SIMULATION OF A SINGLE PHASE UPS SYSTEM WITH MODIFIED BOOST CONVERTER

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Abstract

An uninterruptible power supply (UPS) system provides backup power supply for an application in the event of an electrical outage. Several basic topologies exist, differentiated by function during a power outage. The development process of all is concerned with unit efficiency, cost performance, operability, maintainability and safety. This paper describes a model of on-line UPS with modified boost converter. ie to improve the boost converter efficiency, soft-switching technologies using an active and a passive method have been developed. The soft-switching topologies using the passive methods have advantages, such as high reliability and the simplicity of both power circuit and control compared to the active methods. The proposed converter uses a passive snubber to recover the snubber energy into the output. Simulation results are analysed in this paper to illustrate performance differences of a boost converter with and without regenerative snubber and conventional, modified UPS systems.

Key words: Boost Converter, DC-DC Converter, Uninterruptible Power Supply, Regenerative Snubber, Soft-switching, Passive Snubber.

I. INTRODUCTION

Uninterruptible power supply (UPS) systems are being widely used for a variety of critical loads including computers, telecommunication systems and medical equipments to overcome disruptions in utility power such as outage, voltage sag or voltage surge[1].It also provides uninterrupted, reliable and quality power for critical loads.UPS system also suppress line transients and harmonic disturbances.Therefore,some of the applications of UPS systems include medical facilities, data storage and computer systems, emergency equipments, telecommunications, industrial processing, and on-line management systems [2].An UPS is placed between the mains and an electronic equipment, supplying this equipment according to its specifications. This function can be carried out with different system topologies like on-line UPS, off-line or stand-by UPS [3].

The main building blocks of any given UPS are the rectifier/charger, dc-dc converter, inverter and battery bank. Recently, dc-dc converter circuits have been widely used for the dc power generation stage of a renewable energy system, such as a battery system, fuel cell system and a photovoltaic system. For these applications, the converter efficiency improvement is one of the most important considerations for achieving the high efficiency conversion of the whole system [4].To improve the converter efficiency, soft-switching technologies using some switching-aid circuits, called snubbers, can be used to reduce the switching losses and stresses of the semiconductor elements. The usual turn-on snubber employs an inductor in series with the switch in order to control its current rising rate during the turn-on process, In the turn-off snubber,the energy is diverted from the switch into a parallel capacitor, delaying the switch voltage rise and reducing turn-off losses [5,6].The energy stored in the turn-on snubber inductor(L_S) is related to the load current I_L, switching frequency f_s as $1/2L_SI_L^2f_s$ and the energy stored in the turn-off snubber capacitor (C_S) is related to the supply voltage V_{dc} and f_s as $1/2C_SV_{dc}^2f_s$[7].Therefore, during snubbing action energy is stored in the magnetic/electric field of these inductive/capacitive components. In a simple conventional RLCD snubber circuit, these stored energies are dissipated as heat in resistors. The average power loss in the resistor equals the product of the stored energy in the inductor/capacitor and the switching frequency [8].Alternatively to improve the circuit efficiency, the snubber-energy losses of the converter should be improved. The solution is to transfer this snubber energy to the load or to the source by an auxiliary circuit (Regenerative snubber) so that the energy is recovered instead of dissipated [9, 10, 11]. The energy recovery uses either a passive snubber network or active one. The passive regenerative snubber has advantages such as high reliability, less expensive, do not require an extra switch or additional control circuitry [4, 12].

The proposed UPS uses a boost converter with passive snubber network. This snubber comprises two identical capacitors, and they are charged in parallel and discharged in series automatically by the on-off transition of the main switching device, recovering all the snubber energy into the output. The soft-switching at turn off is achieved by the use of the snubber capacitors, while the soft-switching at turn on is achieved by a small inductor connected in series with the main switch [13].

II. CIRCUIT OPERATION OF UPS BLOCK

Fig.1 shows the block diagram of the proposed UPS, The operation of each unit is described as follows.

