Non-Linear PWM Controlled Single-Phase Sepic Converter based on Photovoltaic

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***Abstract*— In this project we will connect a SEPIC mode photovoltaic grid-connected inverter.SEPIC converter are investigated in depth in this paper. Sampling time is reduced the grid-connected voltage modulation current in each switching cycle is tracked. Energy storage inductance current and the balance of the voltage step-up ratio are realized. Nonlinear PWM controlled single-phase SEPIC grid-connected photovoltaic inverter with limited storage inductance current. In order to improve the quality of output waveform of the traditional single-phase SEPIC mode inverter. A new idea that regenerating duty ratio 1-d of the inverter decreases with the decline of the grid-connected voltage namely a nonlinear PWM control strategy based on inverting bridge's modulation current is proposed.**

Keywords—component; formatting; style; styling; insert (key words)

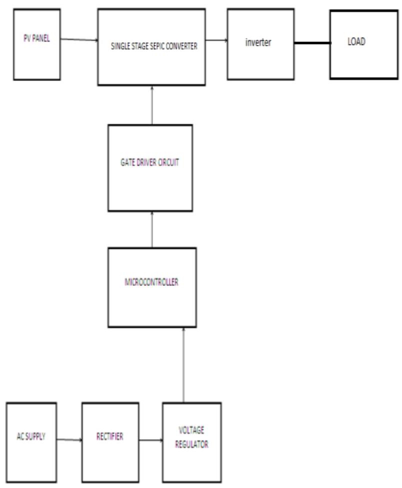
I. INTRODUCTION

The Single-stage electrical converter has become an exploration hotspot within the new energy power generating field [1]-[8]. Compared with the buck mode electrical converter, the boost mode electrical converter has the benefits of single-stage voltage boosting, direct management of the output current and straightforward realizing the utmost electric receptacle trailing (MPPT) of the electrical phenomenon (PV) cell, long lifetime of the energy storage inductors' parts, timely protection with over current and high system dependableness etc. In recent years, with the emergence of latest sort devices like bi face interference IGBT and therefore the development of superconducting technology, boost mode electrical converter can have additional vital application worth. Three-phase boost mode grid-connected electrical converter adopting two-loop management strategy with motor speed outer loop and dc link current inner loop has obtained higher performance[5].The One-cycle management methodology derived by the Buck dc-dc device has additionally been applied for three-phase boost-type grid-connected electrical converter [6]. However, the standard single-phase boost mode SPWM {inverter| electrical device} doesn't meet the fundamental principle of boost converter once the output voltage is less than the input voltage. specifically whether or not the energy storage inductance L is magnetizing or make energy, its current is often increasing, that cause electrical converter cannot get curved grid-connected current. Therefore, the electrical converter whose regenerating duty ratio Disincreasing with the decreasing of -connected voltage international organization has inherent defects like massive energy storage inductance and its current, serious output wave type distortion ,and low conversion potency .For all this, some new resolution son circuit topology and management strategy ar proposed[7]-[15]. A current-fed Z-source electrical converter has been projected which might with success buck and boost voltage in reference [7], however this electrical converter has additional complicated circuit topology as a result of overmuch energy storage part quantity. A one-cycle controlled single-phase Z-source electrical converter with unsymmetrical characteristic is projected in reference [8]. This electrical converter has straight forward circuit topology, input and output sharing a similar ground, however it will solely buck voltage, the conversion potency and doctorate of the output voltage aren't given. A differential electrical converter that 2 bi-directional boost dc-dc converters are connected in parallel within the input facet and connected serial reversely within the output facet is projected in reference [9]-[10]. The 2 bi-directional boost dc-dc converters operate at the same time and severally output low-frequency beating curved voltage with a similar dc element and 180º section distinction. And curved voltage is obtained on the output load. A current-fed Z-source inverter has been proposed which can successfully buck and boost voltage in reference [7], but this inverter has more complex circuit topology due to overmuch energy storage element amount. A one-cycle controlled single-phase Z-source inverter with unsymmetrical characteristic is proposed in reference [8]. This inverter has simple circuit topology, input and output sharing the same ground, but it can only buck voltage, the conversion efficiency and THD of the output voltage are not given. A differential inverter that two bi-directional boost dc-dc converters are connected in parallel in the input side and connected in series reversely in the output side is proposed in reference [9]-[10]. The two bi-directional boost dc-dc converters operate simultaneously and respectively output low-frequency pulsating sinusoidal voltage with the same dc component and 180^{o} phase difference. And sinusoidal voltage is obtained on the output load. But it is hard to get ideal conversion efficiency of the inverter because of the loop current from the simultaneous operating of the two converters. An inverter whose power switch is connected in series between the positive end of the input source and energy storage inductor, and a freewheeling diode is connected in parallel between the negative end of the input source and energy storage inductor in the traditional circuit is proposed in reference [11]. The serial connected power switch and the inverting bridge power switches are controlled by the hysteresis control strategy of the output voltage and energy storage inductor current, the inverter is operating in boost Mode or Buck Mode, and the dual sinusoidal half-wave energy storage inductor current and output sinusoidal voltage with high frequency (HF) ripple which are synchronized with the output voltage are obtained. This scheme reduces the energy storage inductor to 0.3mH, but the output filter capacitance is still as high as 20μF, the conversion efficiency is only 78% and THD of the output voltage is as high as 3.87%.

