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Published in:
CPSS Transactions on Power Electronics and Applications

DOI (link to publication from Publisher):
10.24295/CPSSTPEA.2019.00011

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

A Modified Aalborg Inverter Extracting Maximum Power From One PV Array Source

Houqing Wang, Weimin Wu, Shuai Zhang, Yuanbin He, Henry Shu-Hung Chung, and Frede Blaabjerg

***Abstract*—Distributed Photovoltaic Generation (DPVG) systems have become more important in recent years because of energy pinch and air pollution. Grid-tied inverters, as the indispensable parts of the DPVG systems, have drawn a lot of research attentions. Among various constructors, the Aalborg inverter was proposed as a candidate for the interface between the PV arrays and the power grid for some potential advantages, such as the wide range of input DC voltages, high efficiency, low cost and no leakage current. For a conventional Aalborg inverter, however, in order to gain a symmetrical gird-injected current, when the input DC voltages generated by the PV arrays are not equal, part of the input DC energy has to be discarded, which will reduce the conversion efficiency of the whole system. In this paper, a modified Aalborg inverter with a single input DC source is proposed to extract the maximum DC energy of PV arrays. The operating principle is illustrated via equivalent circuits. The control strategy is designed to balance the capacitor voltages and smooth the grid-injected current. A 110 V/50 Hz/800 W prototype has been built to verify the validity of the proposed inverter together with the effectiveness of the control strategy.**

***Index Terms*—Aalborg inverter, Buck-Boost, maximum power piont tracking (MPPT), photovoltaic system, voltage balance.**

I. Introduction

WITH the development of global economy and the increase of population, environmental pollution and energy shortage are becoming increasingly serious. Distributed Photovoltaic Generation (DPVG), as one of the most important renewable energy resources, has experienced dramatic growth worldwide due to its environmental friendliness [1]–[3]. The grid-tied inverters, connecting the power grid with PV arrays, play an integral role in DPVG systems and have been investigated [4]–[6]. Owning to the advantages of low cost, high efficiency and small size, transformerless inverters using MOSFET switches are regarded as one of the most promising topologies [7]–[9].

Recently, a grid-tied inverter called Aalborg inverter has been proposed in [5], where it is a new family of high efficiency MOSFET-switch-based half-bridge type inverter with a wide variation of input DC voltage. Similar to the conventional dual mode time-sharing inverters [10], [11], since only one power stage chops at high frequency at any time, the minimum switching power losses and high efficiency of the Aalborg inverter can be realized. Meanwhile, a low drop voltage across the filtering inductors in power loop can further reduce the power losses [12]. So this type of inverter is suitable for the connection between power grids and PV arrays. However, in order to ensure the grid-injected current amplitude value is equal during both positive and negative half line cycles, the maximum energy would not be extracted when the input DC voltages are unbalanced, which will result in sacrificing the whole conversion efficiency of the DPVG systems.

In real PV applications, the output energy of each independent PV array is influenced by many factors, such as the shape of PV panels, the air humidity [13], the incidence angle [14] and the irradiation temperature [15]. In this scenario, output DC voltages of the two independent PV sources are not always equal. Consequently, input DC energy from the PV modules cannot be fully utilized for the conventional Aalborg inverter if no other measures are taken. Thus, it is significant to make full use of each input source energy and improve the efficiency of Aalborg inverter, when the output DC voltages of independent PV arrays are unequal.

To fully utilize the DC power generated by the PV arrays, a PV string boost stage is generally applied to the interface between the inverters and PV arrays [4], [16]–[18]. The boost circuit could improve the lower input DC voltage and enable both input DC voltages to be the same for conventional Aalborg inverter, but the auxiliary hardware circuit needs extra devices which leads to a two-stage architecture which inevitably increases the cost and the complexity of the whole system. Based on the operating principle of the coupled inductor, [19] presented a coupled-inductor-based inverter which can regulate the input energy and enable the maximum energy of each PV array to be extracted. The merit of this method is that a magnetic core can be saved and a smaller size and lower cost can be attained [19], [20]. Nevertheless, the leakage inductor of the coupled inductor is required to be very small so that it can be ignored, which will increase the

Manuscript received January 21, 2019. This work was supported in part by NSFC under Grant 51577114, in part by Shanghai Municipal Education Committee under Grant 14SG43, and in part by the Shanghai Science and Technology Commission under Grant 17040501500. This paper was presented in part at the 2018 IEEE International Power Electronics and Application Conference and Exposition (PEAC), Shenzhen, China, November 2018.

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Digital Object Identifier 10.24295/CPSSTPEA.2019.00011

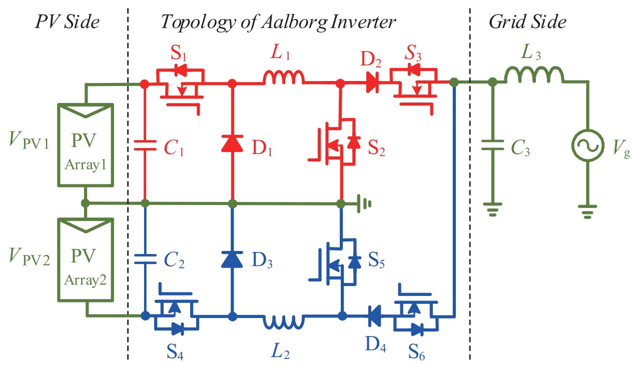


Fig. 1. Conventional Aalborg inverter with two separate input DC sources.