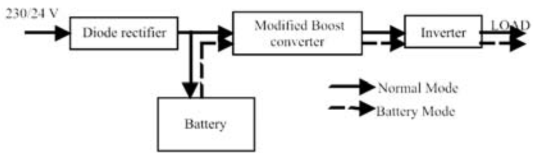

Fig. 1. Block diagram of proposed UPS

A. Rectifier

A diode rectifier generates the dc bus voltage of the UPS. It supplies the power to the boost converter as well as to the battery bank to keep it charged. In the normal mode of operation, the power to the converter is provided by the rectifier. In case of a line outage, power comes from the battery bank.

B. Boost converter

Boost converters are especially useful in stepping-up the voltage from an input rectifier system/battery system under normal and battery mode of operation. This has been installed to increase the rectifier output/battery voltage to a higher level of the required dc bus voltage.

C. Inverter

An inverter generates ac output voltage, which must be sinusoidal with specific frequency (50Hz or 60Hz) and amplitude (equal to the main line voltage).When output of this is filtered, sinusoidal output voltage is generated. Therefore, the AC output voltage is approximately equal to the AC input voltage (Vrms out = Vrms in). The power devices and the output filter create a voltage drop of several volts, which is within the AC voltage tolerance. If a more precise output voltage is required, a voltage transformer can be added to the UPS output.

D. Modified boost converter

In general, a voltage boost is required to step-up the lower voltage of the fuel cell or battery to the higher voltage required by the system. However, conventional high-power boost converters are very large and heavy, partly due to the large inductors used in the design. Also, the drawbacks under high switching frequency operation conditions are, switching losses will increase proportionally with increased frequency, which reduces efficiency and increases cooling requirements. To improve the converter efficiency, soft-switching technologies using an active and a passive method have been developed. The soft-switching topologies using the passive method have advantages, such as high reliability and the simplicity of both the power circuit and control compared to the active methods. Lossless (or regenerative) snubbers are another method to reduce switching losses. As opposed to traditional snubber circuits, which transfer the switching power loss from the switch to a resistor to be dissipated, lossless snubbers use circuit design techniques to transfer this power to the input or output of the converter so that it is not wasted. The proposed boost converter uses a passive regenerative snubber to recover all the snubber energy into the output.

III. PRINCIPLES OF NEW SNUBBER CIRCUIT

A. Basics of capacitor energy recovery

Fig.2 shows the capacitor discharging its initial voltage E_{CO}, into a dc source E resonantly. The diodes D_1 and D_2 provide unidirectional path of both current and voltage of the system.

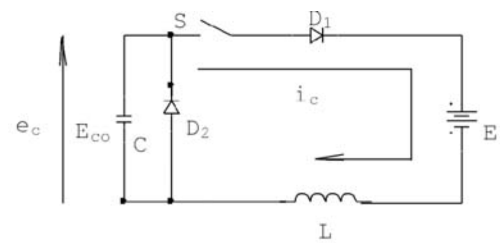

Fig.2. Equivalent circuit of discharging capacitor voltage into dc source

Neglecting the losses in Fig.2, the following equations for i_c and e_c after closing the switch S are obtained.

$$e_c(t) = E(1-\cos\omega t) + E_{co}\cos\omega t$$

where Z = $\sqrt{\frac{L}{C}}$ and ω = $1/\sqrt{LC}$

From these equations the following rules for capacitor energy recovery are found.

1. In case E< E_{co} < 2E, a part of the capacitor voltage ($2E - E_{co}$) remains unrecovered at ωt = π.
2. In case E_{co} = 2E, e_c reaches zero at the end of the oscillation, and then all of the capacitive energy is recovered into E.

3. In case $E_{co} > 2E$, e_c reaches zero before $\omega t = \pi$ and i_c continues to flow through D_2, recovering all of the capacitive energy into E when i_c reduces to zero.

These considerations make it clear that the initial voltage E_{co} on capacitor should be equal to or higher than twice the source voltage (2E), to achieve a complete energy transfer. The new snubber was obtained from this concept.

B. Principles of new snubber circuit

Fig.3 shows the circuit of a new snubber. When switch S, (it can be any semiconductor switching device) turns off in Fig.3(a). Two capacitors are charged equally by the energy stored in the circuit, say Ec.

