{PV} - V_D + I_{PV} R_S = 0 \qquad (2)$$

Where,

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I_{LG} = generated current due to solar radiations,

I_D = diode current

V_D = voltage across diode

$I_{PV=}$ PV current

V_{PV} = PV voltage

$R_{sh=}$ shunt resistance

$R_{s=}$ series resistance.

$$I_{PV} = I_{LG} - I_{Sat}\left(e^{\frac{q(Vpv+Ipv.Rs)}{\alpha kT}} - 1\right) - \frac{Vpv+IpvRs}{Rsh} \quad (3)$$

$I_{Sat=}$saturation current of PV module

T = temperature of PV module (k)

k = Boltzmann constant (J/K) (1.380×10^{-23})

q = electron in charge (C) (-1.602×10^{-19})

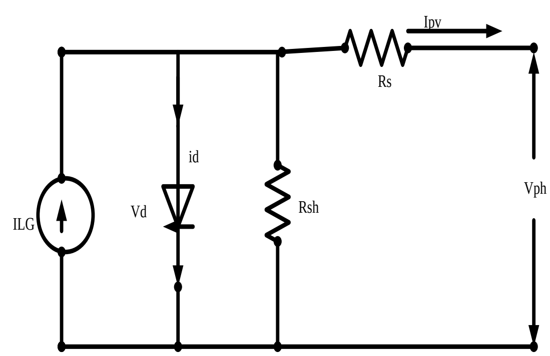

Figure 1: Solar PV cell equivalent circuit.

Quality of PV Cell

Since every cell has a life expectancy. As the time progress the quality of cell goes down. So it is essential to check the quality of solar cell so that it can be discarded once the quality falls below certain specified limit.

The quality of solar cell can be calculated from the I-V characteristic curves shown in figure and denoted by Fill factor(FF).

$$FF = \frac{V_{MPP} \times I_{MPP}}{V_{OC} \times I_{SC}}$$

Ideally the fill factor should be 100 % or 1.A good panel has a fill factor around 0.7 to 0.8 and for bad panel it may be as low as 0.4

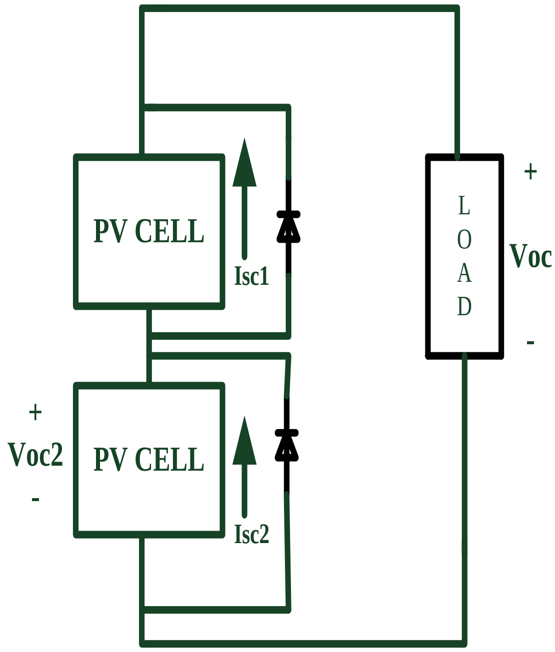

Figure 2: Series combination of two PV cells.

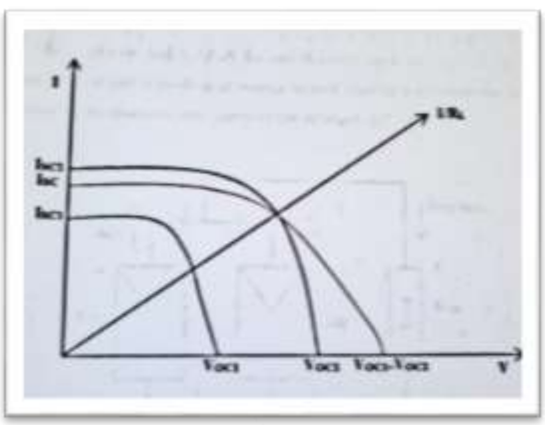

Figure 3: I-V characteristic curve when two PV cell are connected in series.

