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A Novel DC-DC converter for high step-up ratio for PV Cell Applications

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ABSTRACT
The main attention of this paper is designing of an isolated DC-DC converter which was used in railway applications. After the DC voltage is increased to required level the DC to AC conversion is done. The DC-DC converters efficiency may affect the renewable energy source overall performance. In general, there is no isolation between input and output of DC-DC converters but in most of the converters there is an electrical isolation between input and output of the converter using a transformer. This isolation which is between input and output is used to get isolated power output source.

The step up voltage ratio is increased by adopting a high step up interleaved boost converter having a coupled inductor. The converter which is connected in parallel is for sharing the power flow which causes for decreasing the converter size and weight. Also requires low rating inductors and capacitors. The coupled inductor in the converter increases the voltage step up ratio to high value with less duty ratio. The duty ratio need not be set to a high value. The isolated DC-DC converter is implemented by proposed concept in grid connected application. The total work is carries out by using MATLAB/SIMULINK software.

Key words— power electronics, power supplies, rail transportation electronics, DC–DC power conversion.

2.1 DC DC CONVERTERS

2.1.1 Introduction

Every Electronic circuit is assumed to operate some supply voltage which is usually assumed to be constant in nature. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters. The dc-dc converter inputs nun regulated dc voltage input and outputs a constant or regulated voltage. The regulators can be mainly classified into linear and switching regulators. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage. Since a feedback loop is necessary to maintain regulation, some type of compensation is required to maintain loop stability. Compensation techniques vary for different control schemes and a small signal analysis of system is necessary to design as table compensation circuit. State space analysis is typically used to develop a small signal model of a converter and then depending on the type of controls cheme used, the small signal model of converter is modified to facilitate the design of the compensation network. In contrast to a state space approach, PWM switch modelling develops a small signal of switching components of converter.

Behavioural modelling of the IC system represents the functionality of an IC with macro models rather than actual implementation of the circuit using more efficient modelling techniques. ORCAD is powerful tool to develop behavioural models of electronic system. Simulation offers the advantage of its graphical user interface and block diagram implementation of any system. It also supports writing function and integration of C program code. The study undertaken in this thesis develops a system level design approach for switching voltage regulators of the three major control schemes. The basic converter topologies and their waveforms are reviewed. In Particular, a small signal model along with the various transfer functions of a buck converter are derived using state space method.

A very simple and easy technique to arrive at the PWM model and compensation for two types of control schemes: namely voltage control, current control scheme is discussed. System level models are implemented using the in ORCAD. The following study provides details of methodologies for designing each component or blocks mainly the BUCK converter used in the switching regulator. Finally, practical result and simulation results are presented for voltage and current schemes and specified the proper design to get expected values to run the guitar r processor.

2.3 DC-DC converter

DC–DC converters are power electronic circuits that convert a dc voltage to a different voltage level. There are different types of conversion method such as electronic, linear, switched mode, magnetic, capacitive. The circuits described in this report are classified as switched mode DC-DC converters. These are electronic devices that are used whenever change of DC electrical power from one voltage level to another is needed. Generically speaking the use of a switch or switches for the purpose of power conversion can be regarded as an SMPS. From now onwards whenever we mention DC-DC converters we shall address them with respect to SMPS. A few applications of interest of DC-DC converters are where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less for one of the latest CPU chips; where 1.5V from a single cell must be stepped upto 5V or more, to operate electronic circuitry.

In all of these applications, we want to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, we want to per form the conversion with the highest possible efficiency. DC-DC Converters are needed because unlike AC,DC can’t simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. They essentially just change the input energy in to a different impedance level. So whatever the output voltage level, the out put power all comes from the input; there is no energy manufactured inside the converter. Quite the contrary, in fact some is inevitably used up by the converter circuitry and components, in doing their job.

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The Buck Converter

The buck converter is a commonly used in circuits that steps down the voltage level from the input voltage according to the requirement. It has the advantages of simplicity and low cost. Figure1 shows a buck converter the operation of the Buck converters start with a switch that is open (so no current flow through any part of circuit) When the switch is closed, the current flows through the inductor, slowly at first, but building up overtime. When the switch is closed the inductor pulls current through the diode, and this means the voltage at the inductors "output" is lower than it first was. This is the very basic principle of operation of buck circuit.

