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# Simulation of a Bidirectional AC/DC Converter with Feed Forward Control for Grid-Tied Micro Grid Renewable Energy Systems

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## ABSTRACT:

This paper proposes a novel simplified pulse width modulation (PWM) strategy for the bidirectional ac/dc single phase converter in a microgrid renewable energy system. The Bidirectional AC/DC single phase converter can be tied with the PV system, boost converter, inverter for a grid connected Renewable energy systems. Based on the novel simplified PWM strategy, a feasible feed forward control scheme is developed to achieve better rectifier mode and inverter mode performed. The proposed simplified PWM strategy with the proposed feed forward control scheme has lower total harmonic distortion and higher efficiency. The proposed simplified PWM operated in the inverter mode also has larger available fundamental output voltage VAB than both the unipolar and bipolar PWMs. The simulation results verify the validity of the proposed PWM strategy and control scheme by using MATLAB/SIMULINK.

## Index Terms:

Bidirectional ac/dc converter, simplified pulse width modulation (PWM) strategy, PV system, Boost converter.

## I. INTRODUCTION:

The single-phase ac/dc pulse PWM converter is widely used in many applications such as adjustable-speed drives, switch mode power supplies, and un- interrupted power supplies for renewable grid connected energy systems. The single-phase ac/dc PWM converters are usually employed as the utility interface in a grid-tied renewable resource system, as shown in Fig. 1. To utilize the distributed energy resources (DERs) efficiently and retain power system stability, the bidirectional ac/dc converter plays an important role in the renewable energy system.

When DERs have enough power, the energy from the dc bus can be easily transferred into the ac grid through the bidirectional ac/dc converter. In contrast, when the DER power does not have enough energy to provide electricity to the load in the dc bus, the bidirectional ac/dc converters can simultaneously and quickly change the power flow direction (PFD) from ac grid to dc grid and give enough power to the dc load and energy storage system.

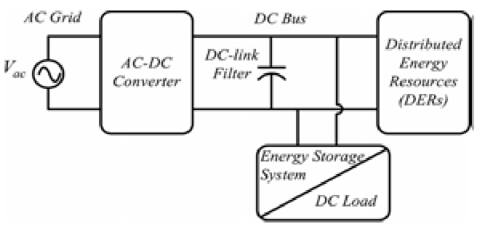


**Fig 1: Distribution energy system.**

There are many requirements for ac/dc PWM converters as utility interface in a grid-tied system; for instance, providing power factor correction functions, low distortion line currents, high-quality dc output voltage, and bidirectional power flow capability. Moreover, PWM converters are also suitable for modular sys- tem design and system reconfiguration. In this paper, a novel PWM control strategy with feed forward control scheme of a bidirectional single-phase ac/dc converter with PV energy system, Boost converter with MPPT control, inverter is presented. In the existing PWM control strategies of a single-phase ac/dc converter, the converter switches are operated at higher frequency than the ac line frequency so that the switching harmonics can be easily removed by the filter. The ac line current waveform can be more sinusoidal at the expense of switching losses. Until now several PWM strategies have been utilized in a single-phase ac/dc converter such as bipolar PWM (BPWM), unipolar PWM (UPWM), HPWM, and Hysteresis switching.

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UPWM results in a smaller ripple in the dc side current and significantly lower ac side harmonic content compared to the BPWM. The UPWM effectively doubles the switching frequency in the ac voltage waveform harmonic spectrum al- lowing the switching harmonics to be easily removed by the passive filter. The HPWM utilizes two of the four switches modulated at high frequency and utilizes the other two switches commutated at the (low) output frequency to re- duce the switching frequency and achieve better quality output. However, the switching loss in the HPWM is still the same as that of the UPWM.

The hysteresis switching method utilizes hysteresis in comparing the actual voltage and/or current to the reference although the hysteresis switching method has the advantages of simplicity and robustness the converters' switching frequency depends largely on the load parameters, and consequently, the harmonic ripples are not optimal. Hysteresis control methods with constant switching frequency have recently been presented. Those are usually based on the voltage and/or current error zero-crossing time to achieve a constant switching frequency. However, the capacitor ripple voltage and inductor ripple current are assumed to be ignored and the implemented inductor and/or capacitor are not very practical.