Battery Storage Systems

The starting battery has greater plate count, therefore is used to deliver power quickly. Therefore the number of plates are greater and thinner. However the deep cycle batteries deliver long term energy supply. The plates used are less in count and are thicker. They survive for number of discharging cycles. Because of the wear and tear of the thinner plates at discharge time, the starting batteries are not feasible for deep cycle applications. The interior design of the deep cycle battery is shown in the figure 4.

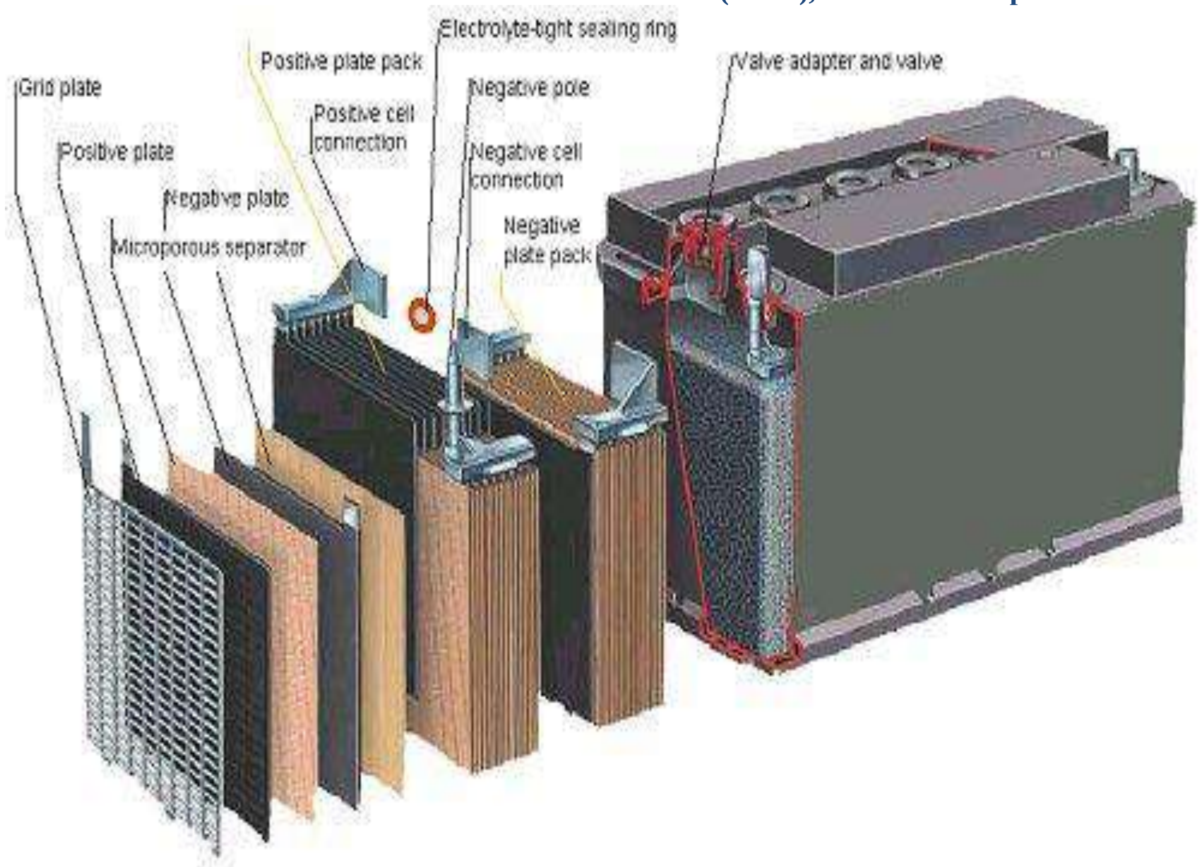

Figure 4: Internal design of deep cycle battery.

The batteries are used in standalone systems for solar power storage. The battery is modulated as a voltage source whose output is dependent not only on the current but also depends upon the state of charge (SOC). The expression for the battery is described as below.

$$V_b = V_o - R_b.I_b - K\frac{Q}{Q-\int I_b dt} + A.\exp(-B\int I_b dt) \qquad (4.1)$$

$$SOC = 100(1-\frac{\int I_b dt}{Q}) \qquad (4.2)$$

Where,
R_s= the internal resistance of battery.
V_o= the open circuit potential.
K= polarization voltage.
Q= battery capacity.
A= exponential voltage.
B= exponential capacity.

