Bidirectional AC-DC Power Converter

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Abstract—With the growing emphasis on compact, smaller and efficient power systems there is an increasing interest in using
the bi-directional converters, especially in DC power-based applications like space, telecommunications and computer
systems. In this paper the ac-dc converter, capable of bilateral power flow, provides the functionality of two uni-directional
converters in a single converter unit. Achieving bi-directional flow of power using the same power components provides a
simple but efficient topology for a high power bi-directional ac-dc conversion with unity power factor.

A bidirectional converter combines of a converter and an inverter. It is referred as the converter which converts AC supply to
DC supply and the same circuit can be used for converting the DC supply to AC supply. In this paper, for the proposed
converter the AC input voltage that goes into a converter is normally at fixed RMS value and fixed frequency. The inclusion
of phase-controlled MOSFETs in the converter ensures that a regulated DC output voltage is obtained.

Key words: Bilateral power flow, unity power factor.

I. INTRODUCTION

In the field of power electronics, converters and inverters play an important role in alternating and direct voltage
conversions. DC voltages are used for home appliances on a large scale whereas AC voltages at higher
frequencies are converted using step down transformers and used for industrial systems and other automations.

Direct current having higher voltages are not transferred directly to loads. Thus, inverters and converters play an
effective role in these conversions for providing power to the desired load from the required sources.

To reduce the hardware for high end power applications and sufficient conversions Bidirectional converters
alongwith MOSFETs as switches are implemented in this project.

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For the high-end power applications, we use boost converter after the voltage has been stepped down by the
transformer using high value components such as inductors, capacitors and switch for the converter. For this
reason, in this converter, the conventional boost type topology and PWM rectifier are used together to share the
power and to meet the standard conditions. The MOSFETs at the later stage are used as switches for the
conversion of AC voltages to DC. They are fed the gating PWM pulses of variable duty cycle.
For the inversion of the DC voltages to AC the inverter with a H Bridge circuit is implemented to handle high power. Earlier many different bidirectional flow capability topologies have been proposed. The most commonly used single phase bidirectional converter topology consists of four fully controlled switches. Such proposals use expensive fully controlled switches such as IGBT or GTO thyristors. But, there also exists an exception in one such bidirectional converter circuit that primarily uses SCR thyristors and one fully controlled switch such as IGBT.

In this paper, the efficient operation of the MOSFETS is re-examined and modified. The potential of the boost converter for power factor correction is explored. By implementing a simple control method, the power correction can be achieved in both the power flow operations. Thus, the input current is sinusoidal shaped to follow the input voltage (i.e. either in phase with the input voltage for motoring operation or 180 out of phase with the input voltage in the regenerating mode). Thus, the current distortion factor approaches unity and the new proposed converter operation can reduce harmonic pollution and disturbances on the power supply by minimizing the input current harmonics.

The bidirectional power flow feature of this converter thus allows to store the energy in the load, such as a motor, to be recovered back to the supply, which leads to an increase in overall energy efficiency and a reduction in the DC link capacitance. This converter can also be applied to general industrial electronic motor drive systems for variable drive applications. Thus, by the implementation of the power factor correction feature in this converter this proposed circuit can meet international harmonics standards.

II. LITERATURE SURVEY

We have studied Bidirectional Converter by referring “AC Drives and Converter Circuit” by B. K. Bose. To convert AC to DC basic boost topology is used, and while converting DC to AC, sinusoidal pulse width modulation is given to MOSFETs used in inverter.
While studying about the bidirectional converters an IEEE paper published on Single phase improved power quality by AC-DC converters, has proved that converters provide improved power quality not only at the input ac mains but also at dc output for the better overall design of equipment. These converters have given the feature of universal input to the number of products which can have input power either from ac mains of a varying voltage of 90 to 300 V with a varying frequency from 40 to 70 Hz or dc input.

Another paper by IEEE presents a complete discussion of several aspects of system interface design for the grid-interface converter under both single-phase and three-phase system conditions. A passive plus active filter solution is proposed to accomplish the common mode-related noises minimization as well as a dramatic reduction of the converter system volume.