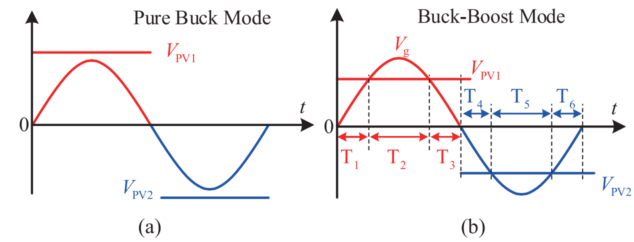


Fig. 2. Operating modes of the Aalborg inverter: (a) Pure “Buck” mode, $|V_g|$ is lower than V_{PV1} and V_{PV2}, (b) “Buck-Boost” mode, $|V_g|$ is higher than V_{PV1} and V_{PV2}.

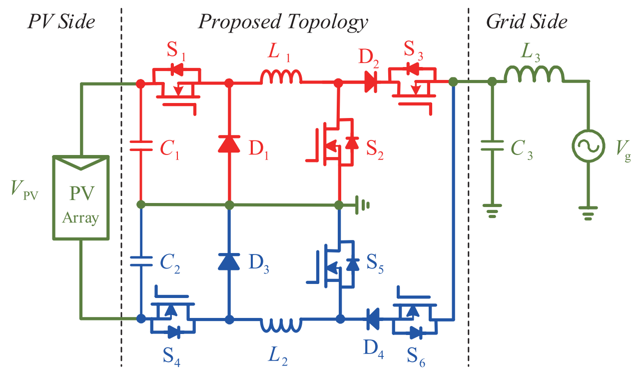


Fig. 3. The modified Aalborg inverter with a single input DC source.

difficulty of the manufacturing process. On the other hand, in terms of software, some methods, like the space vector PWM (SVPWM) [21]–[23], and the predictive control strategy [24], [25], are applied to solve the imbalance issue of DC link capacitor voltage in multilevel multiphase converters, but not applicable to the conventional single-phase Aalborg inverter presented in [5]. This paper presents a modified Aalborg inverter with a single input DC source. Compared with the conventional Aalborg inverter, the main difference in configuration is that the two PV-array sources are replaced with one PV-array source and the mid-line connected ground is dismissed in the proposed inverter. The voltage balance controller is employed in the outer voltage control loop to balance the voltages of electrolytic capacitors.

The rest of this paper is organized as follows. The conventional Aalborg inverter and its principle of operation are first briefly introduced in Section II. Then, the modified Aalborg inverter is presented and analyzed through the equivalent circuits in different working states in Section III. The leakage current of the proposed inverter is analyzed in Section IV. Continuously, in Section V, the whole control strategy is designed to balance the capacitor voltages and get a sinusoidal grid-injected current. The criteria to select the values of passive element are presented in Section VI. Next, an experimental setup is built in Section VII, to verify the validity of the operating principle and the effectiveness of the control strategy. Finally, conclusions are drawn in Section VIII.

II. Conventional Aalborg Inverter

Fig. 1 shows the conventional Aalborg inverter with two separate input DC sources. The red devices work during the positive period of grid voltage. The blue devices work during the negative period of grid voltage. As shown in Fig. 2, according to the amplitude relation between the grid voltage (V_g) and the input DC voltage (V_{PV1}, V_{PV2}), the Aalborg inverter can operate in pure “Buck” mode and “Buck-Boost” mode. When the amplitude value of the grid voltage is lower than the DC voltage, it operates in “Buck” state. Otherwise, it operates in “Boost” state. Therefore, it can regulate the output voltage by changing its working states and is suitable for a wide range of input DC voltage. Furthermore, MOSFET devices are adopted, the inductor voltage drop in the power loop is minimized and only one switch is chopping at high frequency at any time. Thus, high efficiency can be achieved. Besides, no leakage current exists.

However, due to the overshadowed solar panels, installation angle or some other factors in the photovoltaic system [13]–[15], it is very hard for two different PV arrays to generate and output equal DC energy. In order to get a symmetrical grid-injected current, differential DC energy of the two PV arrays has to be lost [4]. Therefore, some extra measures should be taken to fully utilize the output energy of the independent PV array sources.

III. Proposed Single-Input-DC-Source Aalborg Inverter and Its Operation

A single-input-DC-source Aalborg inverter is proposed and shown in Fig. 3. The modified Aalborg inverter inherits the advantages of the conventional Aalborg inverter, such as high efficiency, no leakage current and wide range of input DC voltage. The main difference is that the PV array1 source and array2 source are replaced with one PV array source, and the mid-line connected ground is dismissed. The PV array source first supplies power to the electrolytic capacitors (C_1, C_2), then the electrolytic capacitors will supply the energy to the grid side respectively during the positive and negative period of line frequency. The modified Aalborg inverter can fully extract the energy of the PV array.