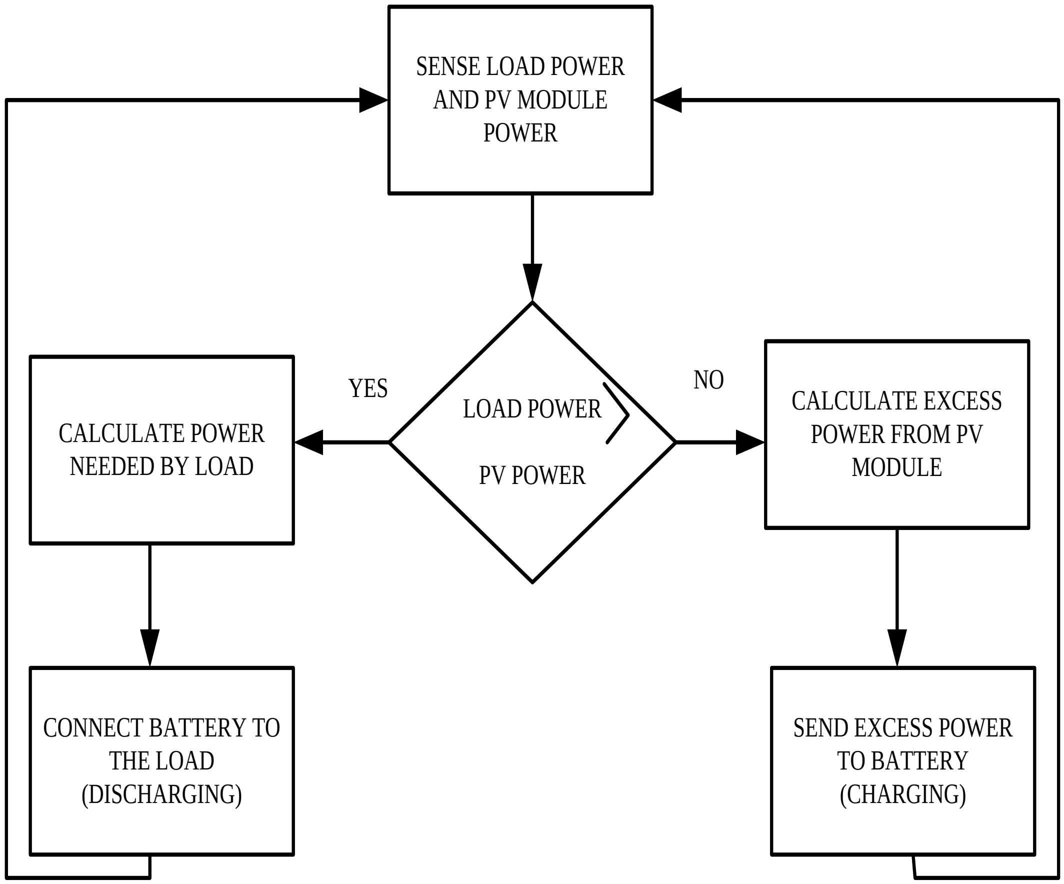

Figure 5: Flow chart of controller in battery management system.

DC-DC CONVERTERS

DC to DC converter is a device which converts a source of dc from one voltage level to some other level. These DC-Dc converters are used in many applications like electrical vehicles, fuel cells, battery charging and discharging, laptops, etc. Besides of these applications they are also used in maximum power point trackers (MPPT). DC-DC Converters are becoming quite useful for providing the flexibility in order to adjust the DC voltage or DC current at any point in the given circuit. In comparison to linear regulators they are more efficient smaller, light in weight and provide output of high quality. The output voltage obtained can be higher or lower as compared to input voltage, unlike to the regulators that can provide output voltage which is less than the input voltage. The DC-DC should have the fallowing specifications.

- The power flow between the battery and DC bus should be controllable.
- It must be bi directional in case of battery interface with PV system.
- Both the higher voltage (boost mode) and lower voltage (buck mode) should be provided by DC-DC converter
- The current should be controlled for the battery charging.
- The control should be able to operate in four quadrant manner.

