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An Embedded "All in one" Photovoltaic DC-AC Converter (seven-level inverter)

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Abstract: Now a day, renewable of energy of different sources is attracted the various researchers and investors for the research work. The photovoltaic system is the best example of the energy renewable, because of it is suitable for different applications like as distributed generation, satellite systems, and transportation. In this paper, a single-phase seven-level inverter (DC-AC Converter) based on photovoltaic system for grid connection is presents. The proposed system uses single-stage transformer which has photovoltaic array for the interfacing to the grid and it has maximum power. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. The inverter is capable of producing seven levels of output-voltage levels (Vdc, 2Vdc/3, Vdc/3, 0,−Vdc,−2Vdc/3, −Vdc/3) from the dc supply voltage. A digital proportional–integral current-control algorithm was implemented in a PIC 30F2010 to keep the current injected into the grid sinusoidal for dc bus voltage 400V.To magnetize the dc-link inductor a modified carrier based modulation technique is used in this paper. The experimental results of the proposed system show the dynamic performance and power quality.

Keywords: DC-AC Converter, Grid-Connected, Photovoltaic (PV) system, Pulse Width-Modulation(PWM), Total Harmonic Distortion (THD),Maximum Power Point (MPP) etc.

I. INTRODUCTION

Now a day lots of energy crisis and environmental issues occurs around us, therefore the renewable of these energy sources are attracted the attention of different researchers and investors. The most promising technology which is available for the renewable energy sources is the photovoltaic system. The photovoltaic system is suitable for distributed generation, transportation system and satellite systems. Generally, to design the single phase photovoltaic system, single stage grid connected system is used and for three phase photovoltaic system, three stage grid connected system is used. The single stage grid connected photovoltaic system uses a dc/ac power inverter for interfacing the photovoltaic system to the grid and to track the Maximum Power Point (MPP). In this topology, photovoltaic the grid has maximum power with very high efficiency, low cost and small size. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW [1]. Types of single-phase grid-connected inverters have been investigated [2]. A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation [3]. The two stage grid connected photovoltaic system uses two conversion stages. In a first stage a dc to dc converter is present which used boost the photovoltaic output voltage. Also, this stage can track the Maximum Power Point (MPP). In a second stage this converter is used for interfacing the photovoltaic system to the grid. The main disadvantage of the two stage grid connected photovoltaic system is, it has very low efficiency, high cost and large size. Due to the above maintained limitations of two stage grid-connected photovoltaic system, single stage converters are used in low voltage applications. The conventional voltage source inverters are simple to operate and easily available in the market. Therefore these inverters are most commonly used as an interface unit for the grid connected photovoltaic system. In case of bulky transformer which provides a high dc voltage the voltage source inverters can be used. Moreover, an electrolytic capacitor is used in case of critical point of failure [1].

Different multilevel inverters are also presented in this paper to improve the different parameters of the photovoltaic system. These multilevel inverters are used to increase the ac side waveform quality, to reduce the electrical stress on the power switches, and to reduce the power losses due to a high switching frequency. In this paper, a single stage single phase seven-level inverter (DC-AC Converter)grid connected photovoltaic system which is based on a Pulse Width-Modulation (PWM) is present. The PWM is used in this system because of the dc input current of PWM is continuous and it is important for a photovoltaic application. The PWM increases the reliability of system. The reliability of system can be increased by replacing the shunt input of electrolytic capacitor with a series input inductor. Also due to this PWM, a low-voltage photovoltaic array can be interface to the grid without the need of a transformer or an additional boost stage [2].To demonstrate the effectiveness and robustness of the proposed system, computer-aided simulation and practical results are used to validate the system. Organization of this paper is in the following way. Section II reviews the development of system, the different proposed methods used in this paper are presented in this section. In section III the experimental performance results are presented. And finally section IV concludes this paper.

