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Design and Implementation of Synchronous Buck Converter Based PV Energy System for Battery Charging Applications

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ABSTRACT: In this paper synchronous buck converter based PV energy systems for portable applications especially low power device applications such as charging mobile phone batteries are considered here the converter topology is used. The uses of soft switching technique to reduce the switching losses which is found prominently in the conventional buck converter thus efficiency of the system is improved and the heating of Mosfets due to switching losses reduce and the mosfets have a longer life. The dc power extracter from the PV array is synthesized and modulated by the converter to suit the load requirement further the comparative study between the proposed synchronous buck converter and conventional buck converter is analyzed in terms of efficiency improvement and switching loss reduction.

INTRODUCTION; In recent years, many places in the world have been experiencing continued shortage of electric power or energy crisis due to their fast increasing demand. To solve this problem, significant efforts of research and development have been given in two areas: Firstly, improve the efficiency of present power conversion and utilization system. Secondly, develop efficient renewable energy generation and conversion systems to supplement conventional fossil fuel based energy supply and eventually replace it.

Renewable energy sources offer a promising solution to the energy crisis. The renewable energy generation and conversion system has many advantages over conventional energy supply, e.g. the ability of regeneration, reusability and less pollution.

However, the renewable energy generation and conversion technologies are not completely mature yet. There still exist problems such as low efficiency and high cost. The main sources of renewable energy currently under development include solar, wind, hydropower and biomass. These renewable energy sources like solar and wind have shown promise as possible cost efficient alternatives to fossil fuels.

Compared to wind energy, the most effective and harmless energy source is probably solar energy.

Most renewable sources are based on energy from the sun, geothermal forces and planetary motion in the solar system. Solar, wind, hydropower, wave energy, tidal power, ocean thermal energy conversion, and bio fuels are renewable where as fossil fuels constitute non-renewable. Solar energy is the solar radiation that reaches the earth. Every day Sun radiates or sends out an enormous amount of energy.

Broadly, following three approaches are generally followed for utilizing solar energy.

- Absorbing solar energy directly or by using concentrators and then converting into thermal energy for needed applications,
- Converting solar energy into electrical power using photovoltaic or thermoelectric devices, and
- Utilizing solar energy indirectly.

The solar power system has the potential to become one of the main renewable energy sources due to the commercial availability of semiconductor-based photovoltaic devices, reduction in the system cost and development of power electronic technologies.

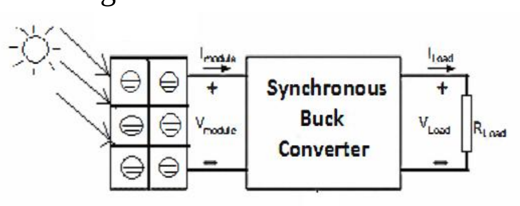

Fig 1 schematic diagram for PV base converter system

Analysis of synchronous buck converter:

The voltage-mode soft-switching method that has attracted most interest in recent years is the zero voltage transition. This is because of its low additional conduction losses and because its operation is closest to the PWM converters. The auxiliary circuit of the ZVT converters is activated just before the main switch is turned on and ceases after it is accomplished.

The auxiliary circuit components in this circuit have lower ratings than those in the main power circuit because the auxiliary circuit is active for only a fraction of the switching cycle; this allows a device that can turn on with fewer switching losses than the main switch to be used as the auxiliary switch. The improvement in efficiency caused by the auxiliary circuit is mainly due to the difference in switching losses between the auxiliary switch and the main power switch if it were to operate without the help of the auxiliary circuit.

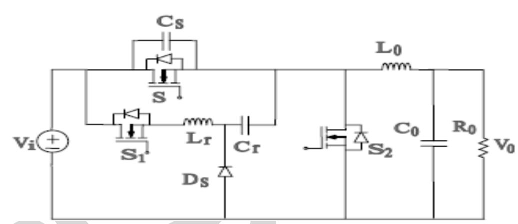

Fig : 2 The Auxiliary Converter

II. OPERATION PRINCIPLES AND ANALYSIS

The circuit scheme of the new ZVT synchronous buck converter is shown in Fig.1. The auxiliary circuit consists of switch S1, resonant capacitor Cr, Resonant inductor Lr.