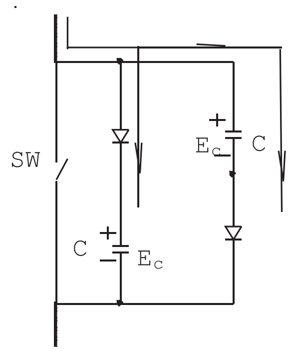

Fig. 3(a). New snubber circuit
Two snubber capacitors are charged in parallel when SW turns off

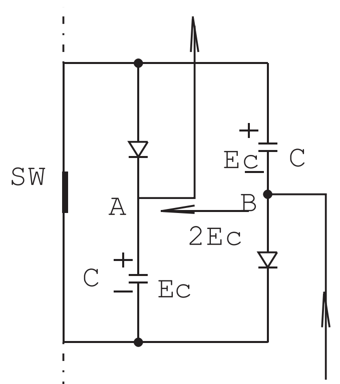

Fig. 3. (b) capacitors discharged in series when SW turns on

This final voltage of each capacitor Ec is usually a little higher than the source voltage or the load voltage. When switch turns on in Fig.3(b), these two voltages are superimposed and 2Ec appears across the terminals A and B. If these two terminals are connected with the source or the load in the circuit through an inductor, the capacitor voltages will discharge resonantly to zero, thus recovering the snubber energy. The switch turns off softly at zero voltage by the use of capacitors.

IV. BOOST DC-DC CONVERTER WITH THE NEW SNUBBER

Fig.4 shows the basic boost dc-dc converter with the proposed snubber circuit. The diodes D_1 and D_2 are added to prevent each snubber capacitor voltage as well as the output capacitor voltage from being short-circuited through the switch. Also, two pairs of a snubber inductor L_{s1} and L_{s2} in series with diodes D_5 and D_6 are necessary to assure symmetrical operation and to avoid oscillation of the capacitor voltage.

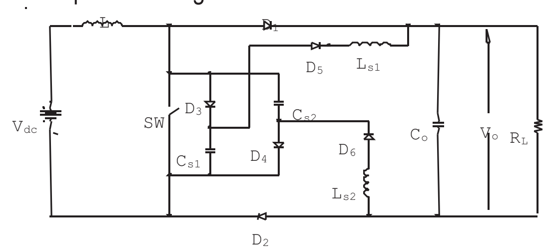

Fig. 4. Boost dc-dc converter with proposed snubber

The operation of the circuit can be explained in the following four modes.

Mode 1: Assuming that the initial voltages across the snubber capacitors, $C_{S1}=C_{S2}=C_S$ are zero and the main switch turns on at zero voltage as shown in Fig. 4(a). The switch carries the inductor current i_L.

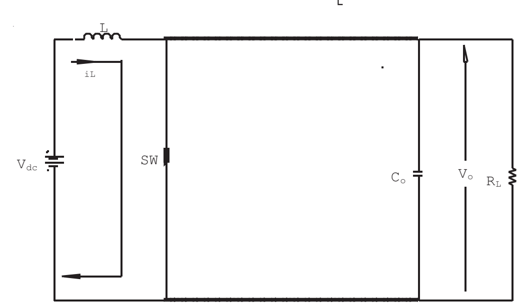

Fig. 4(a). Switch turns on to carry main current i_L

Mode 2: In Fig. 4(b), the main switch turns off at zero voltage and the inductor current i_L is transferred to the snubber capacitors C_{S1} and C_{S2} charging them equally by the energy stored in the circuit. The inductor current I_{L0} at turn off is kept constant during this mode, each capacitor voltage e_c is given as follows:

$$e_c(t) = \frac{I_{Lo}}{2C_s} t$$

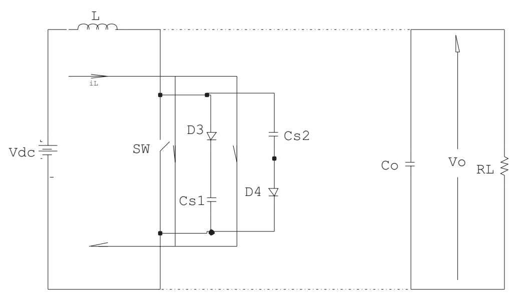

Fig. 4(b). Switch turned off - Charging snubber capacitors

Actually, at the turn off of the switch, each capacitor voltage e_c rises slowly up to a little higher than the output voltage V_0 and then discharges down to V_0.