II. OPERATING PRINCIPLE

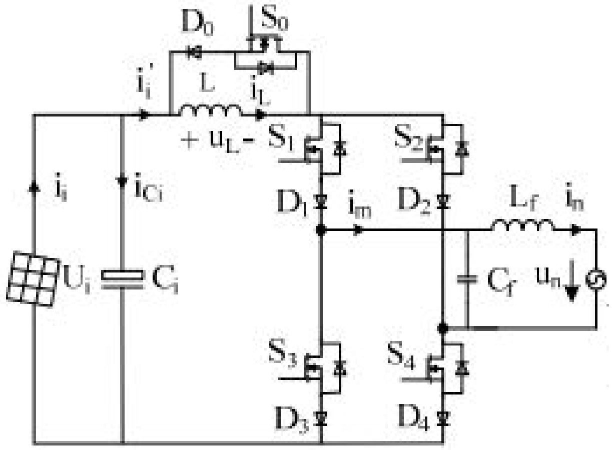
Single-phase boost mode photovoltaic grid-connected inverter Kind of inverter are investigated in depth. Sampling decrease the grid-connected voltage.modulation current in each switching cycle tracked. Energy storage inductance current and the balance of the voltage step-up ratio are realized. Nonlinear PWM controlled single-phase SEPIC grid-connected photovoltaic inverter with limited storage inductance current. In order to improve the quality of output waveform of the traditional single-phase SEPIC mode inverter A new idea that regenerating duty ratio 1-d of the inverter decreases with the decline of the grid-connected voltage namely a nonlinear PWM control strategy based on inverting bridge's modulation current is proposed.

III. BLOCK DIAGRAM



Nonlinear PWM controlled single-phase SEPIC grid-connected photovoltaic inverter with limited storage inductance current .In order to improve the quality of output waveform of the traditional single-phase SEPIC mode inverter. A new idea that regenerating duty ratio 1-d of the inverter decreases with the decline of the grid-connected voltage namely a nonlinear PWM control strategy based on inverting bridge's modulation current is proposed. The SEPIC converter not only boosts the supply the supply voltage but also acts as filter.

IV.CIRCUIT DIAGRAM



V. NONLINE PWM CONTROL STRATEGY

A. Control Principle

In order to improve the quality of output waveform of the traditional single-phase boost mode inverter, a new idea that regenerating duty ratio 1-D of the inverter decreases with the decline of the grid-connected voltage u_n, namely a nonlinear PWM control strategy based on inverting bridge’ s modulation current is proposed in this paper, as shown in Fig. 1. This control strategy is that the inverter’ s regenerating energy duty ratio 1-D is real-time regulated by detecting and feeding back the modulation current i_m and high quality grid-connected current is obtained. When the grid voltage u_n is less than the input voltage U_i, i_m is greater than the expected value and the integral time $(1-D)T_s$ of the feedback signal i_m to the reference value $|i_r|$ will become shorter, 1-D will be decreased, thus the waveform quality of the grid-connected current i_n will be improved.