The auxiliary circuit operates only during a short switching transition time to create ZVS condition for the main switch. The body diode of the main switch is also utilized in the converter. A high frequency schottky diode DS is used for discharging the capacitor voltage to the output, which happens before the turn on of the synchronous switch. During one switching cycle, the following assumptions are made in order to simplify the steady-state analysis of the circuit.

1. Input Voltage V_i is constant.
2. Output Voltage V_0 is constant or output capacitor C0 is large enough.
3. Output current I_0 is constant or output inductor L_0 is large enough.
4. Output Inductor L_0 is much larger than resonant circuit inductor Lr.
5. Resonant circuits are ideal.
6. Semiconductor devices are ideal.
7. Reverse recovery time of all diodes is ignored.

B. **Modes of Operation**

The operation of synchronous buck converter with ZVS and ZCS technique for reducing the switching loss of main switch is described as follows. Eight stages take place in the steady-state operation during one switching cycle in the converter. The key waveforms of these stages are given in Fig. and the equivalent circuit schemes of the operation stages are given. The detailed analysis of every stage is presented below:

Mode 1 (t0, t1):

Zero-current turn-on as it is in series with the resonant inductor Lr. The current through resonant inductor Lr and resonant capacitor Cr rise at the same rate as falls of current through iS2. Resonance occurs between Lr and Cr during this mode. The mode ends at t = t1, when i_{Lr} reaches I0 and iS2 falls to zero in result the body diode of S2 stops conducting.

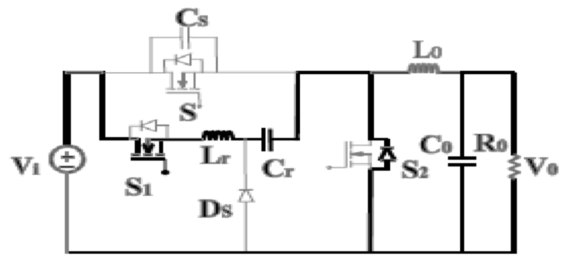

Fig:3 Mode 1$(t_0 - t_1)$

The voltage and current expressions which govern this circuit mode are given by:

At t=t1

$$t_{01} = \frac{1}{\omega}\left[\sin^{-1}\left(\frac{I_0}{V_i} Z\right)\right]$$

$$V_{cr(t_{01})=V_{cr1}}$$

$$i_{lr(t_1 - t_0)} = I_o \quad t_{01=0.00834\mu s}$$

Mode 2 (t1, t2):

Lr and Cr continue to resonate. At tl the synchronous switch S2 is turned on under ZVS. This mode ends when S2 is switched of and i_{Lr} reaches its maximum value.

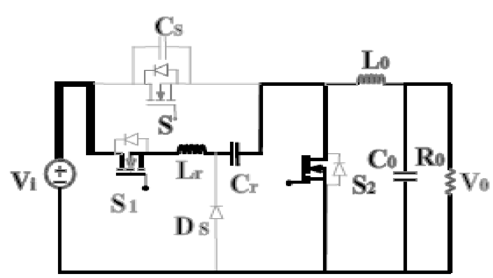

Fig:4 Mode 2

$$t_{12} = \frac{1}{\omega}\left[\tan^{-1}\left(\frac{V_i - V_{cr1}}{I_0 Z}\right)\right]$$
$$i_{Lr}(t_{12}) = I_{LrMax}$$
$$V_{cr}(t_{12}) = V_{cr2}$$
$$t_{12} = 0.306\mu s$$

Mode 3 (t2, t3):

At the starting of this mode, iLr reaches its peak value i_{LrMax} . Since i_{LR} is more than load current i_0, the capacitor Cs will be charged and discharge through body diode of main switch S, which leads to conduction of body diode. This mode ends when resonant current i_L, falls to load current. So current through body diode of main switch S becomes zero which results turned off of body diode. At the same time the main switch S is turned on under ZVS.