Mode 3: When the capacitor voltage reaches V_0, diodes D_1 and D_2 turn on in Fig. 4(c), so that the excess voltage leaks towards V_0.

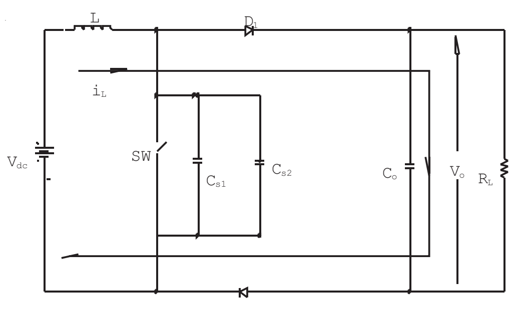

Fig. 4(c). Snubber voltages clamped at V_0

Mode 4: Fig. 4(d). shows the current paths at turn on of the main switch. The two snubber capacitor

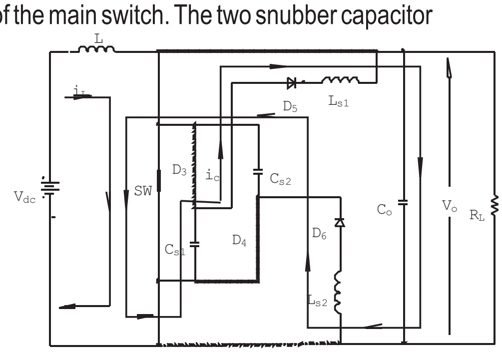

Fig. 4(d). Switch turns on- Discharging snubber voltages into V_0

voltages are superimposed and discharges resonantly into the output voltage V_0 after the main switch turns on. The switch carries both the main current i_L and the discharging current i_c. Neglecting the losses, the capacitor current i_c and voltage e_c are given as follows:

$$i_c(t) = \frac{Vo}{2Z_s} \sin \omega_s t$$

$$e_c(t) = \frac{V_o}{2}(1 + \cos \omega_s t)$$

where $C_{s1} = C_{s2} = Cs$ and $Ls1 = L_{s2} = Ls$

$Z_s = \sqrt{L_s / C_s}$, $\omega_s = 1 / \sqrt{L_s C_s}$

Due to losses in the actual current path, the capacitor voltage does not completely come down to zero at $\omega t = \pi$, leaving a small portion of the initial voltage. This residual voltage on the capacitors should be minimized by using low-loss components.

V. SIMULATION RESULTS

To evaluate the proposed topology, simulation models have been developed. Fig. 5(a-d) shows the simulation results obtained using MATLAB to describe the output of different sections of conventional UPS (using boost converter with RCD Snubber) and modified/developed UPS (using boost converter with regenerative snubber) for an input voltage of 230V. It shows that there is an increase in output voltage levels of developed UPS due to recovery of snubber energy into the output.