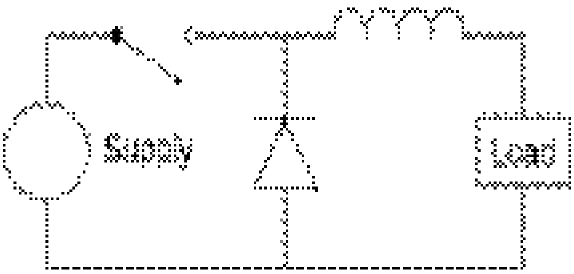

Figure 2.1 BUCK Converter

Analysis of the buck converter begins by making these assumptions:

1. The circuit is operating in the steady state.
2. The inductor current is continuous(always positive)
3. The capacitor is very large, and the output voltage is held constant at voltage Vo. This restriction will be relaxed later to show the effects of finite capacitance.
4. The switching period is T, the switch is closed for time DT and open for time (1-D)T
5. The components are ideal

The key to the analysis for determining the voltage Vo is to examine the inductor current and inductor voltage first for the switch closed and then for the switch open. The net change in inductor current over one period must be zero for steady state operation. The average inductor voltage is zero. There are two types of operational mode for this circuit a) Continuous Conduction Mode and b)D is continuous Conduction Mode. They are described below.

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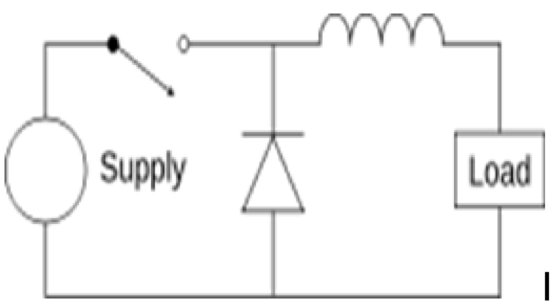

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Continuous Conduction Mode

A buck converter operates in continuous mode if the current through the inductor (IL) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram inFigure1.

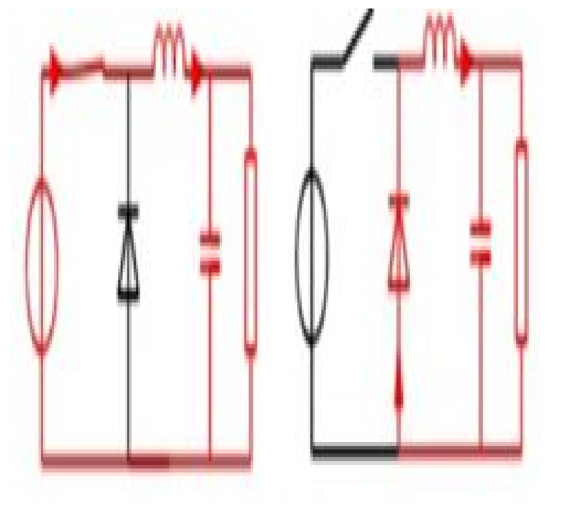

Figure2.2: On and off state of Buck converter

(a)On state (b) off State

Figure.2.2:The two circuit configurations of a buck converter:(a)On-state, when the switch is closed, and(b) Off-state, when the switch is open

- When the switch pictured above is closed (On-state,topofFigure2),the voltage across the inductor is VL =Vi −Vo. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it;
- When the switch is opened (off state, bottom of figure 2),the diode is forward biased. The voltage across the inductor is VL=−Vo(neglecting diode drop). Current IL decreases.

2.7.1.2 Discontinuous Conduction Mode

In some cases, the amount of energy required by the load is small enough to be transferred in a time lower than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (Figure 4). This has, however, some effect on the previous equations.

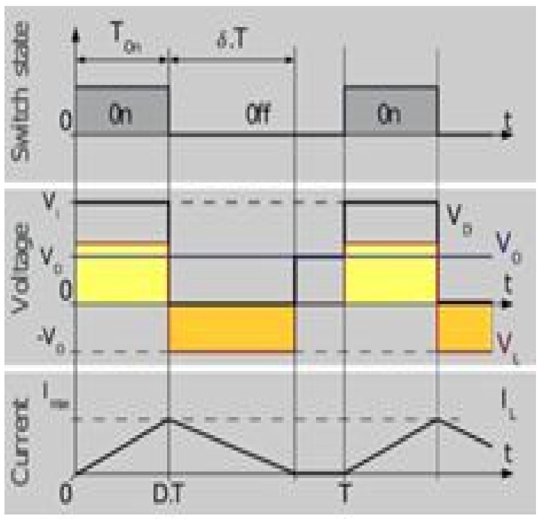

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Fig. 2.4 Evolution of the voltages and currents with time in an ideal buck converter operating in discontinuous mode.