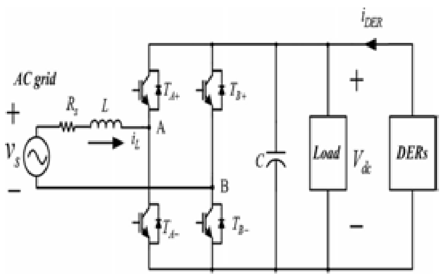


**Fig 2: Application of a bidirectional single-phase ac/dc converter in the renewable energy system.**

The proposed simplified PWM reduces harmonic pollution in Distribution power systems and replaces conventional diode front end rectifier stage in order to reduce the total harmonic distortion. This proposed topology follows an active ripple energy storage method that can effectively reduce the energy storage capacitance. A novel feed forward control scheme is also developed so that both the rectifier and inverter mode can be operated in a good manner. It is worth mentioning that the proposed feed forward control scheme is also suitable for the conventional UPWM and BPWM to provide fast output voltage response as well as improve input current shaping.

## II. Overview of a photovoltaic (PV) module:

To understand the PV module characteristics it is necessary to study about PV cell at first. A PV cell is the basic structural unit of the PV module that generates current carriers when sunlight falls on it. The power generated by these PV cell is very small. To increase the output power the PV cells are connected in series or parallel to form PV module. The electrical equivalent circuit of the PV cell is shown in Fig

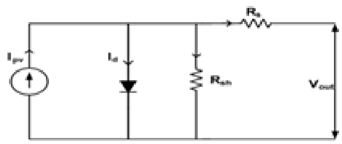


**Fig 3: Electrical equivalent circuit diagram of PV cell**

The main characteristics equation of the PV module is given by

$$I = I_{pv} - I_0\left[\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right)-1\right]-\frac{V+IR_S}{R_{sh}}$$

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{\alpha K}\right]\left(\frac{1}{T_n}-\frac{1}{T}\right)$$

$$I_{pv} = [I_{sc} + K_i(T-T_n)]\frac{G}{G_n}$$

Where,
I and V - cell output current and voltage;
Io - cell reverse saturation current;
T - Cell temperature in Celsius;
K - Boltzmann's constant;
q - Electronic charge;
Ki- short circuit current/temperature coefficient;
G - Solar radiation in W/m2;
Gn- nominal solar radiation in W/m2;
Eg - energy gap of silicon;
Io,n - nominal saturation current;
Rs - Series resistance;
Rsh - shunt resistance;

The I-V characteristic of a PV module is highly non-linear in nature. This characteristics drastically changes with respect to changes in the solar radiation and cell temperature..Whereas the solar radiation mainly affects the output current, the temperature affects the terminal voltage. Fig.4 shows the I-V characteristic of the PV module under varying solar radiations at constant cell temperature (T = 25 ºC).

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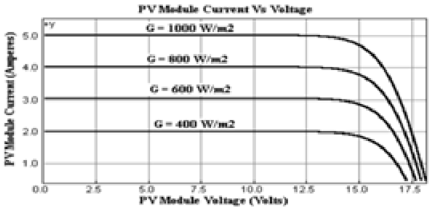

Fig 4: Current versus voltage at constant cell temperature T = 25 ºC.

Fig.5 shows the I-V characteristics of the PV module under varying cell temperature at constant solar radiation (1000 W/m2).

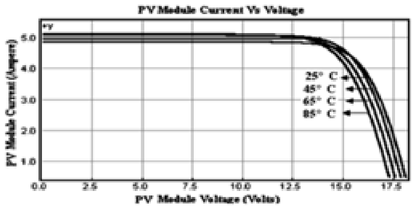

Fig 5: Current versus voltage at constant solar radiation G = 1000 W/m

## III. P&O MPPT algorithm:

It is the simplest method of MPPT to implement. In this method only voltage is sensed, so it is easy to implement. In this method power output of system is checked by varying the supplied voltage. If on increasing the voltage, power is also increases then further 'δ' is increased otherwise start decreasing the 'δ'. Similarly, while decreasing voltage if power increases the duty cycle is decreased. These steps continue till maximum power point is reached. The corresponding voltage at which MPP is reached is known as reference point (Vref). The entire process P&O algorithm is shown in Fig 6.

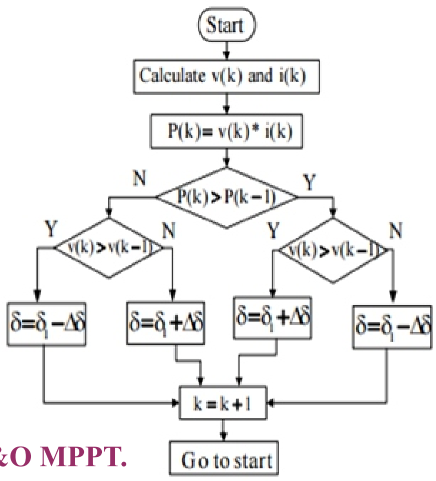


Fig 6: Flow Chart of P&O MPPT.