A.Two Kinds of Switching Pattern

In order to solve problems such as the excess energy of the energy storage inductor, too large step-up ratio, large internal resistance loss and low conversion efficiency for $D>D_{min}$, it needs to limit the energy storage inductor current i_L. It is necessary to add a free-wheeling pattern of the energy storage inductor to limit i_L and transfer its excess energy to the AC grid in the subsequent several switching periods, as shown in Fig. 2.

In Fig. 2, I_{L*} is the limitation value for i_L, T_{es} is the equivalent switching period, and D_{Ii}, D_{IIi} (i=1, 2) are the duty ratio of the inverter in the boost pattern and the free-wheeling pattern respectively.

In order to limit the energy storage inductor current, a two-quadrant bypass switch is connected in parallel at both ends of the inductance L, which is consisting of S_0 and D_0 connected in series.

B. *New Problems Caused by Proposed Control Strategy*

Nonlinear PWM control strategy directly determines 1-D and improves the output waveform. However, the larger u_n and i_n of the inverter, the smaller D is, the greater 1-D is and the smaller the step-up ratio 1/(1-D) is, which does not meet the control requirements of the boost converter, namely the variation law of D is opposite to that of D required by the step-up ratio of the inverter. When u_n and i_n are the maximum, D is the minimum D_{min}, the magnetizing time of the energy storage inductor is the shortest, the demagnetizing time is the longest and demagnetizing voltage is the largest, i_L is most easily discontinuous. In order to ensure proper operation, i_L must be designed on critical continuous state at least when u_n, i_n are the largest and $D=D_{min}$, namely $1/(1-D_{min})\geq u_n/U_i$. Thus a new problem is caused: when $D>D_{min}$, the step-up ratio is too large and the energy of the energy storage inductors is excess. In order to satisfy the control requirements of the boost converter, this kind of nonlinear PWM controlled inverter needs to balance the excess energy of the energy storage inductor and too large step-up ratio by the loss of internal resistance including energy storage inductor' s parasitic resistance and power switches conduction resistance, which leads to inherent defects such as large internal resistance loss and low conversion efficiency.

VI. Solutions to Excess Inductor Energy and Too Larger Step-up Ratio

A. Two Kinds of Switching Pattern

In order to solve problems such as the excess energy of the energy storage inductor, too large step-up ratio, large internal resistance loss and low conversion efficiency for $D>D_{min}$, it needs to limit the energy storage inductor current i_L. It is necessary to add a free-wheeling pattern of the energy storage inductor to limit i_L and transfer its excess energy to the AC grid in the subsequent several switching periods, as shown in Fig. 2. In Fig. 2, I_{L*} is the limitation value for i_L, T_{es} is the equivalent switching period, and D_{Ii}, D_{IIi} (i=1, 2) are the duty ratio of the inverter in the boost pattern and the free-wheeling pattern respectively.

The single-phase boost mode inverter' s topology which does not meet the basic principle of boost converter is very different from the three-phase boost mode inverter' s topology in reference [6] which meets the basic principle of boost converter; the proposed non-linear control strategy real-time adjusts the inverter's regenerating energy duty ratio 1-D which decreases with the decline of the grid-connected voltage u_n by sampling and feeding back the inverting bridge modulation current, and the average value of the modulation current in each switching cycle tracks the reference sinusoidal signal to get high quality grid-connected current; whereas the One-cycle control strategy in reference [6] regulates the inverter's energy storage duty ratio D which decreases with the decline of the grid-connected line voltage by sampling and feeding back the energy storage inductor current, and the average value of the difference between constant related to output power and the energy storage inductor current in each switching cycle tracks the reference line voltage to get grid-connected current with THD value of 5%. Therefore, the proposed non-linear control strategy which can solve the inherent defect of the single-phase boost mode inverter has some difference from the One-cycle control strategy in reference [6]. The comparison results have shown that the proposed inverter obtains excellent comprehensive performance indexes such as small energy storage inductor and output filter, small THD of grid-connected current waveform, high conversion efficiency, and low cost etc.mode inverter' s topology which does not meet the basic principle of boost converter is very different from the three-phase boost mode inverter' s topology in reference [6] which meets the basic principle of boost converter; the proposed non-linear control strategy real-time adjusts the inverter's regenerating energy duty ratio 1-D which decreases with the decline of the grid-connected voltage u_n by sampling and feeding back the inverting bridge modulation current, and the average value of the modulation current in each switching cycle tracks the reference sinusoidal signal to get high quality grid-connected current; whereas the One-cycle control strategy in reference [6] regulates the inverter's energy storage duty ratio D which decreases with the decline of the grid-connected line voltage by sampling and feeding back the energy storage inductor current, and the average value of the difference between constant related to output power and the energy storage inductor current in each switching cycle tracks the reference line voltage to get grid-connected current with THD value of 5%. Therefore, the proposed non-linear control strategy which can solve the inherent defect of the single-phase boost mode inverter has some difference from the One-cycle control strategy in reference [6]. The comparison results have shown that the proposed inverter obtains excellent comprehensive performance indexes such as small energy storage inductor and output filter, small THD of grid-connected current waveform, high conversion efficiency, and low cost etc.