Similar to the conventional Aalborg inverter, working states of the proposed inverter are also dependent on the amplitude relation between input DC voltage and grid voltage. When $V_{PV}/2 \geqslant |V_g|$, the proposed inverter operates in “Buck” state. While when $V_{PV}/2 < |V_g|$, the proposed inverter operates in

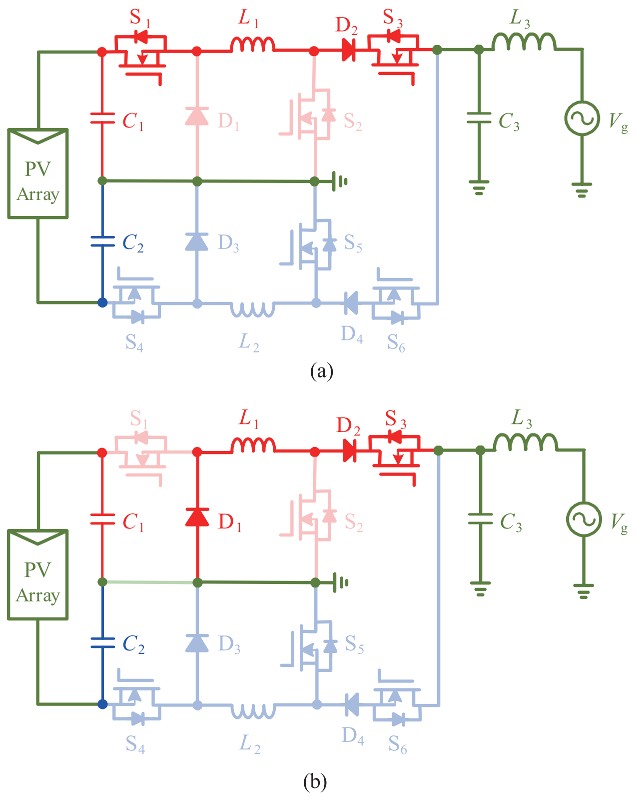


Fig. 4. Equivalent circuits during "Buck" stage in the positive period of line frequency: (a) Energy storing and (b) energy releasing.

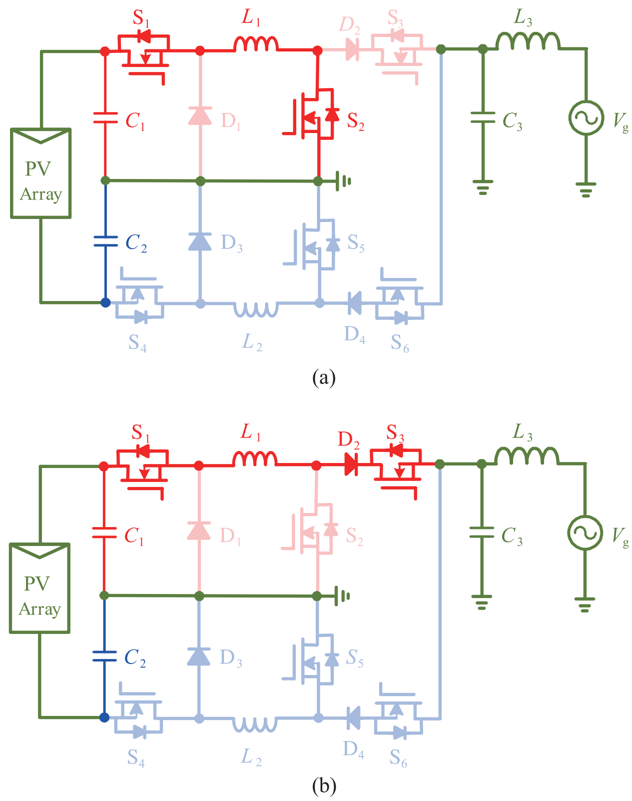


Fig. 6. Equivalent circuits during "Boost" stage in the positive period of line frequency: (a) Energy storing and (b) energy releasing.

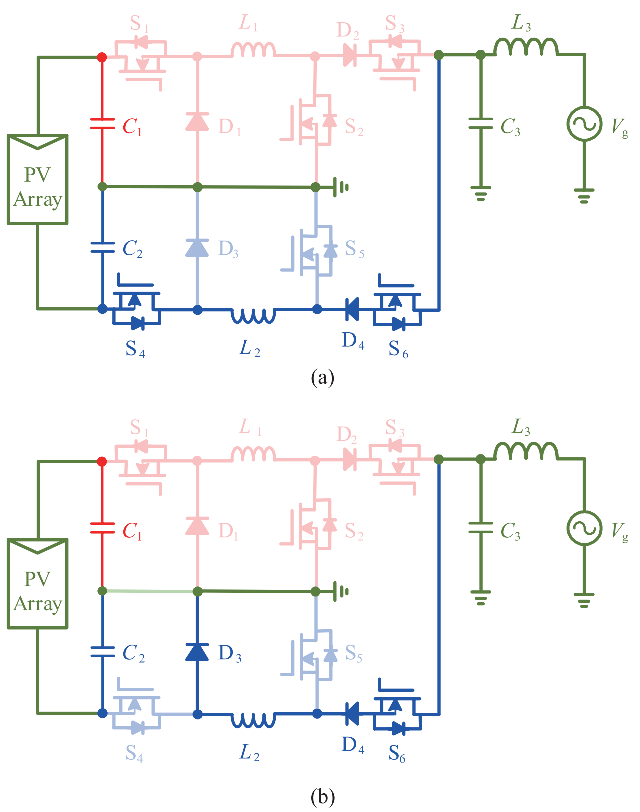


Fig. 5. Equivalent circuits during "Buck" stage in the negative period of line frequency: (a) Energy storing and (b) energy releasing.

"Boost" state. The operating principle of the proposed single-input-DC-source Aalborg inverter will be illustrated through the equivalent circuits.

When the proposed inverter works in "Buck" state, the equivalent circuits are shown in Fig. 4 and Fig. 5. During the positive period of line frequency, S_3 is on, S_1 works in high frequency and the rest of the switches are off. Fig. 4(a) shows that when S_1 is on, capacitor C_1 supplies the energy to L_1 and the grid. When S_1 is off, as shown in Fig. 4(b), the energy stored in L_1 will be released to the grid. During the negative period of line frequency, S_6 is on, S_4 works in high frequency and the rest of the switches are off. Fig. 5(a) shows that when S_4 is on, capacitor C_2 supplies the energy to L_2 and the grid. When S_4 is off, as shown in Fig. 5(b), the energy stored in L_2 will be released to the grid.