We still consider that the converter operates instead y-state. Therefore, the energy in the inductor is the same at the beginning and at the end of the cycle (in the case of discontinuous mode, it is zero). This means that the average value of the inductor voltage(V_L) is zero; i.e., that the area of the yellow and orange rectangles in figure5 are the same. This yields:

$$(V_i - V_o)\,DT - V_o \delta T = 0 \quad \text{.....(2.7)}$$

So the value of δ is:

$$\delta = \frac{V_i - V_o}{V_o} D \quad \text{..............(2.8)}$$

The output current delivered to the load (I_O) is constant; as we consider that the output capacitor is large enough to maintain a constant voltage across its terminals during a commutation cycle. This implies that the current flowing through the capacitor has a zero average value. Therefore, we have:

$$\bar{I}_L \quad I_o \quad \text{..............(2.9)}$$

Where $\bar{I}_L$ is the average value of the inductor current. A scan be seen in figure5, the inductor current wave form has a triangular shape. Therefore, the average value of I_L can be sorted out geometrically as follow:

$$\bar{I}_L - \left(\frac{1}{2} I_{L_{max}} DT - \frac{1}{2} I_{L_{max}} \delta T\right)\frac{1}{T} - \frac{I_{L_{max}}(D-\delta)}{2} \quad I_o \quad \text{.....(2.10)}$$

The inductor current is zero at the beginning and rises during t_{on}up to I_{Lmax}. That means that $I_{Lmax}$is equal to:

$$I_{L_{Max}} = \frac{V_i - V_o}{L} DT \quad \text{..............(2.11)}$$

Substituting the value of I_{Lmax}in the previous equation leads to:

$$I_o = \frac{(V_i - V_o)\,DT\,(D + \delta)}{2L} \quad \text{..............(2.12)}$$

And substituting δ by the expression given above yields:

$$I_o \quad \frac{(V_i - V_o)\,DT\left(D - \frac{V_i - V_o}{V_o} D\right)}{2L} \quad \text{.....(2.13)}$$

This expression can be rewritten as:

$$V_o = V_i \frac{1}{\frac{2LI_o}{D^2 V_i T} + 1} \quad \text{..............(2.14)}$$

It can be seen that the output voltage of a buck converter operating in discontinuous mode is much more complicated than its counterpart of the continuous mode. Furthermore, the output voltage is now a function not only of the input voltage(V_i) and the duty cycle D, but also of the inductor value (L), the commutation period (T) and the output current (I_O).

A boost converter(step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching mode power supply (SMPS)containing at least two semi-conductors switches(a diode and a transistor) and atleast on energy storage element. Filters made of capacitors (sometimes in combination with inductors)are normally added to the output of the converter to reduce output voltage ripple. A boost converter is sometimes called a step-up converters inceit “steps up” the source voltage. Since power(*P*=*VI*) must be conserved, the output current is lower than the source current.

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The boost converter has the same components as the buck converter, but this converter produces an output voltage greater than the source. "Boost" converters start their voltage conversion with a current flowing through the inductor (switch is closed).Then they close the switch leaving the current no other path to go than through a diode(functions as one way valve) The current then wants to slow really fast and the only way it can do this is by increasing it's voltage (a kinto pressure) at the end that connects to the diode, and switch. If the voltage is high enough it opens the diode, and one through the diode, the current can't flowback. This is the very basic concept of boost converter.

2.7.2.3 Continuous mode

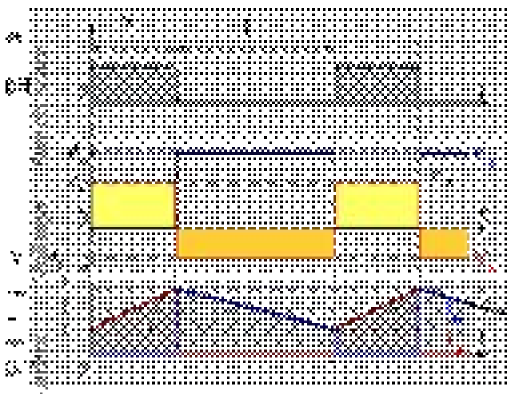

Fig. 2.7 Waveforms of current and voltage in a boost converter operating in continuous mode.

When a boost converter operates in continuous mode, the current through the inductor(I_L)never falls to zero.Figure3 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behaviour)operating in steady conditions:

During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current(I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \quad \text{.............(2.15)}$$

At the end of the On-state, the increase of $I_L$is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i \quad \text{..(2.16)}$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (Sis always on).

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of $I_L$is:

$$V_i - V_o = L\frac{dI_L}{dt} \quad \text{.............(2.17)}$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)dt}{L} = \frac{(V_i - V_o)(1-D)T}{L} \quad \text{.....(2.18)}$$

As we consider that the converter operates instead y-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2 \quad \text{.............(2.19)}$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0 \quad \text{..........(2.20)}$$

Substituting $\Delta I_{L_{On}}$ and $\Delta I_{L_{Off}}$ by their expressions yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0 \quad \text{..(2.21)}$$

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D} \quad \text{.............(2.22)}$$

Which in turns reveals the duty cycle to be:

$$D = 1 - \frac{V_i}{V_o} \quad \text{.............(2.23)}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage(as the duty cycle goes from 0 to1),and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a *step-up* converter.

