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# Design of Interleaved Push Pull Converter For Photovoltaic Systems

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***Abstract:*** *This paper puts forward a proposal for design of a Interleaved push pull DC-DC converter which employs a half bridge current fed push pull DC-DC converter scheme to increase the output voltage obtained from the PV arrays. The proposed system consists of two push pull DC-DC converter modules connected in IPOS configuration to form a single Interleaved DC-DC converter system. This Interleaved converter system is suited for both medium and high power PV applications and provides much better efficiency compared to other converter systems. It is expected to exhibit better boosting capability while showing a significant reduction in switching losses associated with the converter system. The paper also discusses the importance of isolated DC-DC converter topologies in high power applications where isolation between input and output is a matter of great importance. This paper explains in detail about the design steps for the proposed system and also the simulation outputs obtained using the MATLAB software*

***Keywords:*** *DC-DC converter IPOS configuration, Interleaved converter,isolated DC-DC converter ,.push pull DC-DC Converter,PV panels.*

## I. Introduction

Over the past few decades researches on renewable energy have reached a new level of urgency as the world have come to realize the pitfalls of injudicious use of conventional energy sources. This injudicious use of conventional energy sources have made the world the epitome of pollution of all kind. The energy being the primary need of the world, the scientific world realized that the solution to this dilemma lies in harnessing the renewable energy sources.On pursuit of this mission, the scientific world have been successful in harnessing several renewable sources like water, wind, solar etc. Among these solar energy proved to be a sensible choice because of its abundance and clean nature. The technological stagnancy during the initial decades have been overcome and today solar energy is more powerful than ever. There is still some need for innovations in this sector and this paper focus on such an innovation.The Interleaved converter configuration which is focussed upon in this paper is such an innovation that can assist in the growth of PV applications. The proposed system offers simplicity in design and ease of operation that makes it suitable for household applications. The paper discuss in detail about the design procedure of the proposed system and analyses it with the help of simulation software

Extensive study on renewable and solar energy have been made as a part of research for this paper. The study uncovered the fact that how big a role solar energy plays as a part of global initiative against climate change. Nations and organization all over the world have shown support for solar energy empowerment. Developing countries like India have extended their support through the efforts of Ministry of New and Renewable Energy (MNRE) and taking the initiative to form International Solar Alliance (ISA), an organization dedicated to solarise the world. The evolution of power electronics has emerged since last few decades ago and with it has brought an era of digitalisation with wide range of applications in computer, space craft, telecommunication etc .Behind all this applications is power source needed to operate and this is where DC-DC converters comes into play[6].A typical survey revealed that photovoltaic based energy is modern way of generating the energy and DC-DC converters finds an enormous potential in this area[7].The existing converter technologies suffers from various disadvantages thus the concept of cooperative control in multi agent introduced for Interleaved DC-DC converter offers an better alternative[5].

Interleaved multilevel DC-DC converters designed by integrating full bridge converter in series can be used for high power and high voltage DC based applications[4].The system makes use of an interleaved configuration where the OSIS (Output-Series Input-Series) connection to create converters with high efficiency. A three loop control system is dedicated input voltage control system is proposed to achieve equal sharing of input and output voltage by series connected modules[3].Comparisons for different cascaded and multilevel topologies proved that it finds an excellent application in regenerative braking sectors when combined with super capacitors. The Interleaved multilevel Converter arrangement benefits from both reduced frequency and switching losses [2] The papers [1].[10],and [3] provided help with the design procedure for the Interleaved converter topology proposed in this paper.

The principle of working, design and simulation diagram of some basic dc-dc converters were studied to get a better understanding of DC-DC converters. The paper used for study contains the theoretical derivations and parameters equations with design and examples [11].As a part of the research some innovative changes in DC-DC converters were also investigated. The multi-port converters was such an idea and they are considered to be ideal for high power applications [12].The papers [13] [14] and [17] discusses and explains the possibility of multi-port converter systems. The papers [15] and [16] explores the innovative designs implemented in boost DC-DC converters and viability of the design. Control strategies for DC-DC converters is an area of concern while designing a DC-DC converters. Thus they were also thoroughly researched and insights from the research proves influential in the design process of the proposed system. The papers [18] and [19] explains and compares various existing control strategies while [20] proposes a hybrid control strategy from a practical point of view.

