TRANSFORMER LESS FULL BRIDGE THREE PORT CONVERTERS WITH DC BUS CONCEPT FOR RENEWABLE POWER SYSTEMS

R.GUNASEKARAN¹, G.GOWRISHANKAR², T.VIGNESH³ & P.GOKULRAJ⁴

¹Sasurie College of Engineering, Vijayamangalam, Tamilnadu, India
²& ³Student ME (PE&D), Sasurie College of Engineering, Vijayamangalam, Tamilnadu, India
⁴Student, Sasurie College of Engineering, Vijayamangalam, Tamilnadu, India

ABSTRACT

The renewable energy source output has not constant to all the time (day & night). Example wind & solar power plants has not produced electrical energy in all the times. That generation level due to corresponding atmosphere. So that has no used in constant power applications. My proposal has to produce constant output power in all times (day & night). So I used three port full bridge converters in solar electrical energy. That will produce three different level of electrical energy. By using this systematic method, a novel full-bridge TPC (FB-TPC) is developed for renewable power system applications which features simple topologies and control, a reduced number of devices, and single-stage power conversion between any two of the three ports. The primary circuit of the converter functions as a buck-boost converter and provides a power flow path between the ports on the primary side. The FB-TPC can adapt to a wide source voltage range, and tight control over two of the three ports can be achieved while the third port provides the power balance in the system. Furthermore, the energy stored in the leakage inductance of the transformer is utilized to achieve zero-voltage switching for all the primary-side switches. The FB-TPC is analyzed in detail with operational principles, design considerations, and a pulse width modulation scheme (PWM), which aims to decrease the dc bias of the transformer. Experimental results verify the feasibility and effectiveness of the developed FB-TPC.

KEYWORDS: Transformer Less, DC Bus Concept Boost-Buck, DC-DC Converter, Full-Bridge Converter (FBC), Renewable Power System, Three-Port Converter (TPC)

INTRODUCTION

In this solution, the grid neutral line is connected directly to the negative pole of the DC bus, so that the voltage across the parasitic capacitor is clamped to zero. As a result, the CM current is eliminated completely. Meanwhile, a virtual DC bus is created to help generate the negative output voltage. The required DC bus voltage is still the same as the full bridge, and there is not any limitation on the modulation strategy since the CM current is removed naturally by the circuit structure. In this way, the advantages of the full bridge and half bridge based solutions are combined together.

Based on the innovative idea above, a novel inverter topology is proposed with the virtual DC bus concept by employing the switched capacitor technology. The proposed inverter can be modulated with the unipolar SPWM and double frequency SPWM. It consists of only five power switches and a single filter inductor, so the cost of the semiconductor and magnetic components can be reduced.

The required DC voltage is only half of the half bridge solution, while the performance in eliminating the CM current is better than the full bridge based inverters. Based on this idea, a novel inverter topology is proposed with the virtual DC bus concept by adopting the switched capacitor technology.
It consists of only five power switches and a single filter inductor. The proposed topology is especially suitable for the small power single phase applications, where the output current is relatively small so that the extra current stress caused by the switched capacitor does not cause serious reliability problem for the power devices and capacitors.

The distributed photovoltaic (PV) power generation systems have received increasing popularity in both the commercial and residential areas. In most occasions, the inverters are used to feed the PV power into the utility grid. It is important for the PV inverter to be of high efficiency, due to the relatively high price of the PV panels. Small size is also strongly desired for the low power and single phase systems, especially when the inverter is installed indoor.

In the traditional grid-connected PV inverters, either a line frequency or a high frequency transformer is utilized to provide a galvanic isolation between the grid and the PV panels. Removing the isolation transformer can be an effective solution to increase the efficiency and reduce the size and cost. However, if the transformer is omitted, the common mode (CM) ground leakage current may appear on the parasitic capacitor between the PV panels and the ground. The existence of the CM current may reduce the power conversion efficiency, increase the grid current distortion, deteriorate the electric magnetic compatibility, and more importantly, give rise to the safety threats.