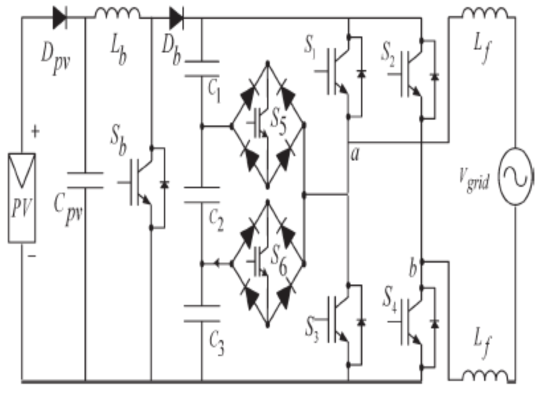
II. DEVELOPMENT OF SYSTEM

This section reports the different methods or components used while developing this system. The experimental setup of the proposed system consists of an agilest modular solar array simulator to evaluate the photovoltaic system operation. The sun is biggest and never ending source of energy which radiates about 3.8 x 10^20MW of electromagnetic energy into the space. But only two percent of it is utilized around the world. Hence it necessitates us to find the way to harness energy which is available in nature in free of cost.

a) Multilevel Inverter Topology:-The proposed single-phase seven-level inverter was developed from the five-level inverter. It comprises a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by C1, C2, and C3, as shown in Fig. 1. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels.

Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter. The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The dc–dc boost converter was requiredbecause the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance Lf was used to filter the current injected into the grid.

Fig. 1.A single-phase seven-level grid-connected DC to AC converter for photovoltaic systems



Proper switching of the inverter can produce seven output-voltage levels (Vdc, 2Vdc/3, Vdc/3, 0,−Vdc,−2Vdc/3,−Vdc/3) from the dc supply voltage.

The proposed inverter's operation can be divided into seven switching states, as shown in Fig. 2(a)–(g).

Fig. 2(a), (d), and (g) shows a conventional inverter's operational states in sequence, while Fig. 2(b), (c), (e), and (f) shows additional states in the proposed inverter synthesizing one- and two-third levels of the dc-bus voltage. The required seven levels of output voltage were generated as follows.

1) Maximum positive output (Vdc):S1 is ON, connecting the load positive terminal to Vdc, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc. Fig. 2(a) shows the current paths that are active at this stage.

2) Two-third positive output (2Vdc/3): The bidirectional switch S5 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is 2Vdc/3. Fig. 2(b) shows the current paths that are active at this stage.

3) One-third positive output (Vdc/3): The bidirectional switch S6 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/3. Fig. 2(c) shows the current paths that are active at this stage.

4) Zero output: This level can be produced by two switching combinations; switches S3 and S4 are ON, or S1 and S2 are ON, and all other controlled switches are OFF; terminal abis a short circuit, and the voltage applied to the load terminals is zero. Fig. 2(d) shows the current paths that are active at this stage.

5) One-third negative output (−Vdc/3): The bidirectional switch S5 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to Vdc. All other controlled switches are OFF; the voltage applied to the load terminals is −Vdc/3. Fig. 2(e) shows the current paths that are active at this stage.

6) Two-third negative output (−2Vdc/3): The bidirectional switch S6 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is −2Vdc/3. Fig. 2(f) shows the current paths that are active at this stage.

7) Maximum negative output (−Vdc):S2 is ON, connecting the load negative terminal to Vdc, and S3 is ON, connecting the load positive terminal to ground.

All other controlled switches are OFF; the voltage applied to the load terminals is −Vdc. Fig. 2(g) shows the current paths that are active at this stage.