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Buck Converter and design equation

Mode I: when the switch is ON: $0 \leq t \leq Dt_s$

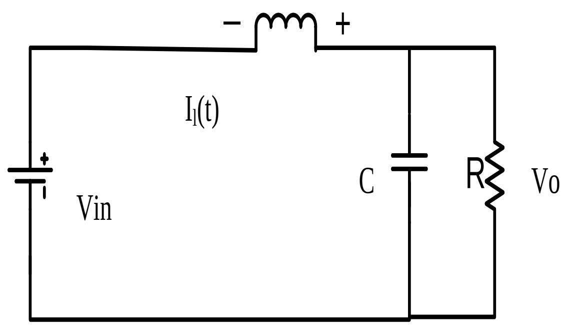

Figure 6: Buck converter in mode I.

$$\frac{dI_l(t)}{dt} = \frac{V_{in} - V_o}{L} \tag{6}$$

$$I_l(t) = \left[\frac{V_{in} - V_o}{L}\right] t + I_l(0) \tag{7}$$

At the end of the mode-I, $t = Dt_s$

$$I_l(Dt_s) = \left[\frac{V_{in} - V_o}{L}\right] Dt_s + I_l(0) \tag{8}$$

$$I_l(max) = \left[\frac{V_{in} - V_o}{L}\right] Dt_s + I_l(min) \tag{9}$$

Mode II: when the switch is OFF: $Dt_s \leq t \leq t_s$

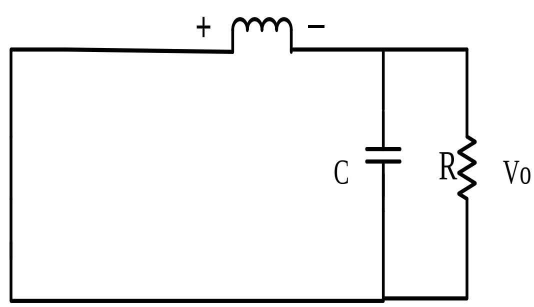

Figure 7: Buck converter in mode II.

$$\frac{dI_l(t)}{dt} = \frac{-V_o}{L} \tag{10}$$

$$I_l(t) = \left[\frac{-V_o}{L}\right] t + I_l(Dt_s) \tag{11}$$

At the end of mode II;t= t_s

$$I_l(t) = \left[\frac{-V_o}{L}\right] (1 - D)t_s + I_l \tag{12}$$

$$I_l(min) = \left[\frac{-V_o}{L}\right] (1 - D)t_s + I_l(max) \tag{13}$$

Adding 1 & 2; we get

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$I_l(max) + I_l(min) =$

$$\left[\frac{V_{in} - V_o}{L}\right] Dt_s + I_l(max) + I_l(min) + \left[\frac{-V_o}{L}\right](1-D)t_s \quad (14)$$

$$\left[\frac{V_{in} - V_o}{L}\right] Dt_s = \left[\frac{V_o}{L}\right](1-D)t_s$$

$$DV_{in} - DV_o = V_o - DV_o \quad (15)$$

Therefore for buck converter

$$Gain = \frac{V_o}{V_{in}} = D < 1$$

From the above equation it is confirmed that the output voltage will be adjusted by adjusting the duty cycle D.

The input and Output Currents are

During ON period, $I_l(t)=I_{in}$

During OFF period, $I_{in}(t)=0$

$$Average\ input\ current = \frac{1}{t}\left[\frac{I_l(max) + I_l(min)}{2}\right] \quad (16)$$

$$I_{in} = D\left[\frac{I_l(max) + I_l(min)}{2}\right] \quad (17)$$

Average output current =average of inductor current

.
$$I_o = \left[\frac{I_l(max)+I_l(min)}{2}\right] \quad (18)$$

$$I_l(max) + I_l(min) = \frac{2V_o}{R} = \frac{2DV_{in}}{R} \quad (19)$$

$$(max) + I_l(min) = \frac{V_{in} - V_o}{l} Dt = \frac{(1-D)V_{in}(Dt)}{l} \quad (20)$$

$$I_o = \frac{1}{2}[I_l(max) + I_l(min)] = \frac{V_o}{R} = \frac{DV_{in}}{R} \quad (21)$$

$$I_l(max) = \frac{DV_{in}}{R} + \frac{(1-D)V_{in}(Dt)}{2l} \quad (22)$$

$$I_l(min) = \frac{DV_{in}}{R} - \frac{(1-D)V_{in}(Dt)}{2l} \quad (23)$$

Inductor current ripple

$$\Delta I = I_l(max) - I_l(min) \quad (24)$$

$$\Delta I = \frac{(1-D)DtV_{in}}{l} = \frac{T_{off}V_o}{l} \quad (25)$$

Therefore current ripple can be minimized by decreasing the switching frequency 'T' and increasing the inductance.