The CM current path in the grid-connected transformer less PV inverter system is illustrated in. It is formed by the power switches, filters, ground impedance $Z_G$ and the parasitic capacitance $C_{PV}$ between the PV panels and the ground. According to, the CM current path is equivalent to an LC resonant circuit in series.

**Derivation of TPFBC**

Close observation indicates that the FB-TPC has a symmetrical structure and both $V_{sa}$ and $V_{sb}$ can supply power to the load $V_o$. The equivalent circuit from one of the source ports to the load port. In addition, a bidirectional buck-boost converter is also integrated in the primary side of the FB-TPC by employing the magnetizing inductor of the transformer $L_m$ as a filter inductor. With the bidirectional buck-boost converter, the power flow paths between the two sources, $V_{sa}$ and $V_{sb}$, can be configured and the power can be transferred between $V_{sa}$ and $V_{sb}$ freely. The equivalent circuit between the two sources is illustrated. According to the equivalent circuits, it can be seen that the power flow paths between any two of the three ports, $V_{sa}$, $V_{sb}$, and $V_o$, have been built. The unique characteristics of the FB-TPC are analyzed and summarized as follows.

- The FB-TPC has two bidirectional ports and one isolated output port. Single-stage power conversion between any two of the three ports is achieved. The FB-TPC is suitable for renewable power systems and can be connected with an input source and an energy storage element, such as the photovoltaic (PV) with a battery backup, or with two energy storage elements, such as the hybrid battery and the super capacitor power system.

- A buck-boost converter is integrated in the primary side of the FB-TPC. With the integrated converter, the source voltage $V_{sa}$ can be either higher or lower than $V_{sb}$, and vice versa. This indicates that the converter allows the sources’ voltage varies over a wide range.

- The devices of the FB-TPC are the same as the FBC and no additional devices are introduced which means high integration is achieved.

- The following analysis will indicate that all four active switches in the primary side of the FB-TPC can be operated with ZVS by utilizing the energy stored in the leakage inductor of the transformer, whose principle is similar to the phase-shift FBC.
DC Bus Concept

By connecting the grid neutral line directly to the negative pole of the PV panel, the voltage across the parasitic capacitance $C_{PV}$ is clamped to zero. This prevents any leakage current flowing through it. With respect to the ground point N, the voltage at midpoint B is either zero or $+V_{dc}$, according to the state of the switch bridge. The purpose of introducing virtual DC bus is to generate the negative output voltage, which is necessary for the operation of the inverter. If a proper method is designed to transfer the energy between the real bus and the virtual bus, the voltage across the virtual bus can be kept the same as the real one.

The positive pole of the virtual bus is connected to the ground point N, so that the voltage at the midpoint C is either zero or $-V_{dc}$.

$C_{PV}$ is directly bypassed by connecting the neutral line to the negative pole of the DC bus, so the CM current is zero in theory. This conclusion is confirmed by the experimental result, no observable CM current is detected.

With points B and C joined together by a smart selecting switch, the voltage at point A can be of three different voltage levels, namely $+V_{dc}$, zero and $-V_{dc}$. Since the CM current is eliminated naturally by the structure of the circuit, there’s not any limitation on the modulation strategy, which means that the advanced modulation technologies such as the unipolar SPWM or the double frequency SPWM can be used to satisfy various PV.

Transformerless Operation

The distributed photovoltaic (PV) power generation systems have received increasing popularity in both the commercial and residential areas. In most occasions, the inverters are used to feed the PV power into the utility grid. It is important for the PV inverter to be of high efficiency, due to the relatively high price of the PV panels.

Small size is also strongly desired for the low power and single phase systems, especially when the inverter is installed indoor. In the traditional grid connected PV inverters, either a line frequency or a high frequency transformer is utilized to provide a galvanic isolation between the grid and the PV panels. Removing the isolation transformer can be an effective solution to increase the efficiency and reduce the size and cost.

However, if the transformer is omitted, the common mode (CM) ground leakage current may appear on the parasitic capacitor between the PV panels and the ground.