Fig. 6 and Fig. 7 show the equivalent circuits when the proposed inverter works in "Boost" state. During the positive period of line frequency, S_1 and S_3 are on, S_2 works in high frequency and the rest of the switches are off. When S_2 is on, capacitor C_1 supplies the energy to L_1. When S_1 is off, capacitor C_1 and L_1 provide energy for the grid. During the negative period of line frequency, S_4 and S_6 are on, S_5 works in high frequency and the rest of the switches are off. When S_5 is on, capacitor C_2 supplies the energy to L_2. When S_5 is off, capacitor C_2 and L_2 provide energy for the grid.

It should be noted that the PV array supplies the energy to both capacitor C_1 and capacitor C_2.

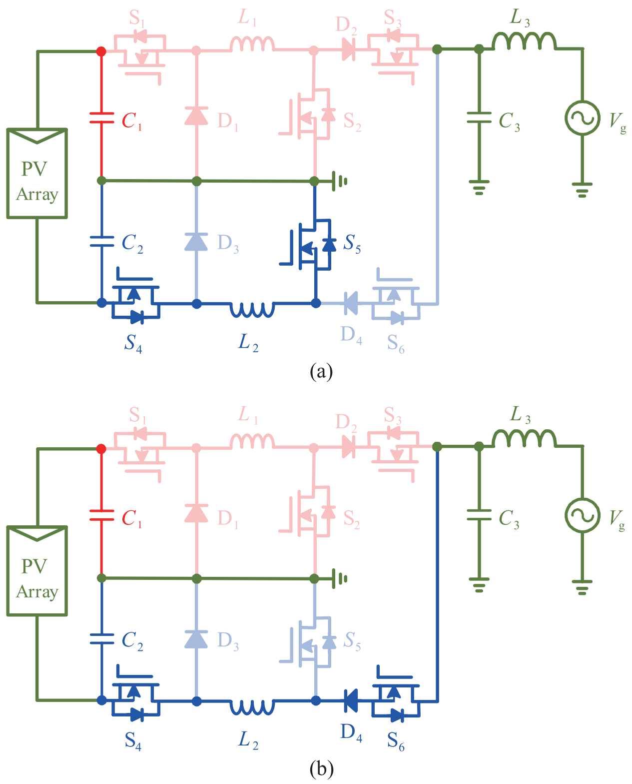


Fig. 7. Equivalent circuits during "Boost" stage in the negative period of line frequency: (a) Energy storing and (b) energy releasing.

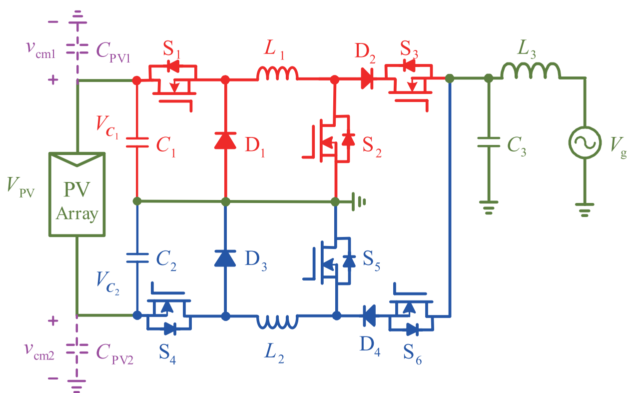


Fig. 8. The structure of the proposed topology with parasitic capacitor.

IV. Leakage Current Analysis of the Modified Inverter

As shown in Fig. 1, since one terminal of the PV panel is connected to the earth, there is no leakage current in the conventional Aalborg inverter. Fig. 8 shows the proposed inverter with parasitic capacitor. The leakage current can be derived as

$$i_{cm}(t) = C\frac{\mathrm{d}v_{cm}}{\mathrm{d}t} \tag{1}$$

Similar to the half bridge topology, the common mode voltage (v_{cm1} or v_{cm2}) across the parasitic capacitor is not affected

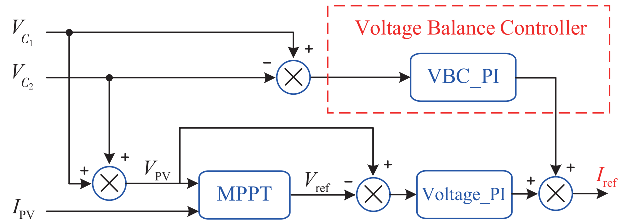


Fig. 9. The outer voltage loop control diagram.

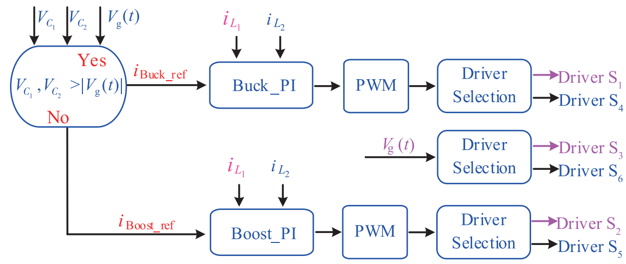


Fig. 10. The internal current loop control diagram.

by switching frequency. If the capacitance of C_1 and C_2 are equal and the capacitance value is large enough, the common mode voltage can be derived as

$$v_{cm1} = v_{cm2} = V_{C_1} = V_{C_2} = \frac{1}{2}V_{PV} \tag{2}$$

Thus, the leakage current caused by the switch operation is almost equal to zero.