2.9.1 Operating Principle

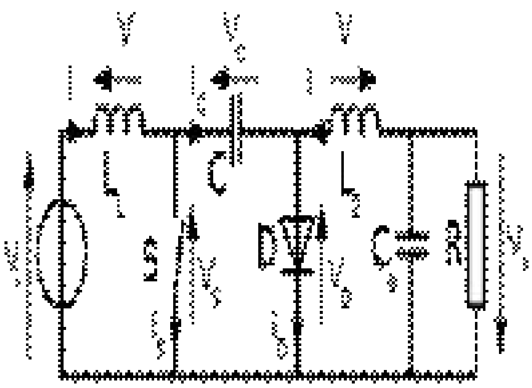

Fig 2.14:Schematicofanon-isolatedĆuk converter.

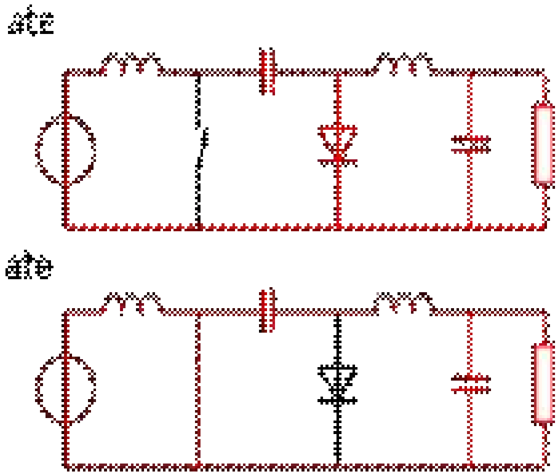

Figure 2.15: The two operating states of a non-isolated Ćuk converter.

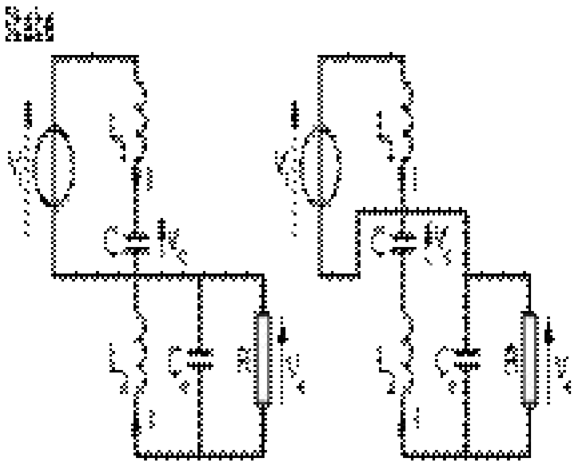

Fig 2.16:Thetwooperatingstatesofanon-isolatedĆukconverter.Inthisfigure,thediodeandtheswitch

are either replaced by a short circuit when they are on or by an open circuit when they are off.

It can be seen that when in the Off state, the capacitor C is being charged by the input source through the inductor L_1.When in the On state, the capacitor C transfers the energy to the output capacitor through the inductance L_2. A non-isolated Ćuk converter comprises two inductors, two capacitors, as witch (usually a transistor),and a diode. Its schematic can be seen in figure1.It is an inverting converter, so the output voltage is negative with respect to the input voltage. The capacitor C is used to transfer energy and is connected alternately to the input and to the output of the converter *via* the commutation of the transistor and the diode(see figures 2and 3).

The two inductors L_1 and L_2 are used to convert respectively the input voltage source(V_i) and the output voltage source (C_o) into current sources. Indeed, at a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by(parasitic)resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor)prevents resistive current limiting and its associated energy loss.

As with other converters(buck converter, boost converter, buck-boost converter) the Ćuk converter can either operate in continuous or discontinuous current mode. However, unlike these converters, it can also operate in discontinuous voltage mode (i.e., the voltage across the capacitor drops to zero during the commutation cycle).

2.9.2 Continuous mode

In steady state, the energy stored in the inductors has to remain the same at the beginning and at the end of a commutation cycle. The energy in an inductor is given by:

$$E = \frac{1}{2}LI^2 \quad \ldots\ldots\ldots\ldots\ldots(2.49)$$

This implies that the current through the inductors has to be the same at the beginning and the end of the commutation cycle. As the evolution of the current through an inductor is related to the voltage across it:

$$V_L = L\frac{dI}{dt} \quad \ldots\ldots\ldots\ldots\ldots(2.50)$$

It can be seen that the average value of the inductor voltages over a commutation period have to be zero to satisfy the steady-state requirements.