$$\frac{\Delta I}{I_l} = \frac{(1-D)DtV_{in}}{l}\frac{R}{DV_{in}} = \frac{(1-D)t}{l}R \quad (26)$$

$$since, \frac{I_{in}}{I_o} = D\ and\ \frac{V_o}{V_{in}} = D$$

Therefore, assuming the converter is lossless

$$P_o = P_{in} \quad (27)$$

To operate designed buck converter in continuous conduction mode, the load current should be usually above certain level of 5 to 10% of full load. The power stage usually defines the input voltage range, load current and output voltage. This helps in suggesting the value of inductor as a design parameter in order to maintain CCM.

Since, I_l (min)=0, therefore

$$DV_{in}\left(\frac{1}{D} - \frac{(1-D)}{RL_{Cri}}\right) = 0 \quad (28)$$

$$L_{cri} = \frac{(1-D)TR}{2} \quad (29)$$

The Output Voltage Ripple of the converter are derived as

During turn ON time

$$\Delta I = I_l(max) - I_l(min) = (1-D)T\frac{DV_{in}}{L}, \quad 0 \le t \le Dt \tag{30}$$

$$I_{C_1}(t) = I_l(min) - I_o + \frac{\Delta I}{DT}t \tag{31}$$

$$I_{C_1}(t) = I_l(min) - \left[\frac{I_l(max)+I_l(min)}{2}\right] + \frac{\Delta I}{DT}t \tag{32}$$

$$I_{C_1}(t) = \frac{I_l(min) - I_l(max)}{2} + \frac{\Delta I}{DT}t \tag{33}$$

$$I_{C_1}(t) = \frac{-\Delta I}{2} + \frac{\Delta I}{DT}t = \Delta I\left(\frac{t}{DT} - \frac{1}{2}\right) \tag{34}$$

During turn OFF time, $0 \le t \le Dt$

$$I_{C_2}(t) = I_l(max) - I_o - \frac{\Delta I}{DT}(t - DT) \tag{35}$$

$$I_{C_2}(t) = I_l(max) - \left[\frac{I_l(min) + I_l(max)}{2}\right] - \frac{\Delta I}{DT}(t - DT) \tag{36}$$

$$I_{C_2}(t) = \frac{\Delta I}{2} - \frac{\Delta I}{(1-D)T}(t - DT) \tag{37}$$

Therefore the Capacitor voltage is given by

$$V_{c_1}(t) = \frac{1}{c}\int_0^t I_c(t)\,dt \tag{38}$$

$$V_{c_1}(t) = \frac{1}{c}\int_0^{DT} \Delta I\left(\frac{t}{DT} - \frac{1}{2}\right)dt + V_{c_0} \tag{39}$$

$$V_{c_1}(t) = \frac{\Delta I}{c}\left[\frac{t^2}{2DT}\right]_0^{DT} - \frac{1}{2c}DT + V_{c_0} \tag{40}$$

$$V_{c_1}(t) = \frac{\Delta I}{2c}DT - \frac{1}{2c}DT + V_{c_0} = \frac{DT}{2c}(\Delta I - 1) + V_{c_0} \tag{41}$$

$$V_{c_2}(t) = \frac{1}{c}\int_{DT}^{T}\int_0^t I_{c_2}(t)\,dt + V_c(DT) \tag{42}$$

$$V_{c_2}(t) = \frac{1}{c}\int_{DT}^{T}\left[\frac{\Delta I}{2} - \frac{\Delta I}{(1-D)T}(t - DT)\right]dt + V_c(DT) \tag{43}$$

$$V_{c_2}(t) = \frac{1}{c}\left[\frac{\Delta I}{2}(1-D)T - \frac{\Delta I}{(1-D)T}\left(\frac{t^2}{2} - \frac{DT^2}{2}\right) + \frac{\Delta I}{(1-D)T}(1-D)T\right] + V_c(DT) \tag{44}$$