Along with these papers, another IEEE published paper specifies that the bidirectional ac-dc converter is the key power electronic unit for the plug-in function in PHEV. The basic electrical requirements and product specifications are summarized in this paper. Further, in the PHEV product development, performance, the cost, volume and weight are important indexes. A high performance lower cost bidirectional ac-dc converter with less volume and weight can benefit to the whole PHEV system. By combining the motor inverter and motor windings, the combination bidirectional ac-dc converter topologies have more advantages than the independent bidirectional converter topologies.

Thus, by studying all these papers and few more related to bidirectional converters we will try to achieve our main motive of power conversion from AC to DC and vice versa as per the requirements at 50Hz frequency. This Bidirectional converter will also deliver 500W output power maintaining unity power factor.

III. PRINCIPLE OF OPERATION

This converter consists of three parts namely; Boost Converter, Inverter, and the Control System.

A. Boost converter

For conversion of AC to DC power supply, the input supply is first stepped down using a transformer. This now needs to be rectified to get DC output. For the rectification, the body diodes of MOSFETs are used as rectifier diodes. Same MOSFETs with the help of body diodes also perform the boost operation.

To achieve unity power factor, we need to modify the output voltage w.r.t current. For maintaining power factor, a boost circuit has to be implemented. The boost circuit consists of a series inductor, a switch in parallel,
a capacitor to reduce the voltage ripple, and a diode to block capacitor to discharge through the switch.

Figure 1: Bidirectional Converter

In the bidirectional converter, the inductor is placed before the switch i.e. the MOSFET H-Bridge. As similar to boost converter, the capacitor is placed parallel to load i.e. parallel to H-Bridge. But in this circuit, due to the requirement of power flow in both directions, the diode is eliminated.

The "OFF" MOSFETs and the body diodes serves the same purpose as the single diode in series to inductor. These MOSFETs in H-Bridge configuration later, serves the purpose of an inverter circuit while conversion of DC to AC supply.
B. Inverter

While conversion of DC to AC supply, the inverter circuit comes into picture. The MOSFETs in the H-Bridge configuration now performs the inversion process. The output of the inverter is inverting voltage. This needs to
be modified to get sinusoidal voltage. A micro-controller is used to generate PWM waveform with duty cycle varying according to required voltage (i.e. sinusoidal). The sinusoidal voltage produced by the inverter now goes through the transformer, which behaves as a step-up transformer, giving 230 Vrms.

C. Control System

An ACS712 hall-effect current sensor is used to generate the feedback from the input as well as output of the circuit, while a simple voltage divider (with op-amps to adjust the gain and to get differential voltage) is used to generate the voltage feedback.

Analog opto-coupler is used to isolate the power circuit with the embedded circuit.

The control system consists of micro-controller to generate the PWM waveform, to receive feedback from the input as well as output voltages & currents. This micro-controller also executes the power factor correction algorithm to make voltage be in phase with the current.

The PFC algorithm will consist of comparison of voltages at output and required, modulation of the error voltage with a factor. This is then acted upon with summation with AC voltage. Then according to the currents at input and output, the final duty cycle of MOSFETs is modified.

Depending on the input (AC or DC) the micro-controller executes the boost module with PFC (Power Factor Correction) or SPWM (sinusoidal Pulse Width Modulation) module.

The control of MOSFETs is done by the IR2110 driver IC. These are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels.

![Figure 3: Power Factor Correction Algorithm](image-url)
IV. OBJECTIVES

A. To convert 230V AC mains input to 48V DC output and 48V DC input to 230V AC output
B. To deliver 500W output power.
C. To maintain unity power factor.
D. To increase the reliability of the conversions from AC to DC or vice versa as per the requirements.
E. The main objective of this power converter is to familiarize with the latest converters based on power semiconductor devices. This provides the basic practical knowledge in the application of power electronics in electrical drives and machines like mosfets driven speed control of DC and AC motors.
F. To step down the voltage from a high voltage source to a lower voltage.
G. To match the loads to the power supply.
H. To isolate the primary and secondary circuits.