If we consider that the capacitors C and C_o are large enough for the voltage ripple across them to be negligible, the inductor voltages become:

- In the off-state, inductor $L_1$is connected in series with V_i and C (seefigure2). Therefore $V_{L1}=V_i-V_C$.As the diode D is forward biased (we consider zero voltage drop),$L_2$is directly connected to the output capacitor. Therefore $V_{L2}=V_o$
- In the on-state, inductor $L_1$is directly connected to the input source. Therefore $V_{L1}=V_i$. Inductor $L_2$is connected in series with C and the output capacitor, so $V_{L2}=V_o+V_C$

The converter operates in on-state from t=0 to t=D·T(D is the duty cycle), and in off state from D·T to T (that is, during a period equal to (1-D)·T).The average values of $V_{L1}$and $V_{L2}$are therefore:

$$\bar{V}_{L1} = D\cdot V_i + (1-D)\cdot(V_i - V_C) = (V_i - (1-D)\cdot V_C) \quad ..(2.51)$$

$$\bar{V}_{L2} = D(V_o + V_C) + (1-D)\cdot -V_o = (V_o + D\cdot V_C) \quad ..(2.52)$$

As both average voltage have to be zero to satisfy the steady-state conditions we can write, using the last equation:

$$V_C = \frac{V_o}{D} \quad \ldots\ldots\ldots\ldots\ldots(2.53)$$

So the average voltage across L_1becomes:

$$\bar{V}_{L1} = \left(V_i + (1-D)\cdot\frac{V_o}{D}\right) = 0 \quad ..(2.54)$$

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Which can be written as:

$$\frac{V_o}{V_i} = \frac{D}{1-D} \quad \ldots\ldots\ldots\ldots\ldots(2.55)$$

It can be seen that this relation is the same as that obtained for the Buck-boost converter.

2.9.3 Discontinuous mode

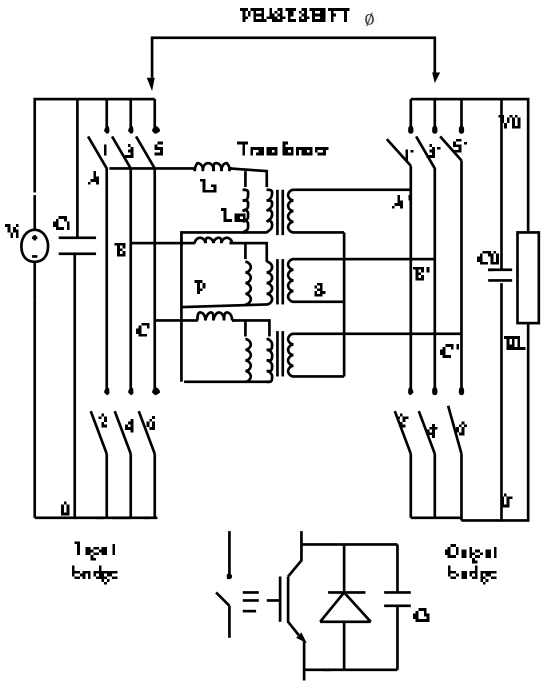
Like all DC-DC converters Cuk converters rely on the ability of the inductors in the circuit to provide continuous current, in much the same way a capacitor in a rectifier filter provides continuous voltage. If this inductor is too small or below the "critical inductance", then the current will be discontinuous. This state of operation is usually not studied too much depth, as it is not used beyond a demonstrating of why the minimum inductance is crucial.

The minimum inductance is given by:

$$L_1 min = \frac{(1-D)^2 R}{2 D f_s} \quad \ldots\ldots\ldots(2.56)$$

Where f_Si s the switching frequency.

THREE-PHASE DAB DC–DC CONVERTER



(a)

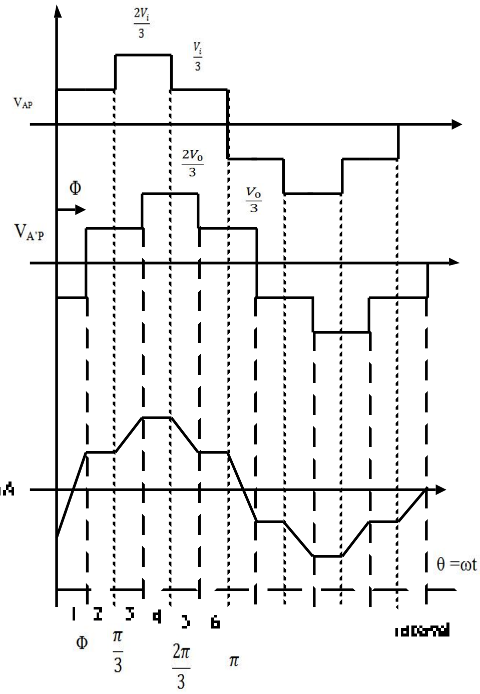


Fig.1. Three-phase DAB. (a) Topology. (b) Idealized waveforms, gatingsignals can be found in [1].