$$V_{c_2}(t) = \frac{\Delta I}{c}\left[\frac{T}{2} - \frac{DT}{2} - \frac{T}{2} - \frac{DT}{2} + DT\right] + V_c(DT) \tag{45}$$

$$V_o = \frac{1}{T}\left[\int_0^{DT} V_{c_1}(t)dt + \int_{DT}^{T} V_{c_2}(t)dt\right] \tag{46}$$

$$V_o = \frac{\Delta I}{Lc2}(1 - 2D)T + V_c(0) \tag{47}$$

$$V_c(0) = DV_{in}\left[1 - \frac{(1-D)(1-2D)}{2LC}T\right] \tag{48}$$

$$V_c(min) = V_{c_1}(t)\Big|, t = \frac{DT}{2} \tag{49}$$

$$V_c(min) = -\frac{\Delta I}{8C} + V_c(0) \tag{50}$$

$$V_c(max) = V_{c_2}(t)\Big|, t = \frac{(1-D)T}{2} \tag{51}$$

$$V_c(max) = \frac{\Delta I}{8C}(1-D)T + V_c(DT) \tag{52}$$

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$$\Delta V_o = V_c(max) - V_c(min) = \frac{V_o}{8LCf^2}(1 - D) \quad (53)$$

Therefore,

$$Ripple = \frac{\Delta V_o}{V_o} = \frac{(1 - D)}{8LCf^2} \quad (54)$$

Boost converter

The boost converter is a power converter also called as step up converter with an output DC voltage greater than input voltage. The circuit diagram of boost converter is shown in figure 5.5 given below.

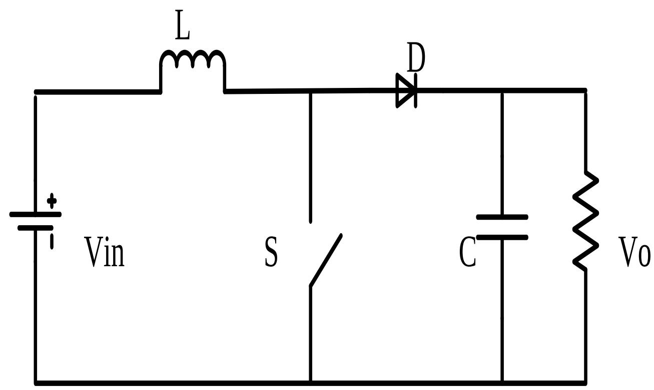

Figure 8: Circuit diagram of boost converter.

Bidirectional DC-DC Converter (BDC)

The above defined DC-DC converters are basically unidirectional converters. This means that there is the flow of power in only one direction. However these converters can be made bidirectional by replacing the diode by auxiliary switch. The Bi-directional DC-Dc converter allows the flow of power in either direction as shown in figure 5.10. They have the ability to reverse the direction of flow of current and there by power flow without changing the voltage polarity of both source ends.

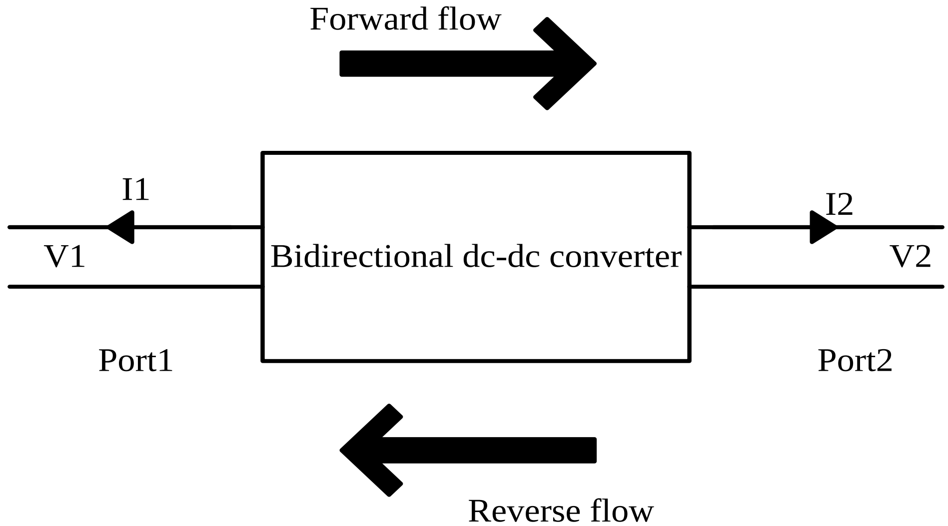

Figure 9: Bi-directional flow in DC-DC converter.