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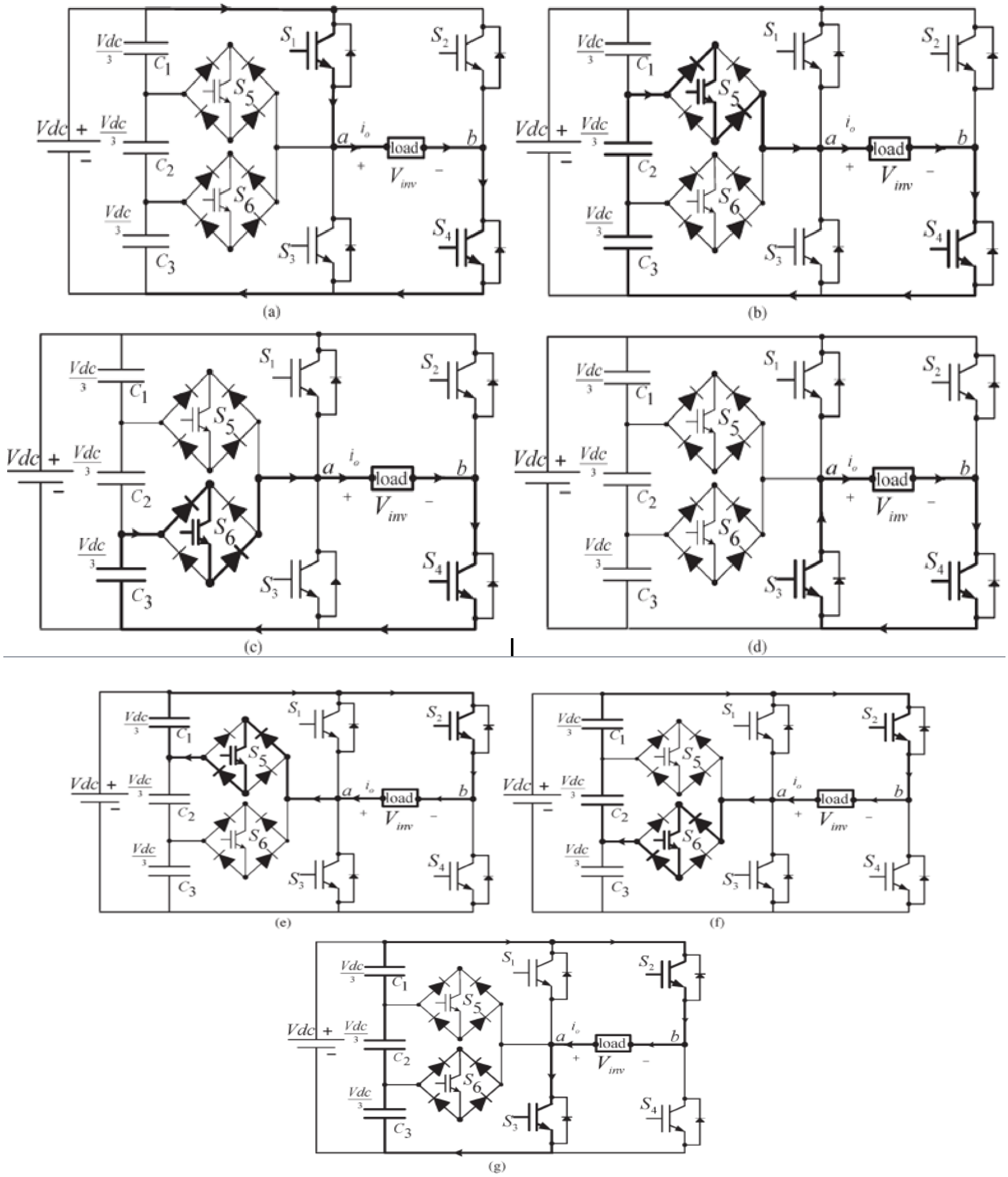

Fig. 2. Seven switching combination required to generate the output voltage (Vab).

TABLE I
OUTPUT VOLTAGE ACCORDING TO THE SWITCHES' ON–OFF CONDITION

v_0	S_1	S_2	S_3	S_4	S_5	S_6
V_{dc}	on	off	off	on	off	off
$2V_{dc}/3$	off	off	off	on	on	off
$V_{dc}/3$	off	off	off	on	off	on
0	off	off	on	on	off	off
0*	on	on	off	off	off	off
$-V_{dc}/3$	off	on	off	off	on	off
$-2V_{dc}/3$	off	on	off	off	off	on
$-V_{dc}$	off	on	on	off	off	off

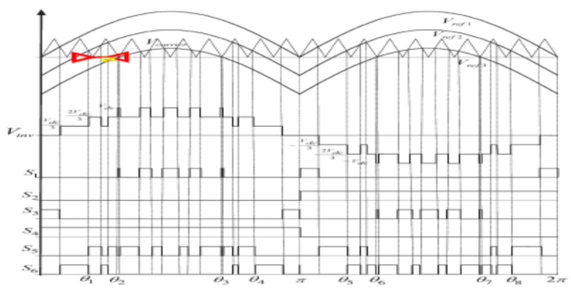

Fig. 3.Switching pattern for the single-phase seven-level inverter

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b) PWM Modulation:-

A novel PWM modulation technique was introduced to generate the PWM switching signals. Three reference signals (Vref1, Vref2, and Vref3) were compared with a carrier signal (V carrier). The reference signals had the same frequency and amplitude and were in phase with an offset value that was equivalent to the amplitude of the carrier signal. The reference signals were each compared with the carrier signal. If Vref1 had exceeded the peak amplitude of V carrier, Vref2 was compared with V carrier until it had exceeded the peak amplitude of V carrier. Then, onward, Vref3 would take charge and would be compared with V carrier until it reached zero. Once Vref3 had reached zero, Vref2 would be compared until it reached zero. Then, onward, Vref1 would be compared with V carrier. Fig. 3 shows the resulting switching pattern. Switches S1, S3, S5, and S6 would be switching at the rate of the carrier signal frequency, whereas S2 and S4 would operate at a frequency that was equivalent to the fundamental frequency.