The existence of the CM current may reduce the power conversion efficiency, increase the grid current distortion, deteriorate the electric magnetic compatibility, and more importantly, give rise to the safety threats.

The CM current path in the grid connected transformerless PV inverter system is illustrated. It is formed by the power switches, filters, ground impedance $Z_G$ and the parasitic capacitance $C_{PV}$ between the PV panels and the ground.

Analysis of the FB-TPC for Renewable Power System Application

The FB-TPC is applied to a stand-alone PV power system with battery backup to verify the proposed topology. To better analyze the operation principle, the proposed FB-TPC topology is redrawn, the two source ports are connected to a PV source and a battery, respectively, while the output port is connected to a load.

There are three power flows in the standalone PV power system from PV to load, from PV to battery, from battery to load. As for the FB-TPC, the load port usually has to be tightly regulated to meet the load requirements, while the input port from the PV source should implement the maximum power tracking to harvest the most energy.
Therefore, the mismatch in power between the PV source and load has to be charged into or discharged from the battery port, which means that in the FBTPC, two of the three ports should be controlled independently and the third one used for power balance. As a result, two independently controlled variables are necessary.

### Switching State Analysis

\[ \text{P}_{\text{pv}} = \text{P}_{\text{b}} + \text{P}_{\text{o}} \]  

(1)

where \( \text{P}_{\text{pv}}, \text{P}_{\text{b}}, \) and \( \text{P}_{\text{o}} \) are the power flows through the PV, battery and load port, respectively. The FB-TPC has three possible operation modes

- dual-output (DO) mode, with \( \text{P}_{\text{pv}} \geq \text{P}_{\text{o}} \), the battery absorbs the surplus solar power and both the load and battery take the power from PV
- dual-input (DI) mode, with \( \text{P}_{\text{pv}} \leq \text{P}_{\text{o}} \) and \( \text{P}_{\text{pv}} > 0 \), the battery discharges to feed the load along with the PV
- single-input single-output (SISO) mode, with \( \text{P}_{\text{pv}} = 0 \), the battery supplies the load power alone.

When \( \text{P}_{\text{pv}} = \text{P}_{\text{o}} \) exactly, the solar supplies the load power alone and the converter operates in a boundary state of DI and DO modes. This state can either be treated as DI or DO mode. Since the FB TPC has a symmetrical structure, the operation of the converter in this state is the same as that of SISO mode, where the battery feeds the load alone. The operation modes and power flows of the converter are listed in Table 3.3.1. The power flow paths/directions of each operation mode have been illustrated.

The switching states in different operation modes are the same and the difference between these modes are the value and direction of \( i_{L_m} \), which is dependent on the power of \( \text{P}_{\text{pv}} \) and \( \text{P}_{\text{o}} \). In the DO mode, \( i_{L_m} \) is positive, in the SISO mode, \( i_{L_m} \) is negative, and in the DI mode, \( i_{L_m} \) can either be positive or negative. Take the DO mode as an example to analyze.

For simplicity, the following assumptions are made:

- \( C_{\text{pv}}, C_{\text{b}}, \) and \( C_{\text{o}} \) are large enough and the voltages of the three ports, \( V_{\text{pv}}, V_{\text{b}}, \) and \( V_{\text{o}} \), are constant during the steady state
- the \( V_{\text{pv}} \geq V_{\text{b}} \) case is taken as an example for the switching state analysis. There are four switching states in one switching cycle. The key waveforms and the equivalent circuit in each state.

It can be seen from that the voltage of the PV source \( V_{\text{pv}} \) can be regulated with \( \text{DA1 and DB1} \) for the maximum power point tracking (MPPT), taking the battery voltage \( V_{\text{b}} \) as constant. The output voltage \( V_{\text{o}} \) can be tightly regulated with \( \text{DI and D3} \).

\[ V_{\text{o}} = n[D1V_{\text{pv}} + D2(V_{\text{b}} - V_{\text{pv}}) + D3V_{\text{b}}] = 2nD1 \cdot V_{\text{pv}} \]  

(2)