This all means that they can operate as buck converter in one direction as well as boost converter in other direction. Bi-directional DC-DC converters for battery charging and discharging, not only controls the current but also regulates the output voltage to the predetermined value. The combined topology has inherently reduced the size, component count, cost and complexity. Another feature is to implement the controller based control. The controller can drastically reduce the component count, adds flexibility and increase reliability.

These Bi-directional DC-DC converters are widely used in solar power converters for charging the battery by utilizing the energy from the solar PV modules and discharging the batteries during the nights or when the supply is low.

RESULTS

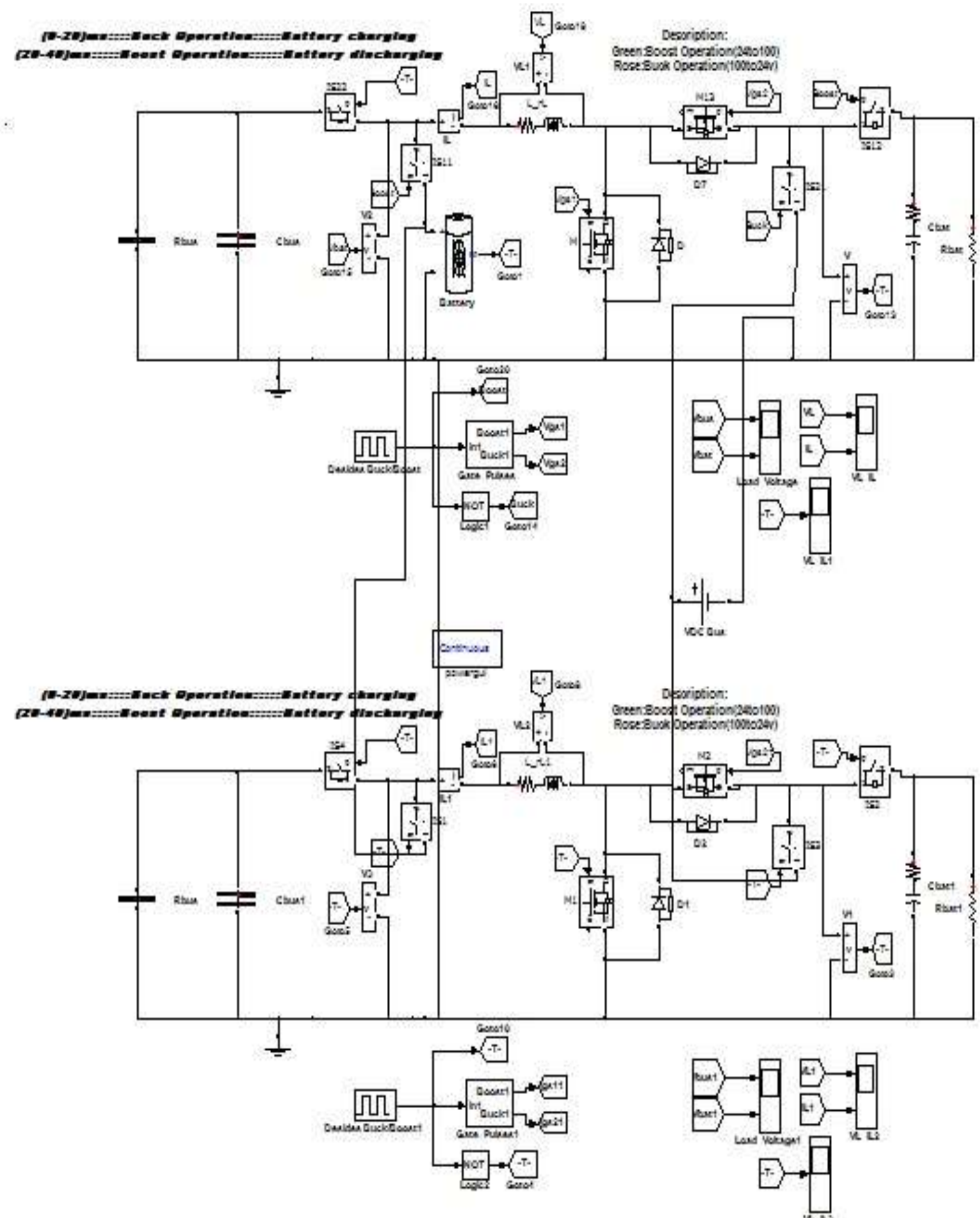

Figure 10: Simulink model of proposed BDC.