## II. Conventional Power Conditioning Devices For Pv Systems

A typical photovoltaic (PV) system whether installed in home or an industry consists of four main section/modules. The first module is solar/photovoltaic array unit, the second section DC-DC Converter unit, third is DCc-AC Converter unit and the final module is the Grid. Photovoltaic (PV) array is the combination of several PV panels which in turn is made of PV modules and each PV module is made of individual PV cells. An individual PV cell can provide output voltage in the range of 0.3-0.5 V depending on the semiconductor material used in the cell. The PV panels or arrays may provide output voltages in the range that cannot be directly utilized for any household or industrial applications. Thus special circuits are utilized to increase the output voltage level from PV panels to a much higher voltage level. These special circuits are called DC-DC converters and they are commonly used as a part of converter system used in photovoltaic applications The DC-AC converters, another integral part of PV converter system converts the boosted DC output to AC output form. Since AC current is the commonly used nowadays all PV systems has DC-AC converters but for applications where DC power is needed, the DC output from the DC-DC converter is stored in battery or connected to a DC grid. Grid can either be DC or AC and it refers to the transmission network that supplies the generated power to the load.

The circuits that are employed in the conversion of DC power level from one level to another level are known as DC-DC converter circuits. There are still applications where constant power is needed for its operation like in integrated circuits (IC) and DC power is used in such applications. The DC power level required in applications vary from a few millivolts in chips to few kilovolts in dc shunt motors used for traction. Thus DC power level has to be adjusted to suit the applications and this is where DC-DC converters come into play. DC-DC conversion can be obtained either electronically or electromagnetically but because of its several advantages like high efficiency, low power dissipation electronic circuits are commonly used. DC-DC converters operate on the principle of switching regulation. In switching regulation, the conversion circuit usually consists of one or more switches that are either fully controlled like GTO, TRIAC or half controlled like MOSFET, inductors, or capacitors. The switching action is regulated to store the energy temporarily and release it to obtain desired output power level. Either the inductors, or capacitors can be used to store the energy or diodes assist in the rectification.

Generally DC-DC converters can be classified on the basis of mode of operation. The two types of converters belong to this classification: one is Linear DC-DC converter and other one is Switched Mode DC-DC converter. Linear converters uses resistive voltage drop to regulate the DC power level whereas switched mode converters regulates the output power level by storing the energy in inductors or capacitors periodically and releasing them. The main advantage of switched mode converters is that they can either increase or decrease the power level of the voltage given to it .It also offers advantages like higher conversion efficiency, higher frequency range of operation, smaller component size etc whereas linear converters suffer from noise, poor conversion efficiency etc. Thus switch mode converters are preferred over linear converters.

On the basis of the criteria of electrical separation converters can be classified into two. They are Isolated DC-DC converters and Non Isolated DC-DC converters.Isolated DC-DC converters are identified by the use of a transformer in its circuit which will electrical separation between input and output sections of the converter. The electrical separation ensures safety of equipment and its user and also has the added advantage of providing higher operating range for isolated converters.. Non isolated transformers on the other hand offers less safety and operating range of voltages due to the lack of transformer but have more stability and simplicity in operation compared to isolated converters.

Some of the commonly used isolated converters topologies were identified and they are mentioned:full bridge converter,fly back converter, forward converter, half bridge converter & push-pull converter to this category. While the presence of transformer tends to make isolated converter design a little bit difficult, the benefits of this outweighs the difficulties. The isolated converters are commonly used and suited for high power applications.

## III. Proposed Push Pull Interleaved System

The proposed system in this paper is based on the isolated push pull DC-DC converter topology. The proposed system consists of Interleaved push pull converter which is made up of two push pull converters connected in input parallel output series (IPOS) configuration. Push Pull topology was selected because of the several advantages that it offered when compared to other topologies. The isolated push pull converter arrangement is preferred because of the following reasons.