Waveform of energy storage inductor current with free-wheeling pattern

In order to limit the energy storage inductor current, a two-quadrant bypass switch is connected in parallel at both ends of the inductance L, which is consisting of S_0 and D_0 connected in series, as shown in Fig. 3(a).

For the same output power, I_{L*} decreases with U_i increasing, the loss of the inverter decreases, its efficiency is increased. Specially when U_{MPP}=122V, the maximum efficiency of the inverter is 90.71%. With the development and application of the bi-directional blocking power device such as the reverse-blocking IGBT, the proposed inverter will be not necessary to connect in series with the reverse blocking diode, and the conversion efficiency will be greatly improved. The lighter the load, the larger the grid-connected current' s THD is, because there are larger measurement error of AD and current transducer with larger scale under the light load.

The additional bypass switch can actively control i_L. Once i_L is greater than the limitation value I_{L*}, the energy storage inductor freewheeling state when S_0 is conducted replaces the energy storage inductor magnetizing state when the inverting bridge switches are shoot-through, which can effectively suppress the rise of the energy storage inductor current, and solve the problems of too large step-up ratio of the inverter and excess energy of the energy storage inductance.

The two types of switching pattern which can limit the energy storage inductor current: When $i_L < I_{L*}$, the magnetizing state of the energy storage inductors through the pass-through bridge arm during the DT_s and the regenerating energy state of the energy storage inductors to the grid during $(1-D)T_s$ are called the switching pattern I-boost pattern; When $i_L > I_{L*}$, the freewheeling state of the energy storage inductor through the

bypass switch S_0 during the DT_s and the regenerating energy
state of the energy storage inductors to the grid during $(1-D)T_s$
are called the switching pattern II-freewheeling pattern.
Three-loop control strategy which consists of the inner-loop of
the nonlinear PWM control based on the modulation current,
the central-loop of the grid-connected current and the outer
power loop of the MPPT shown in Fig.3(b) is introduced in the
proposed inverter with two kinds of switching pattern and
limitation of the energy storage inductor current. It is necessary
to add, i_m is i_L during $(1-D)T_s$, namely i_m of the nonlinear PWM
control loop shown in Fig.1(c) can be replaced by the energy
storage inductor current i_L shown in Fig.3(b); the MPPT is a
dual-mode MPPT which is combination

PHOTOVOLTAIC STRUCTURE

A PV cell receives energy from sun and converts the sunlight into DC power [10]. The essential device of PV system is PV cell; these cells are grouped known as arrays or panels. A PV cell basically is made of semiconductor materials, such as silicon. The voltage and current from PV device terminal may directly supply small loads such as DC motors and lighting system [1, 2, 3, 14]. Using MATLAB software the mathematical model of PV cell can be developed. From the theory of semiconductor mathematically explain the V-I characteristic of the idea PV cell is specified by [1, 8, 9, 12]; PV cell d , I = − I I (1) , [ex p ( ) 1] d o cell q v I I nkT = − (2) , , PV cell o cell exp( ) 1 qv II I nkT ª º =− − « » ¬ ¼ (3) Practical arrays are composed of several linked PV cell and check of the characteristics at the terminal of PV array requires the inclusion of additional parameters.