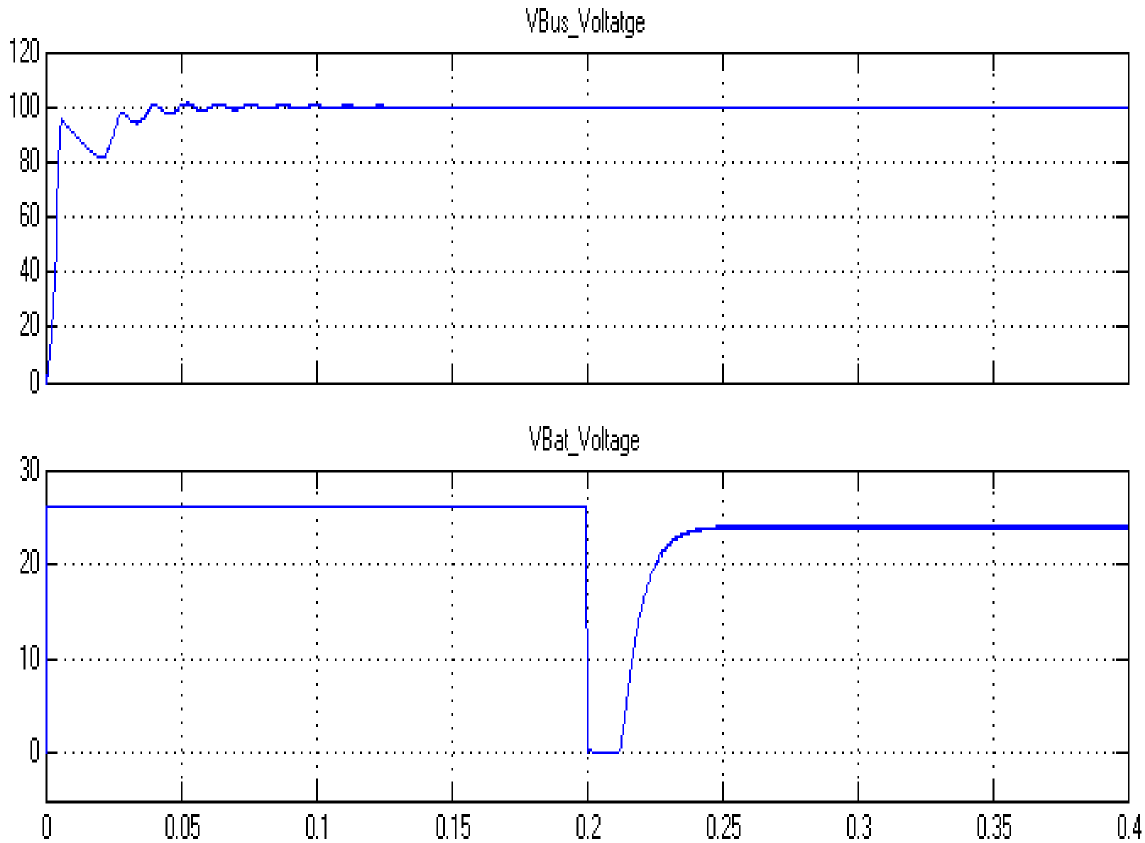

Figure 11: Voltage waveforms of BDC either sides(Bus side and battery side) in single phase

CONCLUSION

This paper introduces the complementary gate signal control to get high power efficiency and improve the discontinuous conduction mode operation EMI noise. On the basis of this control scheme, a third-order general-purposed model of a bidirectional dc dc converter for battery charging is proposed, developed and investigated. A unified controller, which results in smooth mode transition, is designed based on the general purposed model. The bidirectional current flow control naturally has smoothly mode transition because of the unified power stage model and the adopted unified controller, but for all the other mode transitions a certain control scheme is needed to develop and further investigated. The other mode transitions include transition between current mode battery charging and voltage mode battery charging control, transition between voltage mode battery charging and bus system voltage mode discharging, and transition between current mode battery discharging and voltage mode discharging.

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