V.MATLAB/SIMULATION RESULTS

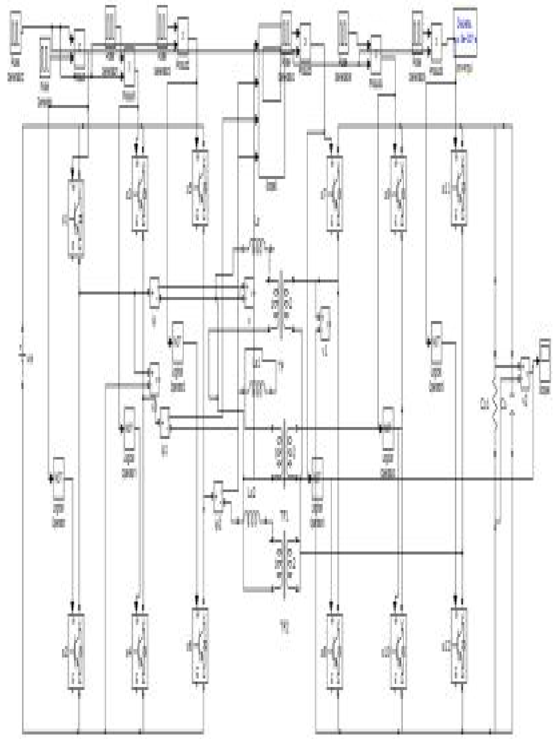


Fig 3 Matlab/simulation conventional circuit of three-phase DAB dc-dc converter Topology.

