Study of Bidirectional AC/DC Converter with Feedforward Scheme using Neural Network Control in Microgrid System

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Abstract—This paper presents the study of bidirectional ac/dc converter PWM with feedforward neural network control. Bidirectional ac/dc converter act as a utility interface between ac grid and distributed energy resources or renewable energy resources. The converter facilitates a battery energy system for power charge or discharge to compensate for the dc bus voltage deviation during severe distribution conditions. Due to these disturbances such as fault occurrences, system loads and varying environmental condition causes overshoot and undershoot problem. This proposed system reduces the overshoot and undershoot to very low value. Current harmonics in a PWM bidirectional ac/dc power converter are reduced considerably by using feedforward neural network. This paper presents a modified feedforward technique having neural network and existing model with feedforward technique having PI controller will be compared. Both schemes are explain with experimental result. The proposed simplified PWM provides the better voltage regulation and high fundamental dc output voltage with lower THD and high efficiency. This proposed project has larger fundamental output voltage in inverter mode. Both simulation and experimental results verify the validity of the proposed PWM strategy and control scheme.

Key words: Bidirectional ac/dc converter, Total harmonic distortion, Feedforward control, Neural Network

I. INTRODUCTION

A single-phase ac/dc PWM converter is used in many applications such as uninterrupted power supply (UPS), switch mode power supply, wind energy conversion system and boost converter and many more. The increased power demand, depletion of fossil fuel resources and the growth of the environmental pollution have lead the world to think seriously of other alternative sources of energy like solar, wind, tidal, geothermal etc. So to utilize these distributed resources efficiently and retain power stability, bidirectional ac/dc converter plays an important role in renewable energy system. In particular, small-capacity distributed power generation systems using solar energy may be widely used in residential applications in the near future [3], [4]. A systematic organization of these DG system, energy storage system, and cluster of loads form a micro grid. When DERs have enough power to provide electricity to dc load as well as ac grid then immediately power flow direction changes towards the ac grid. Similarly, when there is not enough power to supply dc load then immediately the ac grid supply the power to dc load as well as energy storage system through bidirectional converter. In this paper a simplified PWM strategy feedforward control technique with Neural network (ANN) is presented. The neural network calculates the exact switching angles for converter to eliminate selected harmonics.

Fig. 1: Distributed energy system

Due to feedforward control with NN, the converter switches operated at higher frequency so that switching harmonic can be easily filter out. Artificial neural network (ANN) has the capacity to learn system through nonlinear system through nonlinear Mappings. In [1] and [2], the PWM converter have been modelled in a single non-linear system using a power balance concept between the input and output sides. Advantages of neural network are controller is robust to parameter drifting and changes of operating point, quick switching response, simpler structure and better output waveform. However, the conventional PI controllers have the inherent drawbacks that its response is somewhat slower for very fast transient and its control range is limited because of its fixed gain. So, in this proposed project PI is replaced by neural network (NN) that increases response during transient and fast switching operation. Also due to some disturbance like fault, load change or any environmental condition causes overshoot and undershoot in dc output voltage and hence reduced efficiency. There are many PWM techniques for AC/DC converter like UPWM, BPWM, HPWM and hybrid PWM. However, these PWM have higher switching stress but in proposed PWM, only one switch is active during one switching period. By using neural network switches operated at very high frequency in ac voltage waveform harmonic spectrum allowing the harmonics to be filter out. A feedforward control scheme gives better operation than a dual loop control. The proposed system has the following advantage such as lower THD, minimize settling time, minimize overshoot, undershoot and fast switching operation. This scheme provides fast output voltage response and improves input current shaping.

