A PIPO Boost Converter with Low Ripple and Medium Current Application

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Abstract. This paper presents a Parallel Input Parallel Output (PIPO) boost converter is proposed to gain power ability of converter, and reduce current inductors. The proposed technique will distribute current for n-parallel inductor and switching component. Four parallel boost converters implement on input voltage 20.5Vdc to generate output voltage 28.8Vdc. The PIPO boost converter applied phase shift pulse width modulation which will compare with conventional PIPO boost converters by using a similar pulse for every switching component. The current ripple reduction shows an advantage PIPO boost converter then conventional boost converter. Varies loads and duty cycle will be simulated and analyzed to verify the performance of PIPO boost converter. Finally, the unbalance of current inductor is able to be verified on four area of duty cycle in less than 0.6.

1. Introduction
A photovoltaic (PV) power generation is introduced to deploy green energy system on our environment. This system requires battery bank for energy storage and also direct connected toward load. Both methods have been used an energy conversion to deliver electric power. Dc-dc converter regulated voltage about 20.5V from PV panel to 28.8V dc voltage to charge the battery bank. Conventional dc – dc boost converter is usually applied for low input voltage to produce high output voltage. Limited voltage and current gain depend on value of inductance and capacitance and also ability of selecting the switching component.

Boost converter has to consider to current and voltage ripple on input and output side, then also voltage stress on switching component. Voltage and current ripple can be eliminated by calculating inductance and capacitance components to maintain value properly that depends on switching frequency. When voltage multiplier cell method and topology are applied on boost converter therefore voltage stress on semiconductor is able be minimized. Interleaved boost converter is also simulated by to eliminate the output ripple on high power application. By coupling inductor in one core also produces high power dc-dc converter.

Input-parallel output-series dc-dc boost converter has been implemented by. The proposed converter achieved wide range input with high gain output by adopting interleaved dc-dc converter for fuel cell application. Synchronous boost converter with input parallel and output parallel (IPOP) provided a current ripple reduction and high efficiency. 400V input and 800V output which were implemented on PIPO bidirectional converter for charging battery bank.
In this paper, synchronous PIPO boost converter is developed to distribute current that divided by a number of parallel modules. It shows a feasible solution to apply low current MOSFET into medium power of converter for charging battery. It has approximately 20.5V input voltage from parallel connection solar panels which will convert to maximum 28.8V/1kW output converter.

2. Proposed Topology and Operational Principle

Figure 1 shows a proposed boost converter that applied for high power with low current ripple. Four-parallel basic-boost converter is expected to reduce current ripple, and reduce voltage stress on switching component. Four-parallel basic-boost converter is expected to reduce current ripple, and reduce voltage stress on switching component.

![Figure 1. N-Parallel input parallel output boost converter](image)

It refers to basic boost converter applied single inductor, diode, and switching component. Thus, output voltage will describe as,

\[
\frac{V_o}{V_i} = \frac{1}{1-D}
\]

But n-parallel input and parallel output boost converter are supported for high current input, while the output voltage is similar with output voltage of basic boost converter. A number of parallel boost converters which will distribute current input into n-parallel inductor and switching component. Hence, the current and voltage stress on switching component can be reduced. Relation between input current, output current and duty cycle are explained as,

\[
I_{in} = \frac{1}{1-D} I_o 
\]

\[
I_{L1} = I_{L2} = I_{L3} = I_{L4} = \frac{1}{n(1-D)} I_o
\]

The switching components of PIPO boost converter operates at sequential time with different starting phase angle. The angle depends on n-parallel of switching components. When four-parallel boost converters are applied on proposed battery charging, therefore the starting angle for every MOSFET has a 90° difference. It was displayed on Figure 2 and Figure 3.
This converter is high current application with output voltage suitable for charging 24 volt battery. To determine the components value of boost converter, parameter calculation and simulation are required. The 20.5 volt input voltage will be converted into 28.8 volt output voltage with power 1kW. Simulation is important to verify all parameters before developing the hardware. In this case, a PSIM software application has been used to analyze PIPO Boost Converter. Figure 4 shows circuit simulation used to PSIM. Similar PWM is applied toward four components switching on PIPO converter. Four-parallel inductor will distribute current and reduce temperature of inductor. Hence, low current MOSFET is able to be implemented for high current converter.
Another way, separating drives MOSFET with phase-shift PWM can be implemented to reduce current ripple on output side. Figure 5 displays a circuit PIPO converter with separated switching drive for implementing phase shift PWM.

![Figure 4. PIPO converter with Similar PWM](image)

![Figure 5. PIPO Converter with phase shift PWM](image)

It refers to [7], the PIPO boost converter will be investigated about current balancing on n-parallel inductor, and also output current ripple. As a better performance in order to get 1kW output with 28.8volt, PIPO boost converter has to have the following specifications.

| Table 1. Characteristic of Components |
|--------------------------------------|
| Parameters                          | Value |
| Input Voltage                       | 20.5V |
| Minimum Output Voltage              | 25.5V |
| Maximum Output Voltage              | 28.8V |
| L1,L2,L3,L4                         | 1Mh   |
| Capacitor                           | 470µf |
| Resistive Load                      | 0.8 ohm |
| Diode                               | MUR1560 |
| MOSFET                              | IRFP460 |
| Frequency Switching                 | 20kHz |
3. Simulation Results

It refers to Figure 4 and specification, PIPO boost converter with single PWM has been simulated. The simulation results displayed on Figure 6. It has been driven by 0.2 duty cycle with similar PWM. The ripple current on inductor L1, L2, L3, and L4 are similar with average 0.8 ampere. While ripple of input current is 3.2 ampere and ripple of output current is 3.5 ampere. The result displayed high current ripple on PIPO boost converter.

![Figure 6](image)

**Figure 6.** Conventional single PWM PIPO Boost converter on 0.2 duty cycle

Figure 7 explains about simulation of PIPO converter result that applied phase shift PWM. The circuit simulation is displayed by Figure 5 have a four MOSFET as switching component. This MOSFETs will be driven by PWM that explained by Figure 2. The simulation shows a low current input and current output when PIPO converter was applied by 0.2 duty cycle. The average ripple of input current is 0.04 ampere and average ripple of output current is 0.2 ampere.

![Figure 7](image)

**Figure 7.** Phase shift PWM PIPO Boost converter on 0.2 duty cycle
From the results, it can be concluded that proposed PIPO boost converter is more suitable to be applied with phase shift PWM. The better performance with low ripple current input and output was presented on 0.25 duty cycle. It displayed on Figure 8.

**Figure 8.** Balance inductor current on 0.25 dutycycle

Another experiment was observed toward PIPO boost converter by implementing variation duty cycle for similar value of load. There were unbalancing inductors current with ripple distortion that occurred during intersection two or more pulses for MOSFET. This cycle repeated during intersection time between pulses. It shows on Figure 9.

**Figure 9.** Unbalance inductor current on 0.27 dutycycle
The unbalancing of current inductor occurred during transition pulse with duty cycle less than 0.6. There were four unbalance areas verified when phase shift PWM implemented for PIPO boost converter (marked by yellow background). Table 1 and Figure 10 explain about unbalancing inductor current. During PIPO boost converter running on unbalancing inductor current, power loss occurred on inductor side with over current flow as the result, it increased temperature of inductor.

4. Conclusion
PIPO boost converter with a low current ripple was presented in this paper that the Phase shift PWM method used to drive PIPO boost converter was success to reduce ripple current become 1mA as compared with single pulse PWM. The second observation was also concluded that four parallel input and parallel output boost converter would be implemented, as the result, four areas duty cycle would be noticed.
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