## IV. Operation principle of the proposed simplified PWM strategy:

A bidirectional single-phase ac/dc converter is usually utilized as the interface between DERs and the ac grid system to deliver power flow bidirectional and maintains good ac current shaping and dc voltage regulation with the renewable PV energy system, boost converter and inverter (Vs), as shown in Fig. 7. Good current shaping can avoid harmonic pollution in an ac grid system, and good dc voltage regulation can provide a high-quality dc load.

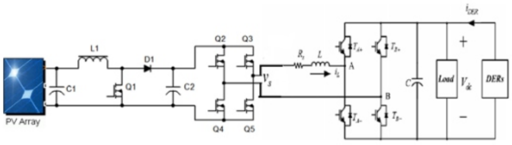

Fig 7: Proposed bidirectional ac/dc converter with PV array

The below two tables mentioned about the bidirectional ac/dc converter operating switching conditions in rectifier mode and inverter mode.

| | Status | $T_{A+}$ | $T_{A-}$ | $T_{B+}$ | $T_{B-}$ | Inductor status |
|---|---|---|---|---|---|---|
| $v_s > 0$ | A | OFF | OFF | ON | OFF | $v_L > 0$ |
| | B | OFF | ON | OFF | OFF | |
| | E | OFF | OFF | OFF | OFF | $v_L < 0$ |
| $v_s < 0$ | C | ON | OFF | OFF | OFF | $v_L < 0$ |
| | D | OFF | OFF | OFF | ON | |
| | E | OFF | OFF | OFF | OFF | $v_L > 0$ |

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

| | Status | $T_{A+}$ | $T_{A-}$ | $T_{B+}$ | $T_{B-}$ | Inductor status |
|---|---|---|---|---|---|---|
| $v_s > 0$ | F | ON | OFF | OFF | OFF | $v_L > 0$ |
| | G | OFF | OFF | OFF | ON | |
| | H | ON | OFF | OFF | ON | $v_L < 0$ |
| $v_s < 0$ | I | OFF | ON | OFF | OFF | $v_L < 0$ |
| | J | OFF | OFF | ON | OFF | |
| | K | OFF | ON | ON | OFF | $v_L > 0$ |

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

To achieve bidirectional power flows in a renewable energy system, a PWM strategy may be applied for the single-phase full-bridge converter to accomplish current shaping at the ac side and voltage regulation at the dc side.

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## V. Proposed simplified PWM Strategy:

In the conventional dual-loop control scheme applied to the single-phase bidirectional ac/dc converter, the inner current loop and outer voltage loop are utilized as shown in Fig. 8, where Vdc is the dc voltage command, Vdc is the actual dc voltage; iL is the ac current command, and IL is the actual ac current. The voltage controller calculates the voltage error and generates the current amplitude command IL multiplied by the unit sinusoidal waveform, obtained from the phase lock loop to generate the current command iL . In general, a proportional-integral controller is adopted as the voltage controller and current controller to achieve power factor correction at the ac side and voltage regulation at the dc side.

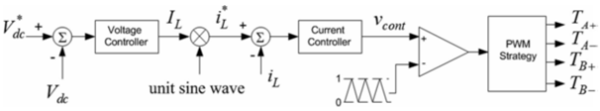


**Fig 8: Conventional dual-loop control scheme for a single-phase bidirectional ac/dc converter.**

Based on the proposed simplified PWM, a novel Direct current scheme is presented in this section. The converter is operated in the rectifier mode and inverter mode. To derive the state-space averaged equation for the proposed simplified PWM strategy, the duty ratio Don is defined as Don = ton /T , where ton is the time duration when the switch is turned ON, i.e., Son = 1, and T is the time period of triangular waveform. The duty ratio Doff is defined as Doff = 1 - Don, which is the duty ratio when the switch is turned OFF. By introducing the state-space averaged technique and volt-second balance theory, the state-space averaged equation is derived as follows:
Vs - (1 - Don) Vdc = O. (1)

When the converter is operated in the steady state, the dc voltage is equal to the desired command Vdc* = Vdc ; (1) can also be expressed in the following form:

Don=1-(Vs/Vdc*)

By introducing the state-space averaged technique and volt- second balance theory, the state-space averaged equa- tion is derived as follows, while the ac grid voltage source is operating in the negative half-cycle vs < O:

Vs + Don Vdc = 0.

Similarly, when the converter is operated in the steady state, the output voltage is equal to the desired command Vdc = V dc. According to the PWM properties, the switching duty ratio can be expressed in terms of the control signal Vcont* and the peak value Vtri of the triangular waveform While the converter is operated in the inverter mode, the control signal v can be obtained using a similar manner in the rectifier mode. Because the control signals Vcont is proportional to Don.