V. System Control Strategy

In real applications, some factors, such as the difference of device parameters, the error of sensor and the asymmetric impedance of circuits [19], may cause the electrolytic capacitor voltages to be unbalanced, which distorts the injected current, worsens the circuit performance or even makes the system out of control. In order to balance the electrolytic capacitor voltages, a voltage balance controller (VBC) is employed in this paper. Fig. 9 depicts the outer voltage loop control diagram. The electrolytic capacitor voltages (V_{C_1}, V_{C_2}) are measured, and the difference between V_{C_1} and V_{C_2} will be regarded as the input of the VBC, the output of the VBC and the output of Voltage_PI are superimposed as the grid-injected reference current I_{ref}. VBC is a traditional PI controller. It should be pointed out that the difference of average capacitor voltages is much smaller than the value calculated by PV Maximum Power Point Tracking (MPPT).

Assuming that the electrolytic capacitors (C_1 and C_2) are large enough so that the voltage disturbance coming from the PV arrays can be ignored, and the AC source can be regarded as an ideal source. The small signal model of the modified Aalborg inverter is the same as the conventional Aalborg inverter [5].

Fig. 10 describes the internal current loop control diagram of the modified Aalborg inverter, where the input signals include the grid voltage ($V_g(t)$), the capacitor voltages ($V_{C_1}(t)$, $V_{C_2}(t)$) and the feedback current of DC inductors (i_{L_1}, i_{L_2}). When the capacitor voltage is higher than the amplitude value of grid voltage, the modified Aalborg inverter operates in "Buck" state and it is a classical voltage source inverter with *LCL* filter, which has been analyzed in [26]–[30]. The reference current of "Buck" can be derived as

$$i_{\text{Buck\_ref}}(t) = I_{\text{ref}}(t) \tag{3}$$

When the modified Aalborg inverter works in "Boost" state, an indirect current control method is adopted since character frequency of the filter is much higher than the control bandwidth [5]. Based on the instantaneous input power equals the instantaneous output power, which can be described as,

$$V_{C_X}(t)\cdot i_{L_X}(t) = V_{\text{g}}(t)\cdot i_{\text{g}}(t),\ (\text{X} = 1,\ 2), \tag{4}$$

the reference current of "Boost" can be derived as,

$$i_{\text{Boost\_ref}}(t) = \frac{V_{\text{g}}(t)\cdot I_{\text{ref}}(t)}{V_{C_1}(t)(\text{or } V_{C_2}(t))} \tag{5}$$

VI. Parameter Selection of C_1, C_2, C_3, and L_1, L_2, L_3

A. The Selection of C_1 and C_2

Similar to the conventional half-bridge type converter, by proper design, the voltage fluctuation could be limited to values which would not affect the MPPT.

The output power P_{O} can be obtained by the instantaneous voltage and the current of the output power grid.

$$\begin{aligned} P_{\text{O}}(t) = v_{\text{g}}\cdot i_{\text{g}} &= V_{\text{gm}}\sin\omega t\cdot I_{\text{gm}}\sin\omega t \\ &= \frac{V_{\text{gm}}\cdot I_{\text{gm}}}{2} - \frac{V_{\text{gm}}\cdot I_{\text{gm}}\cdot\cos 2\omega t}{2} \\ &= P_{\text{dc}} + \hat{P}_{\text{ac}}(t) \end{aligned} \tag{6}$$

where V_{gm} is the peak value of the grid voltage, I_{gm} is the peak value of the grid-side current, $\omega = 2\cdot\pi\cdot f$, f is the grid frequency. It can be seen that the output power P_{O} consists of DC component (P_{dc}) and AC component ($\hat{P}_{\text{ac}}(t)$).

Since the input of the inverters is DC power and the output is AC power, according to the conservation of energy, there is power fluctuation on the DC bus. The instantaneous power difference can be obtained by using (6).

$$\hat{P}_{\text{ac}}(t) = -\frac{V_{\text{gm}}\cdot I_{\text{gm}}\cdot\cos 2\omega t}{2} \tag{7}$$

When $\hat{P}_{\text{ac}}(t) > 0$, the capacitor release the energy, which can be derived as

$$\Delta W = \int \hat{P}_{\text{ac}}(t)\,\mathrm{d}t = \frac{V_{\text{gm}}\cdot I_{\text{gm}}}{2\omega} \tag{8}$$

At the same time, the change of capacitance energy can be obtained according to the change of DC bus voltage.

$$\begin{aligned} \Delta W &= \frac{1}{2}C_X(V_{C_X} + \Delta V_{C_X})^2 - \frac{1}{2}C_X(V_{C_X} - \Delta V_{C_X})^2 \\ &= 2C_X V_{C_X}\cdot\Delta V_{C_X},\ (\text{X} = 1, 2), \end{aligned} \tag{9}$$

where V_{C_X} is the average value of C_1 or C_2, ΔV_{C_X} is the voltage ripple of C_1 or C_2. The capacitance value of C_1 or C_2 can be attained from (8) and (9).

$$C_X = \frac{V_{\text{gm}}\cdot I_{\text{gm}}}{4\omega\cdot V_{C_X}\cdot\Delta V_{C_X}} = \frac{P_{\text{dc}}}{2\omega\cdot V_{C_X}\cdot\Delta V_{C_X}} = \frac{P_{\text{O}}}{2\omega\cdot V_{C_X}\cdot\Delta V_{C_X}\cdot\eta}, \tag{10}$$

where η is the efficiency of the whole system. It can be seen that the minimum value of capacitor C_X is determined by the maximum value of voltage ripple.