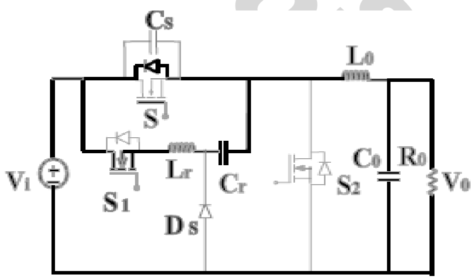

Fig:5Mode 3

The voltage and current expressions for this mode are:

$I_{Lr} = I_0; V_{cr} = V_{cr1};$ V_{cr} is some voltage which can found basing on other mode

$$t_{23} = \frac{1}{\omega}\left[\tan^{-1}\frac{i_{Lrmax}\, z}{V_{cr2}}\right] - \sin^{-1}(i_0)$$

$$i_{Lr9(23)} = I_O$$

$$v_{cr}(t_{23}) = V_{cr3} \quad t_{23} = 0.1973\mu s$$

Mode 4 (t3 t4):

In this mode, the main switch is turned on under ZVS. During this mode growth rate of is is determined by the resonance between Lr and C" The resonance process continues and iLr starts to decrease. This mode ends when i_{LR} falls to zero and SI is turned off through ZCS.

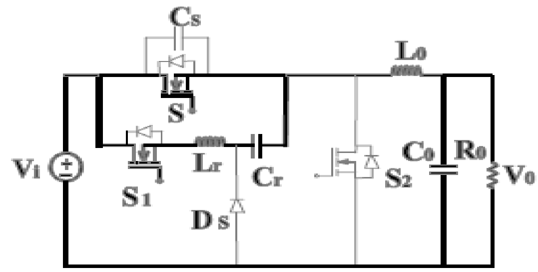

Fig:6 Mode 4

The voltage and current equations for this mode are given by

$$I_{Lr}(t) = 0$$

$$t_{34} = \tan^{-1}\left(\frac{I_0 Z}{V_{cr3}}\right)$$

$$V_{cr}(t_4) = V_{crmax}$$

$$t_{34} = 0.7922\mu s$$

Mode 5 (t4 t5):

In the previous mode, S_1 is turned off. The body diode of S_1 begins to conduct because of discharging of Cr The resonant current i_{Lr} starts increasing in reverse direction and finally becomes zero. The mode ends when body diode of S1 is turned off.

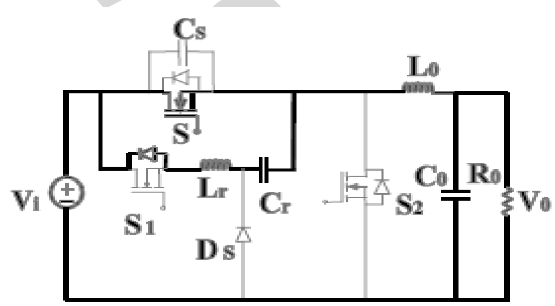

Fig: 7 Mode 5

The voltage and current equations for this mode are given by

$$t_{45} = \frac{\pi}{\omega}$$

$$i_{Lr(t-t_4)} = \left(\frac{V_{crmax}}{z}\right)\sin(t-t_4)$$

$$i_{Lr(t_5)=0}$$

$$V_{cr}(t_5) = V_{cr4}$$

$$t_{45} = 0.628\mu s$$

Mode 6 (t5, t6):

Since in the previous mode, body diode of S1 is turned off, the MOSFET S alone carries the current now. There is no resonance in this mode and circuit operation is same as conventional PWM buck converter.

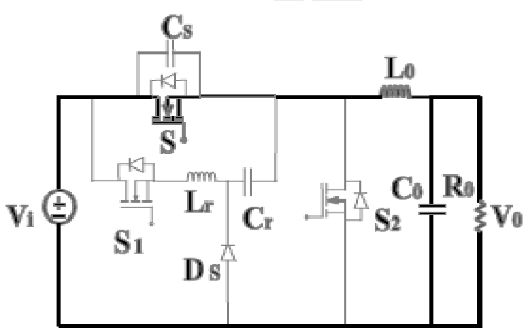

Fig:8 Mode 6

$$i_s = i_0$$

$$i_{Lr}(t_6) = i_0$$

$$V_{cr}(t_6) = -V_{cr4}$$

Mode 7 (t6, t7):

At starting of this mode, the main switch S is turned off with ZVS. The schottky diode D starts conducting. The resonant energy stored in the capacitor Cr starts discharging to the load through the high frequency schottky diode Ds for a very short period of time, hence body – diode conduction losses and drop in output voltage is too low. This mode finishes when Cr is fully discharged.