The main advantage being the electrical isolation provided by the presence of isolation transformer. The conduction losses, ripples and RMS current of the power components is considerably less is also an factor in favor of the chosen converter . Good transformer core utilization provided by the placement of windings on a common core provides electromagnetically stable circuit. Small size of the filter side of circuit i.e. it uses small inductors and capacitors is a space reducing advantage of proposed system.

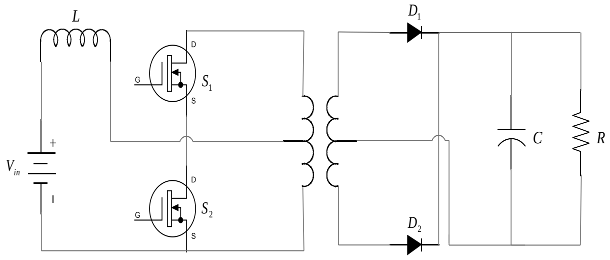



**Fig 1:** Push Pull Converter Circuit Diagram

Fig 1 represents the circuit diagram of the single unit of the proposed interleaved push pull DC-DC converter. The above represented converter topology consists of two MOSFET switches S1 and S2 whose switching operation can be controlled with the help of a gate driver circuit. Diodes D1&D2 Inductor L and capacitor C helps in the transfer and filter of power from input side to outputs.

Fig 2 shows the circuit diagram of Interleaved push pull converter unit which is the proposed system. The proposed system consists of four MOSFET switches S1, S2, S3 and S4 which form the switching circuit of the converter. The switching circuit is responsible for the regulation of power through the circuit. The diodes D1, D2, D3 & D4, Inductor L1&L2, capacitor C1&C2 helps in the transfer and filter of power from input side to output side.

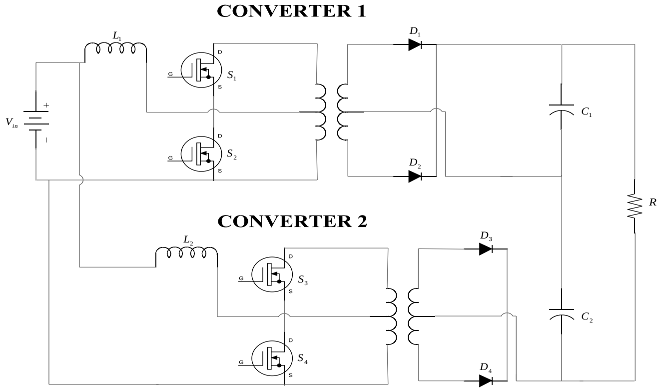



**Fig 2:** Interleaved Push Pull Converter Circuit Diagram

The proposed system has the following advantages: Improvement in the power handling capability of the converter system. The proposed system can deliver high voltages with excellent harmonics. Switching frequency of the system is reduced as the system is made up of low voltage rating components. The proposed system also provides good voltage insulation, mechanical stability and ease of service.

## IV. Design Of The Proposed System

This section discusses about the design of various parameters off the push pull converter. The parameters taken into account includes input voltage $V_{IN}$, output voltage $V_{OUT}$, duty ratio D etc. The design steps also include the design of isolation transformer, inductor design and capacitor design. Semiconductor switch and diode design are also integral for the proper working of the converter.

Following assumptions were made during the design of the converter system: In reality voltage output from solar/photovoltaic cells will not be a constant but for the purpose of design and simulation it is considered to be constant value.Another important factor to be taken into consideration is the Equivalent series resistance (ESR) of the capacitor and for ease of calculation it is neglected.Isolation transformer used in the system is assumed to be of ideal nature.