<table>
<thead>
<tr>
<th>Operation Modes</th>
<th>Power of ( \text{pv} )</th>
<th>Power of Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual output mode</td>
<td>( \text{P}<em>{\text{pv}} \geq \text{P}</em>{\text{o}} )</td>
<td>Battery charging ( \text{P}_{\text{b}} \geq 0 )</td>
</tr>
<tr>
<td>Dual input mode</td>
<td>( \text{P}<em>{\text{pv}} \leq \text{P}</em>{\text{o}}, \text{P}_{\text{pv}} &gt; 0 )</td>
<td>Battery discharging ( \text{P}_{\text{b}} &lt; 0 )</td>
</tr>
<tr>
<td>Single input-single output</td>
<td>( \text{P}_{\text{pv}} = 0 )</td>
<td>Battery discharging ( \text{P}<em>{\text{b}} = -\text{P}</em>{\text{o}} )</td>
</tr>
</tbody>
</table>
**ZVS Analysis**

According to the analysis, the operation of the FB-TPC is similar to the operation of a phase-shift FBC with the two switches, driven with complementary signals. The proposed FB-TPC can utilize the leakage inductance, filter inductance, and the output capacitors of the switches to realize ZVS, zero-voltage turn-ON, and zero-voltage turn-OFF for all the switches. The operation principle is similar to the phase-shift FBC. The only difference is that in the proposed FBTPC, the magnetizing inductor of the transformer Lm can also help to achieve ZVS of the switches if the direction of $i_{Lm}$ is the same as $i_p$.

![Figure 1](image_url)

**Design Consideration**

As for the semiconductor device stress, the FB-TPC is similar to the traditional FBC. But a key difference between these two converters is that the magnetizing inductance of the transformer Lm is operated as an inductor as well. We also take the $V_{pv} \geq V_b$ case as an example for analysis.

The steady state, we have

$$V_{pv}I_{pv} = V_b$$

(3)

$$I_b + V_{o}I_o$$

(4)

According to the switching states I and II, we have

$$I_{pv} = D_{A1}(I_{Lm} + nI_o)$$

(5)

where $I_{Lm}$ is the average magnetizing current of the transformer, and then we have

$$I_{Lm} = [I_{pv}/ D_{A1}] – nI_o$$

(6)

$$I_b = D_{2}(I_{Lm} + nI_o) - D_{3}(I_{Lm} - nI_o) = (DB_1 - 2D_3)I_{Lm} + DB_1nI_o$$

(7)

Then the average transformer magnetizing current $I_{Lm}$ can also be given by the following equation.
ILm = \left[ \frac{Ib - DB1Io}{DB1 - 2D3} \right] \quad (8)

It is noticed that ILm can be reduced by increasing the nominal values of DA1 and DB1; this result is also valid for the \(V_{pv} < V_b\) case by following the same analysis procedure. Therefore, the value of ILm can be decreased with a properly designed modulation scheme.

With the proposed PWM scheme, when \(V_{pv}\) is much higher than \(V_b\), \(v_2 < V_{tri}\), and \(v_3\) stays at zero, DB1 will reach its maximum value. There are only three switching states, states II–IV, in one switching cycle.

**Transformerless and Virtual Bus Operation in Three Port Converter**

In this solution, the grid neutral line is connected directly to the negative pole of the DC bus, so that the voltage across the parasitic capacitor is clamped to zero. As a result, the CM current is eliminated completely. Meanwhile, a virtual DC bus is created to help generate the negative output voltage.

The required DC bus voltage is still the same as the full bridge, and there is not any limitation on the modulation strategy since the CM current is removed naturally by the circuit structure. In this way, the advantages of the full bridge and half bridge based solutions are combined together.

![Figure 2](image)

Based on the innovative idea above, a novel inverter topology is proposed with the virtual DC bus concept by employing the switched capacitor technology. The proposed inverter can be modulated with the unipolar SPWM and double frequency SPWM. It consists of only five power switches and a single filter inductor, so the cost of the semiconductor and magnetic components can be reduced.