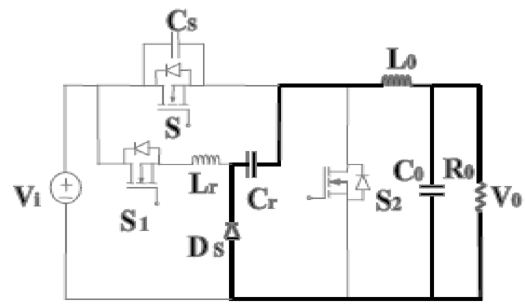

Fig: 9 Mode 7

$$V_{cr}(t-t_6) = -V_{cr4} + \frac{i_0}{c_r}$$

$$V_{cr}(t_7) = 0$$

$$t_{67} = \frac{C_r V_{cr4}}{I_0}$$

$$T_{67} = 0.47816\mu S$$

Mode 8 (t7, t8):

Before starting of this mode, the body diode of switch S2 is conducting. But as soon as resonant capacitor Cr is fully discharged, the schottky diode is turned off under ZVS. During this mode, the converter operates like a conventional PWM buck converter until the switch S_1 is turned on in the next switching.

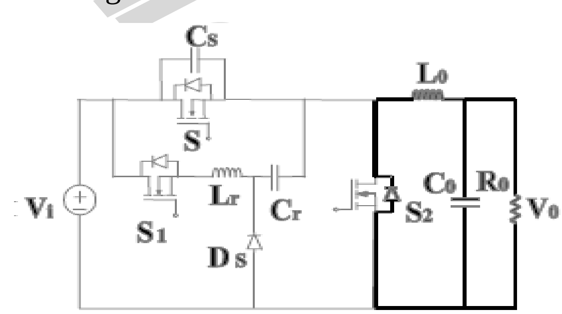

Fig:10 Mode 8

The equation that defines this mode is given by

$$I_{s2} = I_0$$

$$C_r = \frac{(a-1)^2 \, I_{lrmax} \, T_D}{V_0\left[1+\frac{\pi}{2}(a-1)\right]}$$

$$L_r = \frac{V_0 T_D}{I_{lrmax}\left[1+\frac{\pi}{2}(a-1)\right]}$$

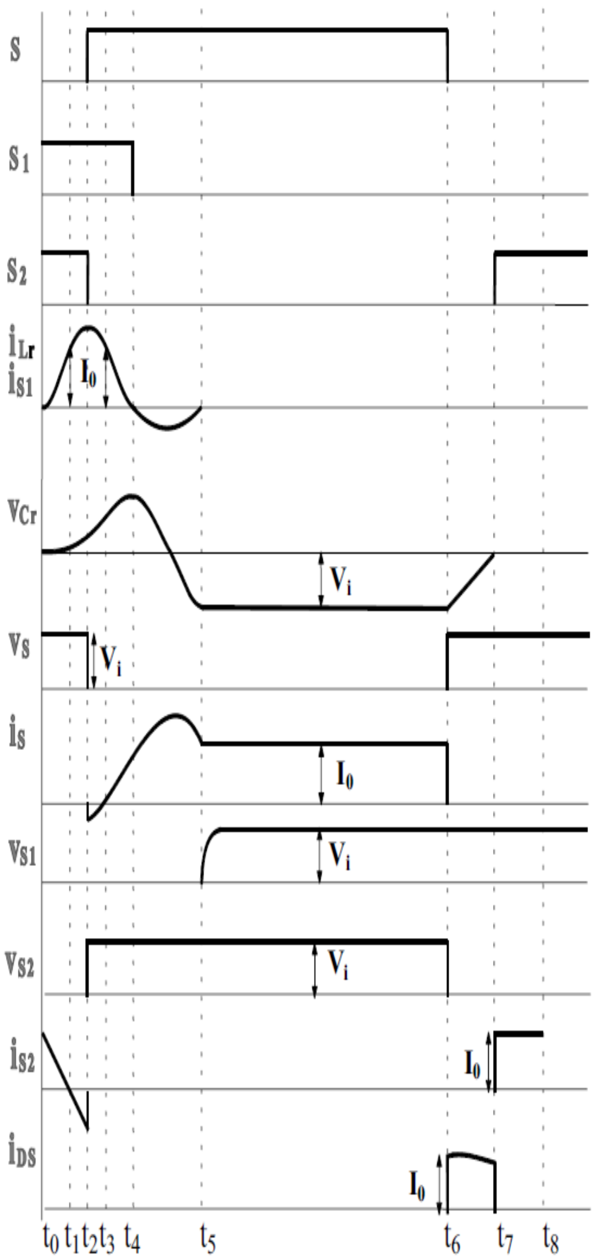

fig:11 key theoretical waveforms concerning the operation stages in the converter.