The actual input voltage range may be greater than or less than the specified range. Therefore, care must be taken during design that the converter can function properly within a voltage range lower or greater than the specified input voltage level. Similarly, the converter must be designed to operate at voltages higher than the specified maximum input voltage. The chosen input voltage is a deciding factor for the input current flowing the converter. This factor also plays an important factor as the range of input current determines the thickness of the wires needed and also the winding of the transformer used. So care should be taken to keep the input current within safe limits

Input current is given by:

$$I_{IN} = \frac{P_O}{\eta * V_D} \qquad (0)$$

The output voltage can be maintained within safe limit of operation taking into consideration the range of line, load, and operating temperature. The current also determines the size of the output inductor and the choice of output capacitors which in turn greatly influence the output ripple and noise.

Output Voltage is given by:

$$V_{OUT} = \frac{N_S}{N_P}\frac{D}{1-D}V_{IN} \qquad (2)$$

Duty ratio decides the output voltage of the converter. The correct duty ratio provides the desired output voltage .Various other parameters associated with the design of the converter like input and output currents is decided by the choice of duty ratio..

Duty Ratio is given by:

$$D = 1 - \frac{V_{IN}}{2V_{CT}} \qquad (3)$$

Knowledge of system parameters allows the designer to determine the power transformer specifications. The transformer in push pull converter is used for coupling and isolation, in which energy storage is undesirable. Detailed procedure for transformer design includes determining flux density excursions, selecting the core, designing the windings, and calculating losses and temperature rise.

Core Area:

$$A_i = \frac{1}{4.44 f B_m T_e} \qquad (4)$$

The core area calculation will help in the determination of core used for winding the transformer.

Primary Winding Calculations:

Primary Current $I_P = \frac{P_T}{V_P}$ (5)

Primary Turns $N_P = T_V * V_P$ (6)

Area of Primary conductor $A_P = \frac{I_P}{\delta}$ (7)

Primary conductor area along with current density ( $\delta$ ) will help in determining the conductor gauge of primary conductor. The current density is arbitrarily chosen.

Secondary Winding Calculations:

Secondary Current $I_S = \frac{P_T}{V_S}$ (8)

Secondary Turns $N_S = T_V * V_S$ (9)

Area of Secondary Conductor $A_S = \frac{I_S}{\delta}$ (10)

Secondary conductor area along with current density ( $\delta$ ) will help in determining the secondary conductor gauge.

Transformer Ratio is given by:

$$n = \frac{N_P}{N_S} = \frac{V_{CT}}{V_O} \qquad (11)$$

The inductor value is mainly influenced by the amount of output ripple current. Higher ripple current means smaller the output inductor both electrically and physically but it demands for more output capacitance with lower equivalent resistance (ESR). Moreover, higher ripple current translates to higher peak current for the power transistor for a given output power which means greater loss and obvious lower efficiency. A design parameter, output ripple factor, defined as the ratio of the peak-to-peak ripple current to the average current in the inductor is used in output inductor selection. Ripple factor can be determined. The ripple factor, $y=I/2I_O$, where Io is the maximum output current. For most practical design, the ripple factor is often set to 0.1-0.2.

$$L = \frac{V_{CT}}{16 * fs * \Delta I} \qquad (12)$$

The ripple current in the output inductor generates a voltage ripple on the output capacitors. Part of the ripple voltage comes from the integration of the current by the capacitance, and part comes from the voltage that appears across the capacitors ESR. The value of the output capacitance must be high enough and the ESR is low enough to give acceptable voltage ripple with the chosen output inductor. The output capacitance can be calculated with the following equation:

$$C = \frac{P_O(2D-1)}{4 * y * fs * V_O^{\ 2}} \qquad (13)$$

The first criterion in selecting a power transistor for switching is the peak current capability. Once the turns ratio for transformer and peak current in the output inductor are known, estimate the peak current through the power switch. The magnetization current can be neglected for this calculation. Switch should be selected such that it has a minimum current limit that is at least 10% greater than the maximum primary current. The second criterion for the selection is VDSS rating of the MOSFET. In push pull converters, the switch will see twice the maximum input voltage plus any spikes caused by winding leakage inductance and rectifier forward and reverse characteristics.

For the output rectifier diode, the maximum reverse voltage and peak output current are the deciding factors. These are calculated with the equations shown below an appropriate device is selected.