II. SYSTEM DESCRIPTION

Distributed energy system consists of ac grid, ac/dc converter, dc link filter, distributed energy resources, energy
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III. OPERATION PRINCIPLE OF THE PROPOSED SIMPLIFIED PWM STRATEGY

The proposed project present a simplified PWM strategy having advantage of good current shaping and dc voltage regulation. Good voltage regulation provides high quality output voltage for dc loads and current shaping provides minimum harmonic pollution. In the simplified PWM only one switch is active during the switching period which means both charging and discharging of ac side inductor current. The proposed PWM reduces the switching losses as well as improve efficiency.

Fig. 3: Application of bidirectional ac/dc converter in renewable energy system

![Fig. 3: Application of bidirectional ac/dc converter in renewable energy system](image)

Table 1: Rectifier mode switching combination in the proposed simplified PWM

<table>
<thead>
<tr>
<th>Status</th>
<th>T_A+</th>
<th>T_A-</th>
<th>T_B+</th>
<th>T_B-</th>
<th>Inductor status</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_S&gt;0</td>
<td>A</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
</tbody>
</table>

Table 2: Inverter mode switching combination in the proposed simplified PWM

<table>
<thead>
<tr>
<th>Status</th>
<th>T_A+</th>
<th>T_A-</th>
<th>T_B+</th>
<th>T_B-</th>
<th>Inductor status</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_S&gt;0</td>
<td>F</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
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<tr>
<td></td>
<td>G</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

A. Rectifier Mode:

Consider a system shown in figure 3, single-phase full-bridge bidirectional ac/dc converter. Let us assume the system impedance is purely inductive as neglecting the resistance. Apply KVL in the circuit operation, the voltage relationship can be obtained as

\[ v_s - L \frac{d}{dt} i_L = 0 \]  

(1.1)

The inductor current increases in both statuses A&B, and the voltage across inductor is vs. Therefore, in this case, inductor current is charging. In status E, all the switches are turned OFF. By using KVL, the voltage relationship will be

\[ v_s - L \frac{d}{dt} i_L - V_{dc} = 0 \]  

(1.2)

Therefore, the inductor voltage is \( v_s - V_{dc} \), thus in this condition inductor current is discharge i.e. discharging state.

Now, consider \( v_s < 0 \) during negative half cycle. So, as according to statuses C and D, voltage relationship will become,

\[ v_s - L \frac{d}{dt} i_L = 0 \]  

(1.3)

the inductor current decreases and hence the inductor current is discharging mode.

In status E,

\[ v_s - L \frac{d}{dt} i_L + V_{dc} = 0 \]  

(1.4)

So, overall it is shown that inductor current can be increased or decreased properly whether ac grid voltage source is operating in positive half-cycle vs>0 or negative half cycle, vs<0.

IV. FEEDFORWARD CONTROLLING SCHEME WITH NEURAL NETWORK

To explain the control operation of single phase bidirectional ac/dc converter, first assume that converter operate in rectifier mode. The rectifier and inverter switching status are given in table 1 and 2 respectively. In rectifier mode when supply voltage \( V_S > 0 \), we can choose either A and E statuses or B and E statuses. If we are selecting status C or D then the

In the proposed project, neural network is used to reduce the overshoot and undershoot, also minimize THD. In below figure br and br1 is the breakers, ‘0’ shows that power flow from ac source to dc load i.e. rectifier operation and ‘1’ shows that PFD is from DC source to AC load i.e. inverter operation.

![Fig. 2: Power flow direction (PFD)](image)
inductor current decrease and if status A or B for increasing inductor current.

![Proposed control scheme for the proposed simplified PWM strategy](image1.png)

**Fig. 3: Proposed control scheme for the proposed simplified PWM strategy**

The status A is consider when the grid voltage operating in positive half cycle thus switching duty ratio for status A is defined as DON and for status E as DOFF.

\[
D_{on} = \frac{t_{on}}{T} \\
D_{off} = 1 - D_{on}
\]

Where \( T \) is the time period of triangular wave.