Suppose $P_{\text{O\_max}} = 800$ W, $\eta = 98\%$, for a maximum ripple of 5%, and substitute other corresponding parameters into (10), the minimum value of C_1 or C_2 can be obtained when the inverter works in "Buck-Boost" mode ($V_{C_1} = V_{C_2} = 100$ V).

$$C_1 = C_2 = 2598\ \mu\text{F} \tag{11}$$

Considering some factors, such as power losses, capacitor aging and steady-state characteristics of the system, the DC bus capacitor [31] is finally selected as $C_1 = C_2 = 4000\ \mu$F.

B. The Selection of L_1, L_2, L_3, and C_3

In this paper, inductors L_1 and L_2 work in continuous conduction mode. The design principle of L_1, L_2 and C_3 given in [32] is followed. When the inverter operates in pure "Buck" mode, values of L_1 and L_2 are obtained from the expression given in [32]

$$\begin{aligned} L_1 &= \frac{V_{C_1}(t) - V_{\text{g}}(t)}{2\,\Delta i_{L_1}}\text{D}\cdot T_{\text{S}}, \\ L_2 &= \frac{V_{C_2}(t) - V_{\text{g}}(t)}{2\,\Delta i_{L_2}}\text{D}\cdot T_{\text{S}} \end{aligned} \tag{12}$$

Typical values of Δi_{L_X} (X = 1, 2) lie in the range of 10% to 20% of the full-load [32]. In this paper $P_{\text{O\_max}} = 800$ W, $V_{\text{g}} = 110$ V, $T_{\text{S}} = 1/40$ k, and suppose the current ripple Δi_{L_X} is

$$\Delta i_{L_X} \leqslant 15\%\cdot i_{\text{g}} \tag{13}$$

By combining (12) and (13), when the inverter works in pure "Buck" mode and D = 0.5, the minimum DC inductor (L_1 or L_2) can be calculated as

$$L_1 = L_2 \approx 0.631\ \text{mH} \tag{14}$$

Considering that the inductance value decreases with the increase of current, $L_1 = L_2 = 0.8$ mH is chosen in this paper. In order to achieve wide stability margin and large control band width, a value which is not larger than L_1 or L_2 is selected for L_3 [33].

Likewise, when the proposed inverter works in "Boost" state,

TABLE I
PARAMETERS FOR EXPERIMENTS

Parameter	Value
DC inductor L_1, L_2	0.8 mH
Electrolytic capacitor C_1, C_2	4000 μF
Filter inductor L_3	0.8 mH
Filter capacitor C_3	2 μF
Grid voltage V_g	110 V
Grid frequency f_o	50 Hz
Switching frequency f_{sw}	40 kHz
Input DC voltage V_{PV}	200 V/400 V

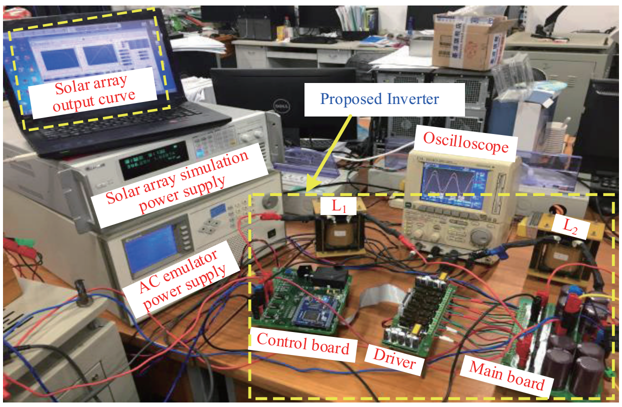


Fig. 11. Experimental prototype developed for the proposed inverter.

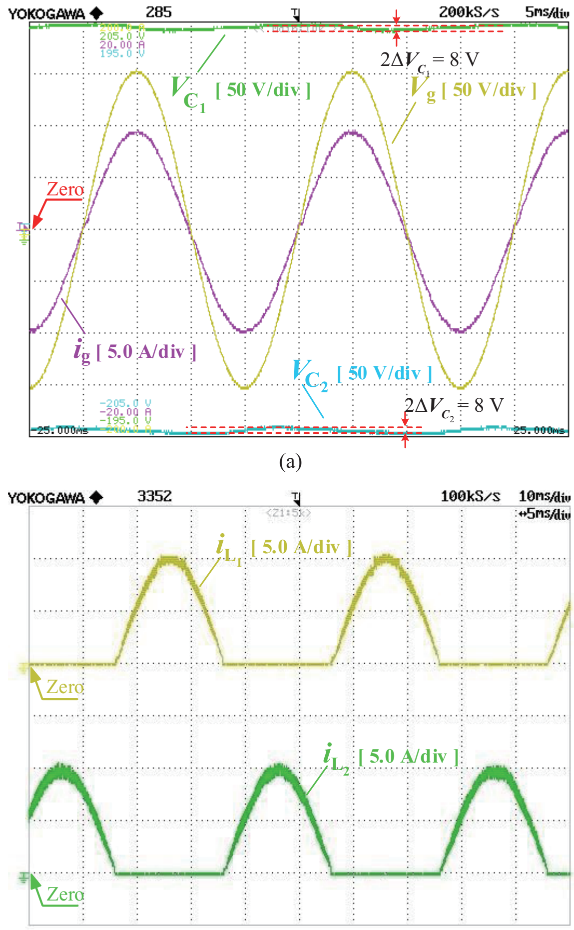


Fig. 12. Experimental waveforms in pure "Buck" mode, when V_{PV} = 400 V, V_g = 110 V and P_O = 770 W. (a) Measured capacitor voltages (V_{C_1}, V_{C_2}), grid-injected current ($i_g(t)$), grid voltage ($V_g(t)$). (b) Measured DC inductor currents (i_{L_1}, i_{L_2}).