V. RESULT ANALYSIS

1. Inverter tested for inductive load successfully.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Voltage</td>
<td>11.5 V</td>
</tr>
<tr>
<td>Output Power</td>
<td>300 W</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>12 V/µsec</td>
</tr>
</tbody>
</table>

2. SPWM Simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>18 kHz</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>Varying from sin (2°) to sin (90°)</td>
</tr>
</tbody>
</table>

3. Boost Calculations\[^2\]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Formula Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{in max}$</td>
<td>555.55 W</td>
<td>$\frac{P_{out}}{\eta}$</td>
</tr>
<tr>
<td>$I_{in (rms \ max)}$</td>
<td>17.5 A</td>
<td>$\frac{P_{out}}{\eta_{min} \cdot V_{in (rms)} \cdot P.F}$</td>
</tr>
</tbody>
</table>
VI. APPLICATIONS

A. Solar grid (mostly referred as smart grid): The grid includes solar module, inverter, switch board and electricity grid. The electricity is produced when the sunlight hits the photovoltaic cells. The electricity then runs from the solar panels through an inverter. The inverter converts the power from direct current (DC) into alternating current (AC), which can be used for electronic appliances in houses. Later, Electric Vehicles (EV's) can be charged using this solar power.

B. Charging and discharging circuits: For li-ion battery a dynamic model for the battery charging process is mainly constructed based on its electrochemical model and the buck-boost power converter dynamic model. The battery charging process forms a system with multiple interconnections. Because of supply voltage variation, the system can switch between buck, buck-boost and boost modes used for charging and discharging of batteries.

C. Industrial automation: With modern power electronics and advanced high-power electronics applications efficient control on the motor speed, improvement in machine automation and effective energy consumption is easily possible. Due to the advancements in power electronics AC motor Drives have been evolved rapidly. Each Drive series is designed to meet specific application needs. Thus, the newly developed AC Drives accurately control speed and torque, smoothly handle an increased load and provide numerous custom control and configuration operating modes. Some AC Motor Drive product line also provide a full range of motor control technologies and are used throughout a wide range of industries, to enhance and improve machine automation.

D. HVDC (High voltage direct current): HVDC (high-voltage direct current) is a highly efficient alternative for transmitting large amounts of electricity over long distances and for special purpose applications. HVDC is truly shaping the grid of the future as a key enabler in the future energy system based on renewables. HVDC transmission technology since 1950s continuously develops the HVDC
technology to meet the demands of economic and sustainable transmission and integration of different electricity generation types.

E. Telecommunication: High-efficiency DC-DC converters for the Telecom/Datacom marketplace are required at large scale. Some highly reliable open-frame DC-DC converter product lines are designed with high flexibility and design support that the worldwide telecom market requires. Converters for Telecom DC/DC power supply applications often require an output voltage somewhere within a wide range of input voltages. While the design of traditional converters will come with a heavy penalty in terms of component stresses and losses, and with the restrictions on the output voltage. Thus, to meet these requirements such converters are designed for numerous applications.

F. SVC (Static var compensation): A static VAR compensator is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilizing the system. In transmission applications, the SVC is used to regulate the grid voltage. In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage.

G. Power supplies (DC and UPS): An inverter and a UPS are both used in providing back-up power supply to electronic devices, in the event of an electricity outage. An UPS will have a battery charger, batteries (and saving DC power) for future use. When there is no power then the supply of electricity to the battery charger at UPS is no longer, whereas the batteries still supply the inverter to serve electrical equipment until the power gets over. The inverter alone is useless without DC power supply (battery).

VII. FUTURE SCOPE

- This project can also be implemented in future for three phase inputs.
- It can be used in matrix converters functioning as a direct AC-AC converter.
- The matrix converter, known for more than thirty years, achieves Bi-directional powerflow, independent control of the input power factor, block operation and frequency conversion.
- To investigate further the effects of system faults such as single phase, short circuit fault, etc. on bidirectional converter.
- To study and implement the three phase to single phase matrix converter for high frequency transformers to bring out the importance of the matrix converter for such applications.
- To investigate the further details about the stability of matrix and bidirectional converter.

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REFERENCES