The maximum reverse voltage $V_{RR(MAX)}$ is:

$$V_{RR(MAX)} = V_{IN(MAX)} * \frac{N_S}{N_P} \qquad (14)$$

The peak output current $I_{OUT(PEAK)}$ is:

$$I_{OUT(PEAK)} = 2.8 I_{OUT(MAX)} \qquad (15)$$

The proposed system which is the Interleaved push pull converter is achieved by connecting two single push pull converter units in IPOS configuration. The design of final interleaved converter starts initially by designing a single push pull converter unit from the design equations that have been explained in this section..Then the single converter unit is connected to another unit designed using the same design pprocedure in IPOS configuration. The working of the proposed system was observed by first creating a simulation model in a simulation software like MATLAB and the values obtained through design calculations are given as the values of various parameters involved in the simulation process created using MATLAB software.

## V. Simulation Results And Analysis

**Table 1:** Simulation Parameter

| SL No | *PARAMETERS* | *VALUES* |
|---|---|---|
| 1 | INPUT VOLTAGE, $V_{IN}$ | 48V |
| 2 | OUTPUT VOLTAGE, $V_{OUT}$ | 220V |
| 3 | INPUT CURRENT, $I_{IN}$ | 12A |
| 4 | DUTY RATIO, $D$ | 0.647 |
| 5 | INDUCTOR VALUE, $L$ | 90.23µH |
| 6 | CAPACITOR VALUE, $C$ | 2.26µF |

| SL No | *PARAMETERS* | *VALUES* |
|---|---|---|
| 7 | TRANSFORMER RATIO, $n$ | 2.29 |
| 8 | OUTPUT CURRENT, $I_{OUT}$ | 22A |

**Table 1:** Simulation Parameters

The proposed system circuit was created in the simulation software MATLAB to have better understanding of the working of the proposed system. The MATLAB simulation model was simulated with the design values calculated using the design equations provided in the above section .The simulation components used in the Simulink model are o ideal nature and in practical scenario the components value must be slightly lower or greater than the simulation values used.