The Vdc can be maintained at a constant value and at more than √2 of V grid to eject power into the grid. Therefore Vdc is set to 400V.

To deliver energy to the grid, the frequency and phase of the PV inverter must equal to those of the grid; therefore a grid synchronization is needed. PLL is used used for grd synchronization. High frequency signal is generated at the output of PLL which is used as an interrupt signal for ds PIC30F2010 DSP. On receiving interrupt signal from PLL, the PWM switching signals will be generated for respective switches. For one cycle of the fundamental frequency, the proposed inverter operated through six modes. Fig. 4 shows the per unit output-voltage signal for one cycle.

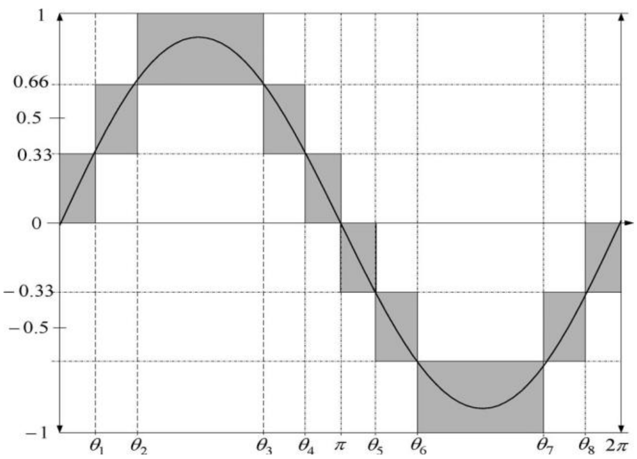

Fig. 4. Seven-level output voltage (Vab) and switching angles.

III.EXPERIMENTAL RESULTS

This section shows the experimental results of proposed system.The PWM switching patterns were generated by comparing three reference signals (Vref1, Vref2, and Vref3) with a triangular carrier signal. Figures 5-10 show the PWM signals for switches S1-s6 respecively. Fig 11 shows the experimental setup for proposed seven level inverer.

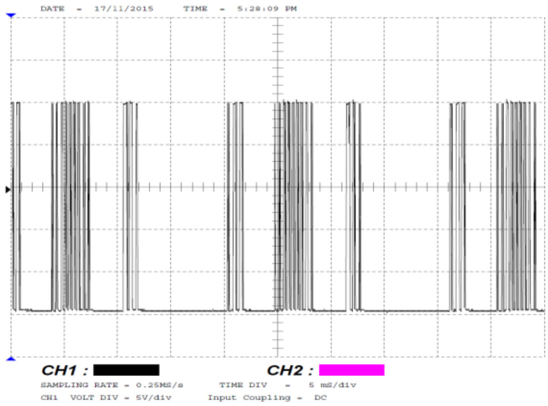

Fig.5. PWM signal for switch S1.

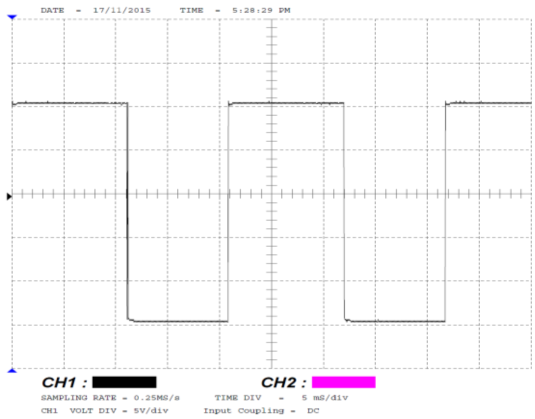

Fig.6.Pwm signal for switchS2.

One leg of the inverter operated at a high switching rate that was equivalent to the frequency of the carrier signal, while the other leg operated at the rate of the fundamental frequency (i.e., 50 Hz).Switches S5 and S6 also operated at the rate of the carrier signal.