the value of C_3 can also be obtained from the expression derived in [32]

$$C_3 = \frac{V_g(t)}{2R_f \Delta v} D \cdot T_S, \tag{15}$$

wherein, R_f is the equivalent resistor for calculating the generated power. Suppose the voltage ripple Δv is

$$\Delta v \leqslant 15\% \cdot v_g \tag{16}$$

Based on (15) and (16), when the inverter works in pure "Boost" mode and D = 0.3548, the minimum capacitor (C_3) can be calculated as

$$C_3 \approx 1.955\ \mu\text{F}, \tag{17}$$

$C_3 = 2\ \mu$F is chosen in this paper.

VII. EXPERIMENTS

As shown in Fig. 11, a 110 V/50 Hz/800 W prototype has been constructed to verify previous analysis. The parameters of the system are listed in Table I. A DSP controller (TMS320LF28335) is adopted to complete all the control tasks. A solar array power supply (Chrome 62150H-600s) is provided to imitate the PV array, and the grid voltage is emulated by using a programmable AC Source of Chroma 6530. The experimental results are displayed in Figs. 11–14, respectively.

Figs. 12–14 show the experimental results when V_{PV} = 400 V, V_g = 110 V, the proposed inverter operates in pure "Buck" mode. Fig. 12 depicts the measured electrolytic capacitor voltages of $V_{C_1}(t)$ and $V_{C_2}(t)$, the grid voltage of $V_g(t)$ and the grid-injected current of $i_g(t)$. From Fig. 12, it can be seen that the grid-injected current is in a good sinusoidal shape and the electrolytic capacitor voltages are almost balanced through the control of VBC (V_{C_1} = 198.68 V, V_{C_2} = 200.45 V). Moreover, the electrolytic capacitor ripple voltage is very small and the ripple voltage is about 4 V. The power factor (PF) and the THDs of the grid-injected current and voltage are measured in Fig. 13. The PF is almost one unit (0.9974) and the THD of the grid-injected current is only 1.86%. Fig. 14 shows that the proposed inverter has a very high MPPT's efficiency, which is around 99.20%.

When V_{PV} = 200 V, V_g = 110 V, the proposed inverter operates in "Buck-Boost" mode and the experimental results are shown in Figs. 15–17. Fig. 15 shows the capacitor voltages of $V_{C_1}(t)$ and $V_{C_2}(t)$, the grid voltage of $V_g(t)$ and the injected current of

(a)

(b)

Fig. 13. The measured results in pure "Buck" mode, when V_{PV} = 400 V, V_g = 110 V and P_O = 760 W. (a) The power factor of the system. (b) The THD values of output voltage and current.

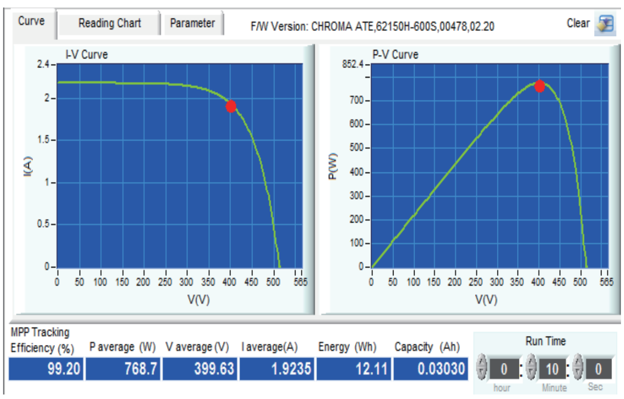
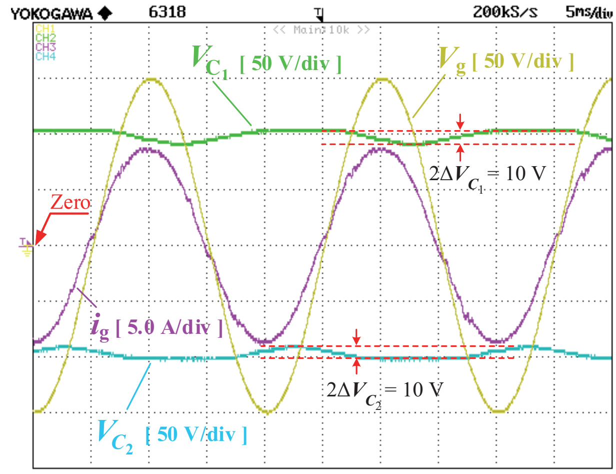
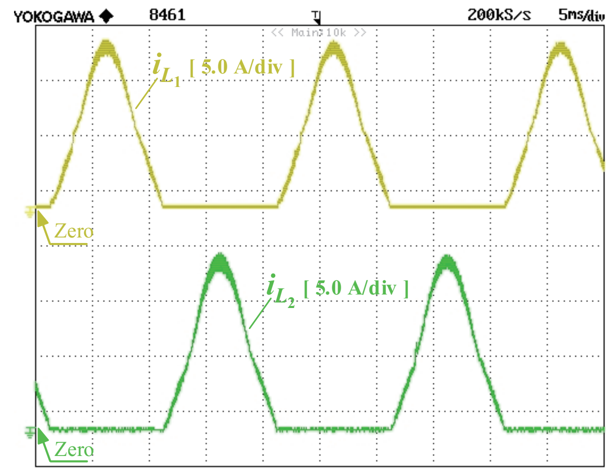


Fig. 14. MPPT results in pure "Buck" mode, when V_{PV} = 400 V, V_g = 110 V and P_O = 770 W.