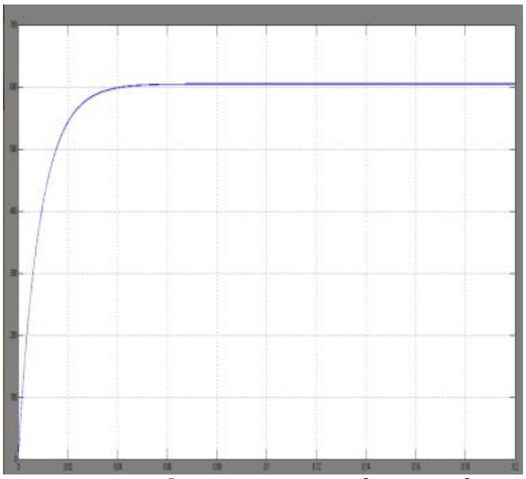


Fig 4 simulation wave form of output voltage

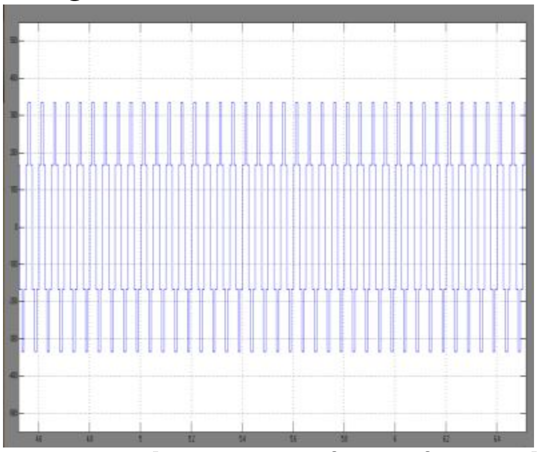


Fig 5 simulation wave form of input line voltage at 750v

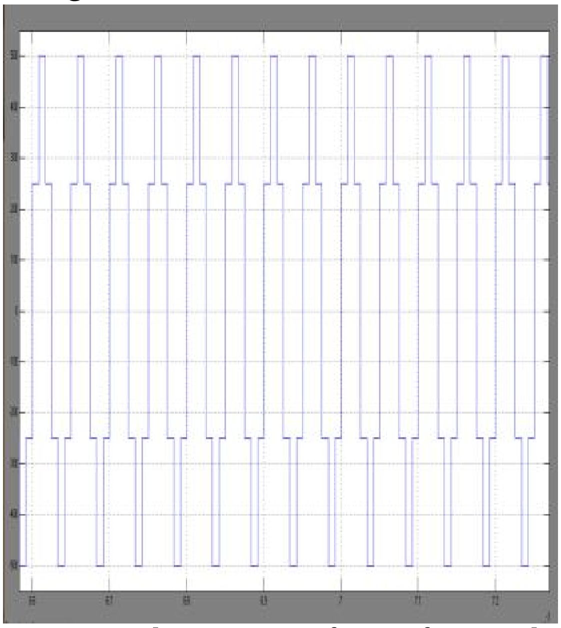


Fig 6 simulation wave form of input line voltage at 750 v

Fig 7 simulation wave form of input line voltage at 900v

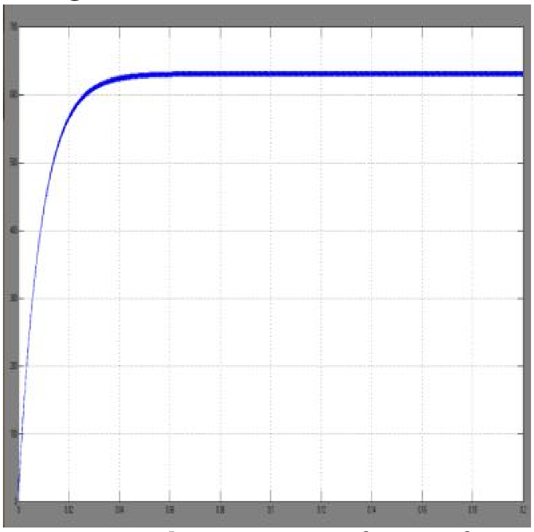


Fig 8 simulation wave form of output voltage

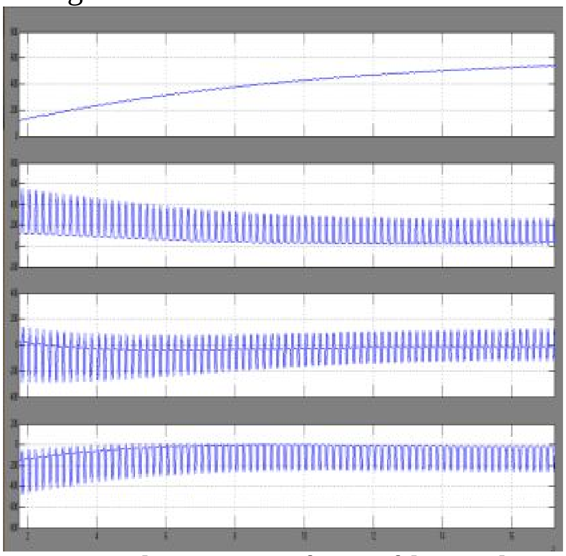


Fig 9 simulation wave form of line voltages and currents

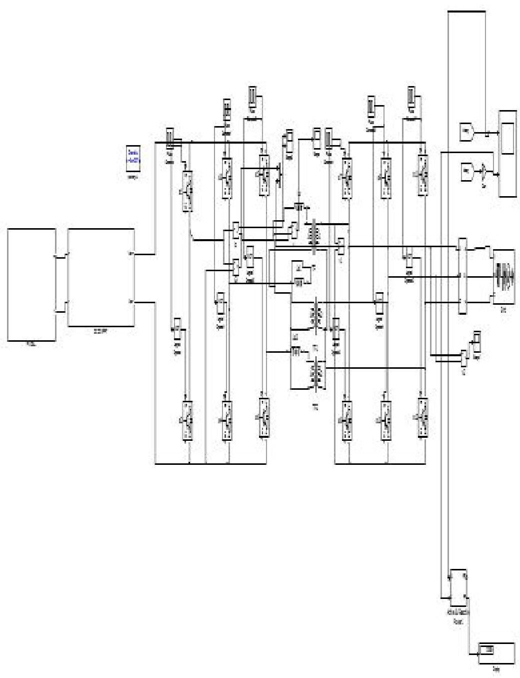


Fig 10 Matlab/simulation proposed method of three-phase DAB dc-dc converter Topology with PV and grid

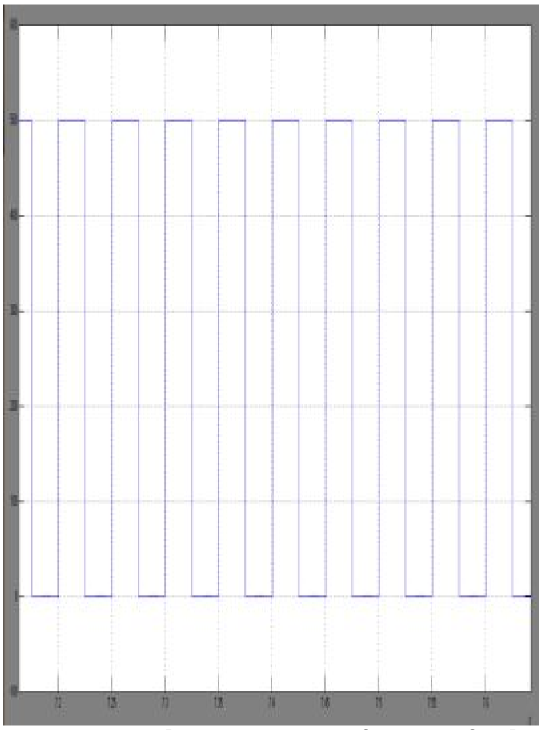


Fig 11simulation wave form of dc-dc converter Topology with before grid connected output voltage