From the experimental results the range of output voltage is 100V to 230V for the output current 434 mA. PV arrays of 40W were used as the inverter's input source. Two modules of SIEMENS SP20 were connected in series to produce 40W of peak power. By comparing the three reference signals with the triangular carrier signal in the DSP, the switching patterns of Figs. 5–10 were obtained. Vinv consists of seven levels of output voltage. The dc-bus voltage was set to 400 V to inject current into the grid.

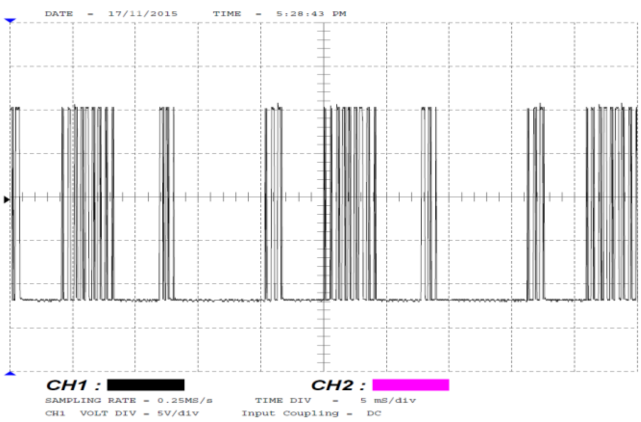

Fig.7. PWM signal for switchS3.

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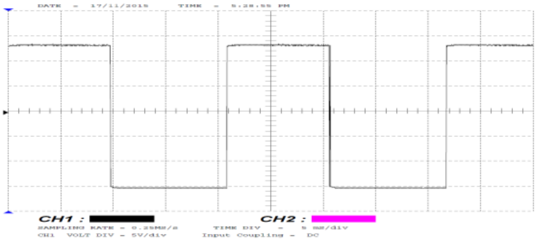

Fig.8. PWM signal for switchS4.

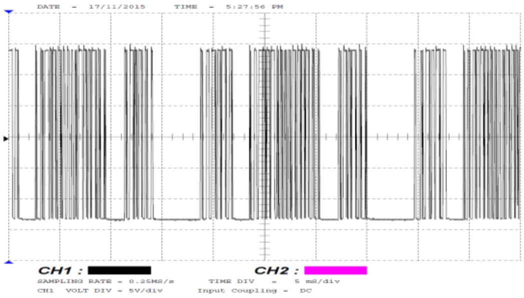

Fig.9. PWM signal for switchS5.


Fig.10.Experimental setup of proposed system

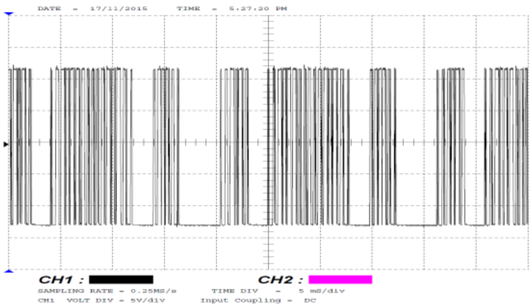

Fig.11. PWM signal for switchS6.

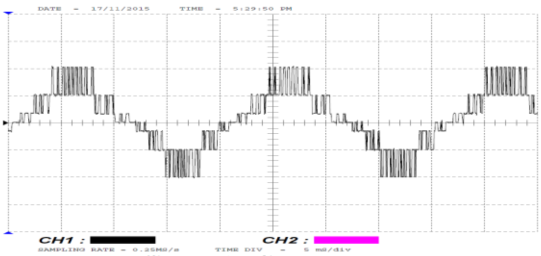

Fig.12. Output Voltage of seven level Inverter.

Below the minimum power condition (for example, during heavy clouds or nighttime) or above the maximum power condition (for example, over rating of the PV arrays, in which the inverter's rating is exceeded), the inverter should not operate to ensure the safety of the PV system and the environment.

IV. CONCLUSION

The proposed multilevel inverters give the improved output waveforms and lower Total Harmonic Distortion (THD). In this paper a novel Pulse Width Modulation (PWM) switching scheme is presented for the proposed multilevel dc to ac converter. This proposed method uses three reference signals and a triangular carrier signal to generate PWM switching signals.
The experimental results show the behavior of the proposed multilevel dc to ac converter. A PIC 30F2010 is used to keep the current injected into the grid sinusoidal for dc bus voltage 400V optimized the performance of the dc to ac converter.

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