$i_g(t)$. It can be seen that grid-injected current also has a pretty sinusoidal waveform except for a little distortion resulted from the Buck-Boost switching point. The electrolytic capacitor voltages are kept balanced (V_{C_1} = 101.3 V, V_{C_2} = 101.2 V) and the average voltage of each capacitor is equal to half of the PV array output

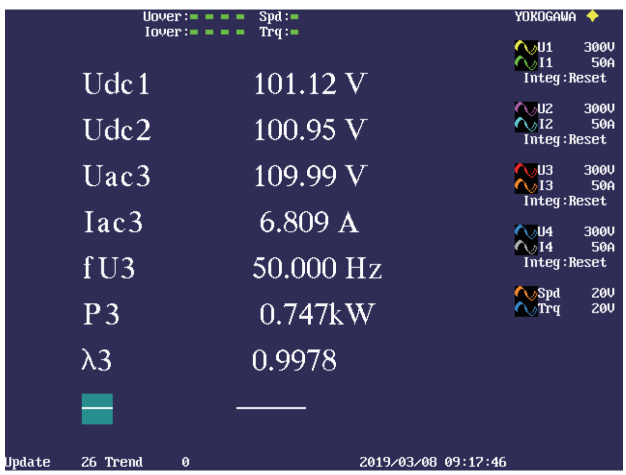


(a)



(b)

Fig. 15. Experimental waveforms in "Buck-Boost" mode, when V_{PV} = 200 V, V_g = 110 V and P_O = 770 W. (a) Measured capacitor voltages (V_{C_1}, V_{C_2}), grid-injected current ($i_g(t)$), grid voltage ($V_g(t)$). (b) Measured DC inductor currents (i_{L_1}, i_{L_2}).



(a)

Fig. 16. Measured results in "Buck-Boost" mode, when V_{PV} = 200 V, V_g = 110 V and P_O = 750 W. (a) The power factor of the system.

(b)

Fig. 16. (*Continued*..) The measured results in "Buck-Boost" mode, when V_{PV} = 200 V, V_g = 110 V and P_O = 750 W. (b) The THD values of output voltage and current.

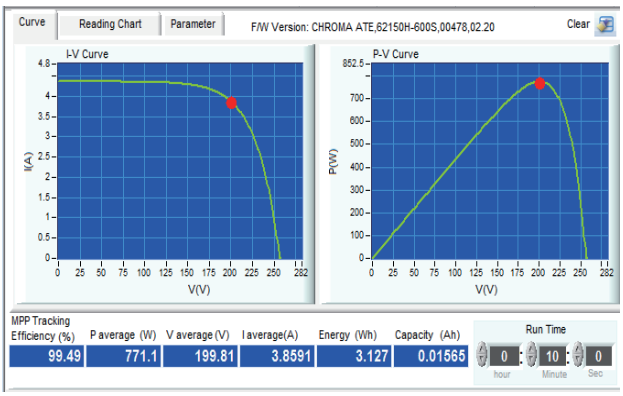


Fig. 17. MPPT results in "Buck-Boost" mode, when V_{PV} = 200 V, V_g = 110 V and P_O = 770 W.

voltage, which means the proposed control method can realize the capacitor voltage balance of the modified Aalborg inverter. At the same time, compared with the electrolytic capacitor voltages, value of the voltage ripple is about 5 V, which is consistent with previous analysis. Fig. 16 shows that the PF is equal to 0.9978 and the THD of the output current and voltage are slightly larger than that in pure "Buck" mode, because of the Buck-Boost switching point. MPPT's results are shown in Fig. 17, it can be seen that the MPPT's efficiency, about 99.49 %, is also very high.

VIII. Conclusion

This paper presents a modified Aalborg inverter with a single input DC source to maximize power yield from the PV array. The characteristics of this inverter can be summarized as follows.

1) Similar to the conventional Aalborg inverter proposed in [5], the inductor voltage drop in power loop is minimized, MOSFET switches are adopted and only one switch operates at high frequency at any time, which ensures that the proposed inverter has a high efficiency. Besides, the input DC voltage can vary widely and no leakage current exists.

2) Different from the conventional Aalborg inverter proposed in [5], the modified Aalborg inverter only requires one PV array source, rather than two. The mid-line connected ground is dismissed. The PV array source first supplies power to the electrolytic capacitors (C_1, C_2), then the electrolytic capacitors will supply the energy to the grid side respectively during positive and negative period of line frequency. The modified Aalborg inverter can fully extracted the energy of the PV array.

The operating principle of the proposed inverter has been illustrated through the equivalent circuits. The whole control strategy is designed to balance the capacitor voltages and obtain a sinusoidal grid-injected current. Experimental results based on an 110 V/50 Hz/800 W prototype have verified the feasibility of theoretical analysis and the effectiveness of the control strategy.

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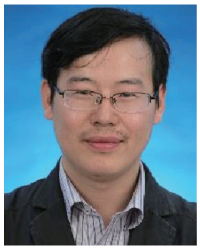

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