IV.SIMULATION CIRCUIT

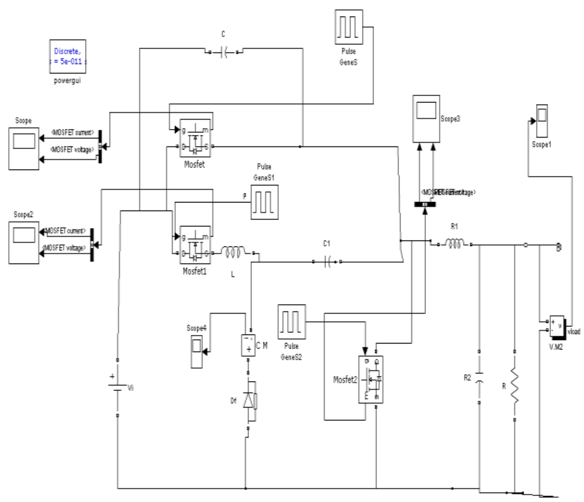

Fig: 12 Simulation of Synchronous Buck Converter

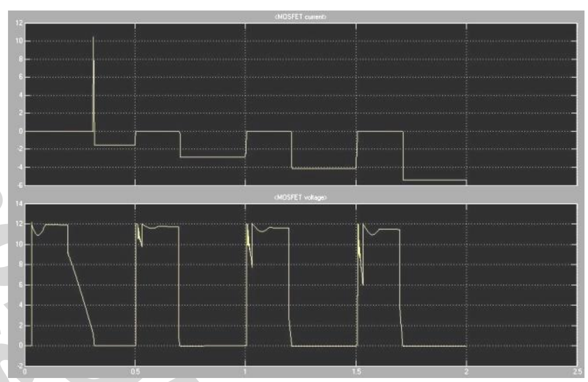

Fig.13 voltage and current of switch 2

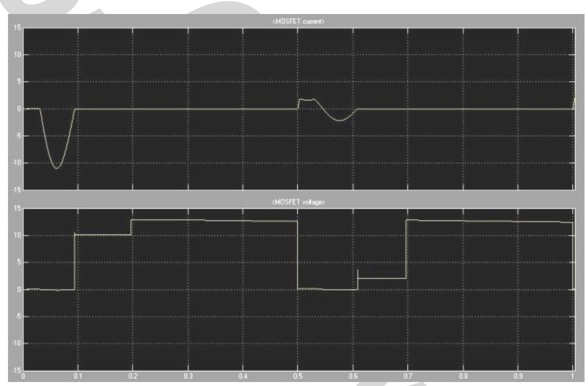

Fig: 13 Switch1 voltage and current (s1)

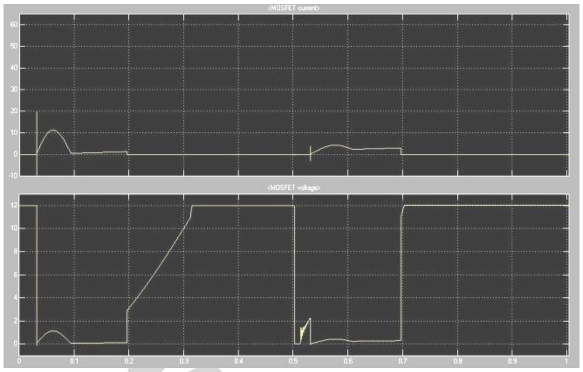

Fig:14 main Switch voltage and current

V.CONCLUSION

The use of smart PV energy system for portable applications is shown in this paper For that a dc-dc synchronous buck converter is introduced between PV system and load to meet the dynamic energy requirement of the load in an efficient way. From the study we observed that, the synchronous buck converter largely increases the system efficiency by reducing the switching losses through soft switching techniques. Consequently, the studied system makes the device portable and cost effective. The simulation results will be validated with study on the converter system.

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