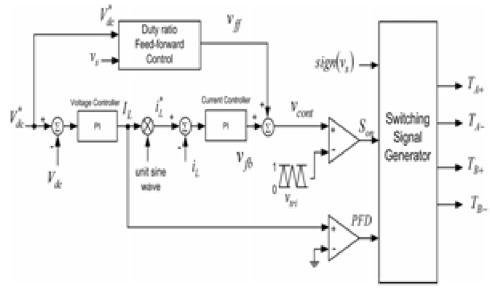


**Fig 9: Proposed control scheme block diagram for a single phase bidirectional ac/dc converter**

## VI. SIMULATION RESULTS:

The below figures shows the simulation circuit diagram of a proposed system and following shows the waveforms getting from the simulation diagram

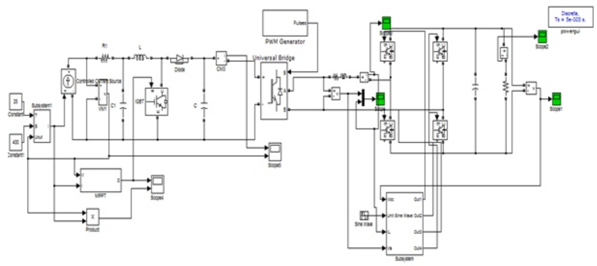

**Fig 10: Proposed Simulation circuit diagram**

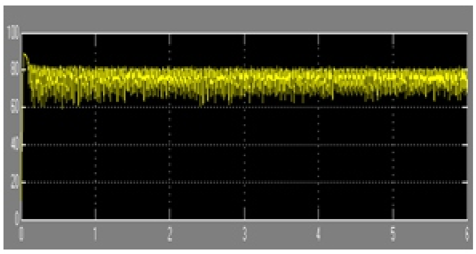

**Fig 11: PV array Voltage**

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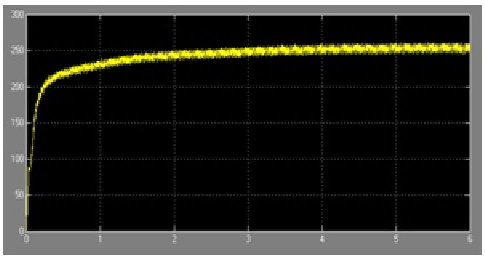

Fig 12: Boost converter voltage

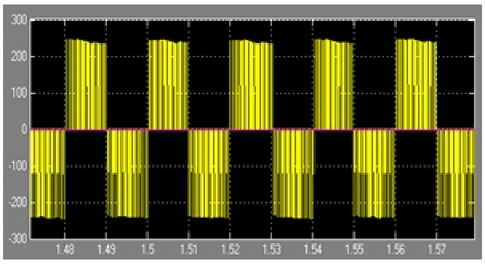

Fig 13: Inverter output voltage

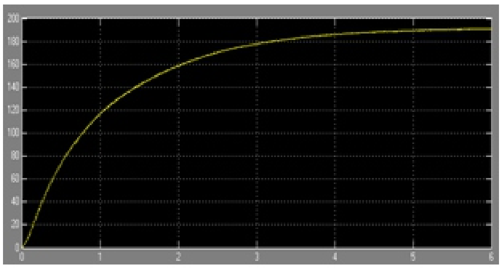

Fig 14: Output Voltage of Bidirectional ac-dc converter

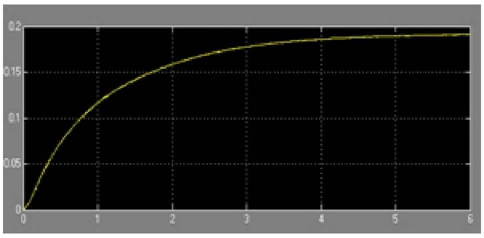

Fig 15: Output current of Bidirectional ac-dc converter.

## VII. CONCLUSION:

This paper presents a novel simplified PWM strategy using a feed forward control scheme in the bidirectional single-phase ac/dc converter with the PV energy system, boost converter for increasing PV input voltage for DER. The proposed simplified PWM strategy only requires changing one active switch status in the switching period. The efficiency of an ac/dc converter operated in the proposed simplified PWM strategy is higher than that in the UPWM and BPWM strategies. Based on the proposed feed forward control scheme, both ac current shaping and dc voltage regulation are achieved in both the rectifier and inverter operating modes. Simulation results are validated in MATLAB/SIMULINK software.

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