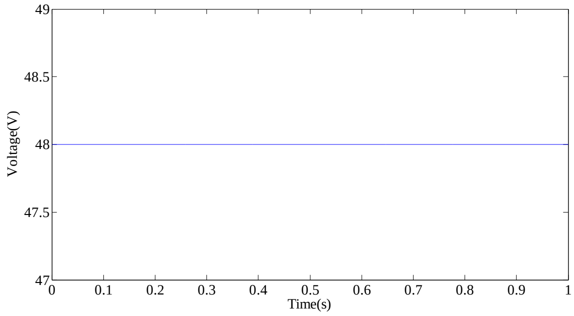



**Fig 3:** Input Voltage Waveform

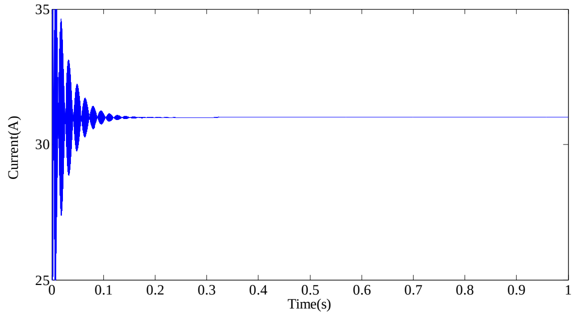



**Fig 4:** Input Current Waveform of Converter 1

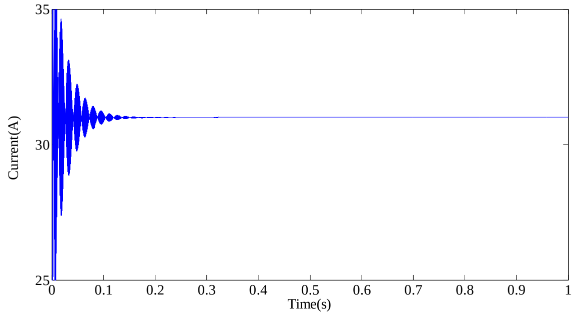
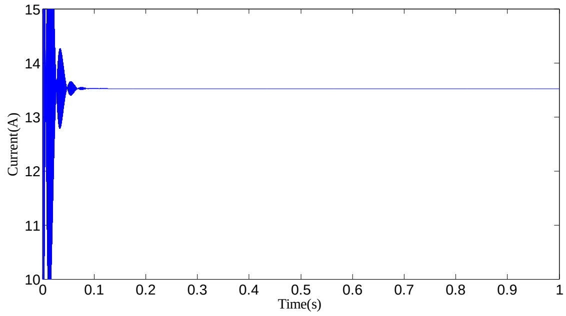



**Fig 5:** Input Current Waveform of converter 2




. **Fig 6:** Output Current Waveform of converter 1

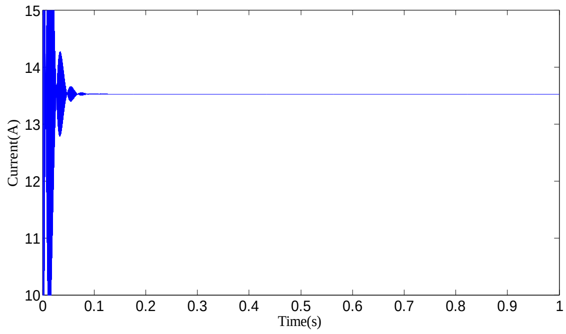



**Fig 7:** Output current Waveform of converter 2

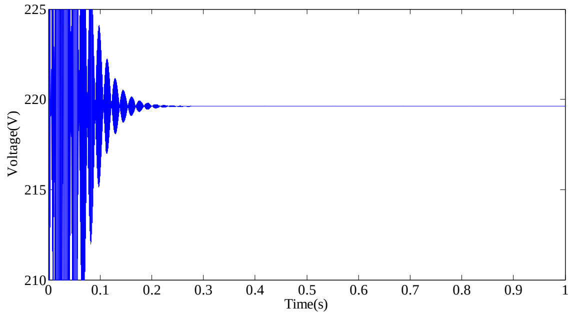



**Fig 8:**Output Voltage Waveform of interleaved system

Fig 3 represents the input voltage waveform of the Simulink model created in MATLAB software. The input voltage can be seen to be represented as a constant voltage source from the waveform despite in reality it should show some fluctuations because of the variations in PV array output. The input voltage was assumed to be supplied by a constant source for the ease in design steps

Fig 4 & Fig 5 represents the input current waveform of the Simulink model output of the converter 1 and converter 2 obtained from MATLAB software. The input current was found to be near 8 Amperes which may be considered quite high value but the ripples in current have be reduced. With some adjustments the input current can be brought down.

Fig 8 shows the waveform of the output voltage obtained from the Simulink model generated in MATLAB software. The output voltage value was found to be near 220 volts which is closer to the design values obtained. Fig 6 & Fig 7 shows the waveform of the output current obtained. The waveform shows the values to be near 16 Amperes which is quite high but can be reduced with some adjustments to the design of the circuit.

## VI. Conclusion

Design and simulation of proposed Converter model was carried out and its results were analyzed in this paper. Many converter topologies were researched as the part of study conducted for this paper and some necessary features for a DC-DC converter used in photovoltaic systems were agreed upon as a conclusion of the research. Push pull converter was selected due to its unique characteristics compared with other DC-DC converter topologies .The circuit principle and their operating modes for both step up and step down conversion are explained in detail. The design calculation and specifications are also discussed. The proposed system was designed to be connected to a PV panel that can supply the proposed interleaved converter with 48V source voltage. The operation of the system was verified through simulation model done in Simulink environment provided by MATLAB software. From the analysis of the data obtained from the simulation model and comparative study of the proposed system proved the effectiveness of the chosen topology taking into consideration the factors like power handling capability, low switching losses and efficiency. A hardware prototype model of 48V/220V can be implemented to verify the effectiveness of the converter.

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