The required DC voltage is only half of the half bridge solution, while the performance in eliminating the CM current is better than the full bridge based inverters. Based on this idea, a novel inverter topology is proposed with the virtual DC bus concept by adopting the switched capacitor technology.

It consists of only five power switches and a single filter inductor. The proposed topology is especially suitable for the small power single phase applications, where the output current is relatively small so that the extra current stress caused by the switched capacitor does not cause serious reliability problem for the power devices and capacitors.

The FB-TPC with the two cells, cells A and B, sharing the negative terminals. Because the two cells as well as the two sources of the FB-TPC are independent, they can also be connected in other manners.
The other two types of FB-TPCs are there. The operation principles of these FB-TPCs are similar. The key characteristic of the FB-TPC is that the magnetizing inductor of the transformer also functions as a filter inductor, and the primary circuit acts as a four switch buck-boost converter to bridge the power flow between the two ports on the primary side.

However, the energy storage ability of the transformer may limit the power rating of the FB-TPC. To overcome this drawback, a block capacitor can be placed in series with the primary winding and another optimally designed inductor placed in parallel with the transformer to transfer power between the primary side’s two ports.

![Figure 3](image)

The improved converter, named FB-TPC with a paralleled inductor (FB-TPC-PI), can be seen as a combination of a four-switch buck-boost converter and an FBC with shared power switches.

### PWM Modulation in FB-TPC

The power management and the control for the TPC proposed in are applied to the FB-TPC because the power control of the renewable power system with battery backup follows a similar principle and has nothing to do with the type of topology.

However, the PWM schemes of different converters are usually different from each other and mainly determined by the topology. For better analysis of the PWM scheme of the FB-TPC, Four regulators, PV voltage regulator (IVR) for MPPT, battery voltage regulator (BVR) for maximum voltage charging control, battery current regulator (BCR) for maximum current charging control, and output voltage regulator (OVR) for output voltage control, are used to implement the power management of the system.

The FB-TPC can work in the DO, DI, or SISO mode, depending on the relationship between the PV power and load power.

The operating principle is similar to that described. Different PWM schemes can be applied to the proposed FBTPC.
The maximum value of $DB_1$ is

$$DB_1 \text{ max} = DA_1 + D_3$$

maximum value of $DA_1$ is determined by $D_3$.

$$DA_1 \text{ max} = 1 - D_3$$

Based on the analysis, the proposed PWM scheme and its generation are illustrated, where $V_{tri}$ is the peak-to-peak value of the carrier voltage $v_{tri}$, and $vc_1, vc_2, vc_3$ are control voltages generated by using a competitive method and given by the following equations:

$$vc_1 = \max (vc_{BVR}, vc_{BCR}, vc_{IVR})$$

$$vc_2 = \min (vc_2, V_{tri})$$

$$vc_3 = \max (0, vc_2 - V_{tri})$$

**Simulation Results**

The following model has been created using SIMULINK Fig.5 shows MATLAB model for dc/dc buck using Genetic algorithms converter. This model contains DC source voltages, gate pulse circuit, power switches like IGBT’s. This circuit serves to produce triggering pulses for the switches in the dc/dc buck converter having four IGBT’s.
Figure 5

Figure 6: Input Voltage

Figure 7: Gate Signals for FB-TPC

Figure 8: Output Voltage
Overall simulation result for the buck converter is shown in Figure 2.5. In this simulation the output is maintained constant while varying the load. The reference voltage is given to the fuzzy controller which compares the set point and the output voltage across the load. Depending on output voltage an PWM is generated and applied to the PWM controller which is given to the PWM controller block.

CONCLUSIONS

- The concept of the virtual DC bus is proposed to solve the CM current problem for the transformer less grid connected PV inverter.
- By connecting the negative pole of the DC bus directly to the grid neutral line, the voltage on the stray PV capacitor is clamped to zero.
- It consists of only five power switches and a single filter inductor. And also the FB-TPC has connected through the efficient way for renewable power systems.
- My input voltage of the renewable power system is 40.3V and the output is 32.1V. That’s the efficient method for connected the renewable power system and grid.

REFERENCES