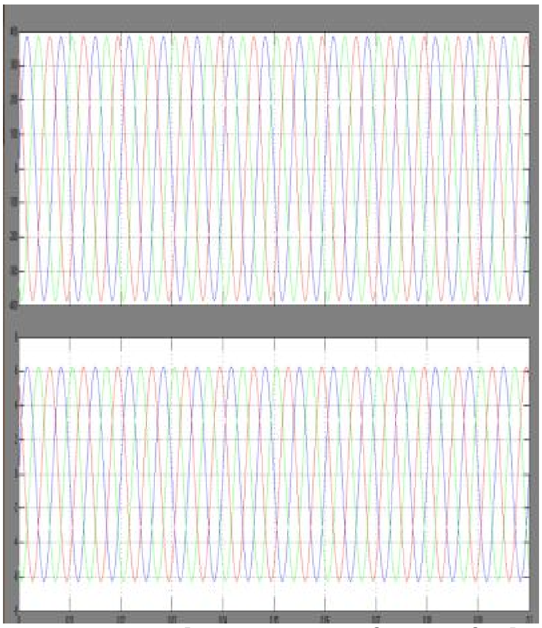


Fig 12 simulation wave form of dc-dc converter Topology with grid connected output voltage and current

CONCLUSION

This work has evaluated the strategy for utilization of PV Cells for induction motor pumping. The electricity bill gets reduced since solar energy is utilized for agriculture pumping. By using Matlab/Simulink the Photo Voltaic powered three phase induction motor drive system is successfully designed, modeled and simulated. The concept of Photo Voltaic grid is proposed. The simulation results of three phase grid connected system for Photo Voltaic pumping are presented. With the theoretical results the simulation results are in line. The scope of this work is the simulation and implementation of three phases PV Powered grid connected system.

REFERENCES

[1].Nico H. Baars, Student Member, IEEE, Jordi Everts, Member, IEEE, Henk Huisman, Jorge L. Duarte, Member, IEEE, and Elena A. Lomonova, Senior Member, IEEE"A 80-kW Isolated DC–DC Converter m for Railway Applications"IEEE Transactions On

Power Electronics, Vol. 30, No. 12, December 2015.
[2] R. De Doncker, D. Divan, and M. Kheraluwala, "A three-phase softswitched high-power-density dc/dc converter for high-power applications," IEEE Trans. Ind. Appl., vol. 27, no. 1, pp. 63–73, Jan. 1991.
[3] J. Dudrik, P. Spanik, and N.-D. Trip, "Zero-voltage and zero-current switching full-bridge dc-dc converter with auxiliary transformer," IEEE Trans. Power Electron., vol. 21, no. 5, pp. 1328–1335, Sep. 2006.
[4] J.-G. Cho, C.-Y. Jeong, and F. Lee, "Zero-voltage and zero-currentswitching full-bridge PWM converter using secondary active clamp," IEEE Trans. Power Electron., vol. 13, no. 4, pp. 601–607, Jul. 1998.
[5] O. Patterson and D. Divan, "Pseudo-resonant full bridge dc/dc converter," IEEE Trans. Power Electron., vol. 6, no. 4, pp. 671–678, Oct. 1991.
[6] R. Steigerwald, "A comparison of half-bridge resonant converter topologies," IEEE Trans. Power Electron., vol. 3, no. 2, pp. 174–182, Apr. 1988.
[7] A. Bhat and R. Zheng, "Analysis and design of a three-phase LCC-type resonant converter," IEEE Trans. Aerospace and Electron. Syst., vol. 34, no. 2, pp. 508–519, Apr. 1998.
[8] R. Steigerwald, "High-frequency resonant transistor dc-dc converters," IEEE Trans. Ind. Electron., vol. IE-31, no. 2, pp. 181–191, May 1984.
[9] X. Li, "A LLC-type dual-bridge resonant converter: Analysis, design, simulation, and experimental results," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4313–4321, Aug. 2014.
[10] J.-W. Kim and G.-W. Moon, "A new LLC series resonant converter with a narrow switching frequency variation and reduced conduction losses," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4278–4287, Aug. 2014.
[11] S. De Simone, C. Adragna, C. Spini, and G. Gattavari, "Design-oriented steady-state analysis of LLC resonant converters based on FHA," in Proc. Int. Symp. Power Electron., Electr. Drives, Autom. Motion,, May 2006, pp. 200–207.
[12] B.-C. Kim, K.-B. Park, C.-E. Kim, B.-H. Lee, and G.-W. Moon, "LLC resonant converter with adaptive link-voltage variation for a high-powerdensity adapter," IEEE Trans. Power Electron., vol. 25, no. 9, pp. 2248– 2252, Sep. 2010.
[13] Z. Hu, Y. Qiu, L. Wang, and Y.-F. Liu, "An interleaved LLC resonant converter operating at constant switching frequency," IEEE Trans. Power Electron., vol. 29, no. 6, pp. 2931–2943, Jun. 2014.
[14] M. Pavlovsky, S. de Haan, and J. Ferreira, "Reaching high power density in multikilowatt dc-dc converters with galvanic isolation," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 603–612, Mar. 2009.