The state space averaged equation is as follow

\[
v_{S} - (1 - D_{on}) V_{dc} = 0 
\]

During steady-state condition the dc voltage is equals to the desired command \( V_{dc} = V_{*dc} \):

\[
D_{on} = 1 - \frac{V_{S}}{V_{*dc}}
\]

During negative half cycle, \( V_{S} \leq 0 \), so the duty ratio of status C is \( D_{ON} \) and for status E is \( D_{OFF} \),

\[
v_{S} + D_{off}V_{dc} = 0 \\
D_{on} = \frac{-V_{S}}{V_{dc}}
\]

Let \( V'_{cont} \) is a control signal during inverter mode and we know that control signal is proportional to \( D_{ON} \). From the controller diagram \( V'_{cont} \) is the addition to the feedback control signal \( V_{FF} \) and dual loop feedback control signal. Thus, the developed control scheme for PWM strategy is present in figure 3. Three main inputs necessary to generate switching signal is \( Son \), the grid voltage sign and power flow direction.

![Modelling of proposed bidirectional ac/dc converter with feedforward control technique](image2.png)

**Fig. 5: Modelling of proposed bidirectional ac/dc converter with feedforward control technique**

### V. SIMULATION PARAMETERS OF THE PROPOSED AC/DC CONVERTER SYSTEM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductance</td>
<td>1.65Mh</td>
</tr>
<tr>
<td>Capacitance</td>
<td>1400μF</td>
</tr>
<tr>
<td>Output voltage command ( V_{*dc} )</td>
<td>300V</td>
</tr>
<tr>
<td>AC grid voltage ( V_{S} )</td>
<td>100√2 sinωt</td>
</tr>
<tr>
<td>Load</td>
<td>150Ω</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>40KHz</td>
</tr>
<tr>
<td>DERs (only inverter mode)</td>
<td>4A</td>
</tr>
</tbody>
</table>

As we know that converter is a device which perform both rectifier and inverter operation. In this, two circuit breaker are used. In this proposed project we analyzing both inverter and rectifier operation of the converter, so for switching from one mode to other two breakers are used. Here breaker 1 is used for rectifier operation i.e. From ac source to dc source, at this time breaker 2 is not functioning. A constant block is set either at 0 or 1. When we set 1 that means power flow from ac source to dc source i.e. rectifier operation. Otherwise, set 0 that means dc source to ac source i.e. inverter operation. To provide the gate signal to the switches a special PWM strategy with a feedforward control scheme presented in this paper. Here we present both existing and proposed control scheme for the proposed simplified PWM strategy. In the existing model PI controller has used due, to which the output voltage contain overshoot and undershoot problem. In proposed project, PI is replaced by neural network, which minimize the overshoot and undershoot problem to very low value. In addition, the total harmonic distortion is reduced to very low.
VI. COMPARISON OF PI AND NEURAL NETWORK CONTROL

Comparison of PI controller and Neural Network controller as shown in table

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description</th>
<th>PI</th>
<th>Neural Network(NN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Frequency</td>
<td>50Hz</td>
<td>50Hz</td>
</tr>
<tr>
<td>2.</td>
<td>THD</td>
<td>11.60%</td>
<td>2%</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

This paper presents a simplified PWM strategy using feedforward control scheme with neural network. In this paper, existing and proposed model is compared based on THD, undershoot, overshoot and system efficiency. In proposed system with PI controller is replaced by neural network. Figure 9 shows that existing system with PI controller has higher THD, and in figure 8 it is shown that, Proposed system with neural network has less THD. That means our proposed system has better efficiency i.e. 98%. 
Also proposed bidirectional ac/dc converter has reduced overshoot and undershoot in dc output voltage. The advantage of this system is low THD, minimized overshoot and undershoot problem in DC output voltage.

The magnitude of fundamental output voltage is higher than the magnitude of fundamental output voltage of the existing model i.e. with PI controller. Both the simulation and experimental result verify the validity of proposed PWM strategy and control scheme.

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REFERENCES