Energy Storage Inductor Current Limitation Value

Set the grid power factor equals 1, the grid voltage and
grid-connected current are respectively

$u_n(t) = \sqrt{2}U_n \sin(\omega t)$ (5)

$i_n(t) = \sqrt{2}I_n \sin(\omega t)$ (6)

The average value of i_n and i_m during k-th T_s are equal, as in (7)

s
s
kT
(k 1)T n
S
1 2I sin(t)dt
T ·

· ·

s
s s
kT t i n
(k 1 D)T (k 1 D)T L S
S
1 U 2U sin( ) d i (k 1 D)T dt
T · · · · L
· · · · · · · · · · · · · ·
· · · ·

· · (7)

When $|u_n| > U_i$, the freewheeling pattern adjusts the relationship between 1-D and the step-up ratio. The number of
the freewheeling pattern reduces with the rise of $|u_n|$. At the
same time, L needs enough magnetizing time to guarantee i_L
continuous, i.e. operating in switching pattern I. So the
regenerating energy duty ratio of the inverter cannot be too
large, as in (8)

· · n s i 1 1· D · u (kT) U (8)

The extreme situation of (8) is that i_n and u_n reach the peak
simultaneously. At the moment, 1-D of corresponding
switching period is the maximum, L has longest demagnetizing
time and highest demagnetizing rate, and i_L rapidly decreases to
the minimum value leading it discontinuous. When · t
· · 2 ,

set · · s k · (· 2) · T , substituting them into (7)

n i n
L s
s
2I (U 2U)(1 D)
i (k 1 D)T
1 D 2Lf
· ·
· · · ·
·
(9)

Derived from (8), (9)

n n n i
L s i
i n s
U I 2U U
i [(k 1 D)T] 2 U
U 2U Lf
·
· · · · (10)

So the limitation value of the energy storage inductor current
must be satisfied
* n n i
L i
i n s
P 2U U
I 2 U
U 2U Lf
·
· · (11)
In order to reduce loss, i_L should be as small as possible.
The minimum limitation value I_{L*} can be directly derived from
(11). At this time, the maximum regenerating energy duty ratio
should be satisfied by (8), namely $1-D_{min}$ i n · U / 2U . In addition,
the bigger L and f_s, the more stable i_L is. When Lf_s is big enough,

• • • • n i i n i n s 2P U · U 2U · U 2U Lf ,

derived as
*
L L n i i · I · 2P U (12)
The regenerating energy duty ratio can be derived from (4), (6)
and (12)
n i
L n
I U
1 D 2 sin(t) sin(t)
i 2U
· · · · · (13)
From (11), I_{L*} mainly depends on the output power of PV cells
for the inverter. If the illumination, the temperature and the
peak value of the grid voltage are constant, I_{L*} will remain
unchanged.

VII. Conclusion

1) A nonlinear PWM control strategy based on inverting
bridge modulation current is proposed. The size of 1-D is
timely adjusted by detecting and feeding back modulation
current im, and the quality of output waveform is improved.
2) A circuit topology of the single-phase boost mode
grid-connected inverter with additional bypass switch of the
energy storage inductor and two types of switching pattern with
limitation current of the energy storage inductor are proposed.
The active control of the energy storage inductor current is
realized by the freewheeling state of energy storage inductor
replacing the magnetizing state. The problems such as excess
energy of the energy storage inductor and too large step-up
ratio of the inverter can be effectively solved and the
conversion efficiency is also improved.
3) There are six kinds of equivalent circuits and eight
operating intervals in one LF output period, there are four kinds
of operating situations and eight operating intervals in one HF
switching period, and the relationship between step-up ratio
and duty ratio of the equivalent switch is derived.
4) Design criteria of the key parameters such as the energy
storage inductor, limitation current of energy storage inductor,
input and output filter are derived.
5) The experimental results of the designed and developed
1kW 110VDC/220V50HzAC inverter prototype show that the
energy storage inductance is significantly reduced, conversion
efficiency is increased, and the quality of output waveform is
improved.

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