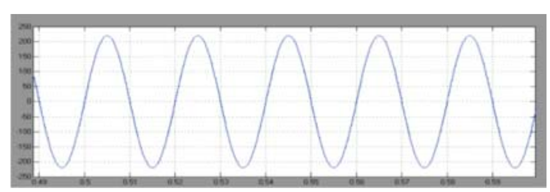

Fig. 5(a) Input AC supply voltage

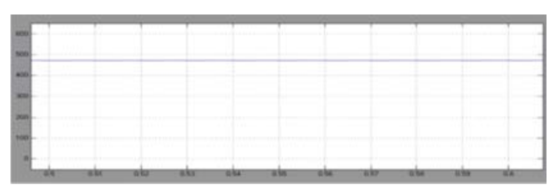

Fig. 5(b) Boost converter output voltage

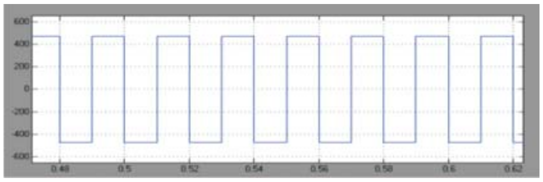

Fig. 5(c) Inverter output voltage

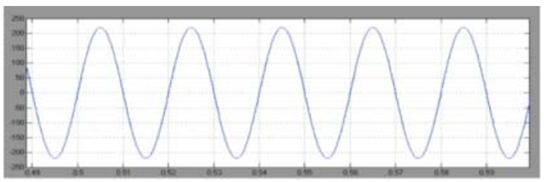

Fig. 5(d) Input AC supply voltage

Fig. 6. compares the output of a boost converter section only. The output voltage is 400V with RCD snubber and it is 440V with Regenerative snubber. Therefore, there is an increase in output voltage of 40V with Regenerative snubber. Fig.7 and Fig.8 are plotted for a different input voltages and the corresponding output voltage, output power of a conventional UPS and developed one. It is proven that there is an increase in output levels of a developed UPS, due to snubber energy recovery into the output. Similarly, the output of each stage of a proposed UPS under normal mode and battery mode of operation obtained are shown in Fig 9&10.

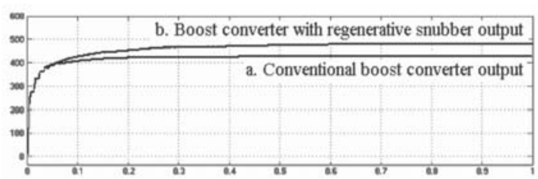

Fig. 6. Outputs of conventional boost converter and boost converter with regenerative snubber

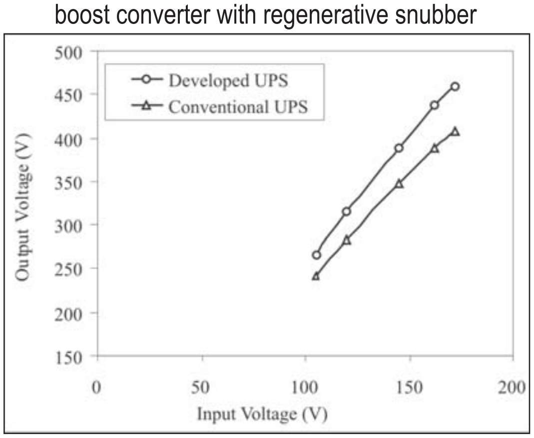

Fig. 7. Input voltage Vs Output voltage of a conventional and developed UPS

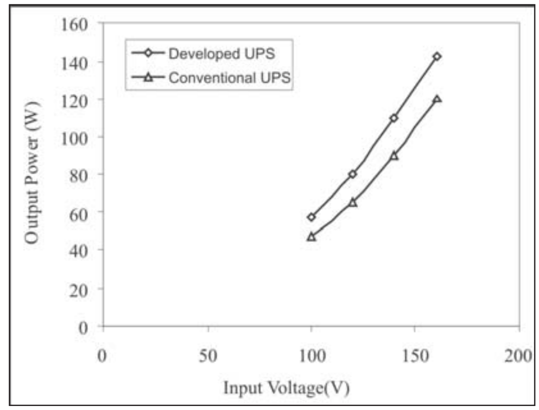

Fig. 8. Input voltage Vs Output power of a conventional and developed UPS

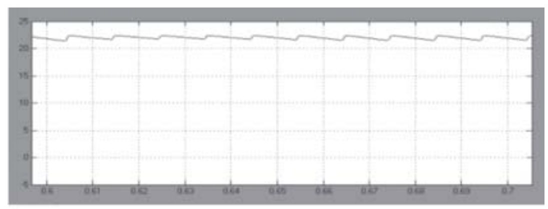

Fig. 9 Diode rectifier output voltage

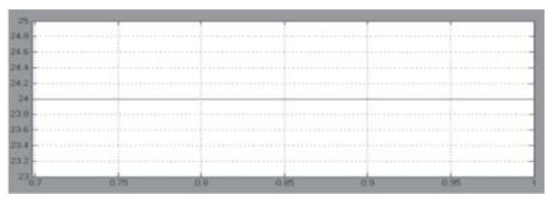

Fig.10. Battery voltage

VI.CONCLUSION

A UPS model with passive regenerative snubber boost converter configuration suitable for high frequency and high power applications has been analysed.The MATLAB-Simulink circuit model is utilized to perform the simulation studies. The proposed boost converter has the advantages of, switching losses are reduced and recovering all the snubber energy into the output, which improves the system performance. It is found that the output of a boost converter is increased to 40V with regenerative snubber, for an input supply of 230V. Also, the use of energy recovery circuit with passive components simplifies the circuit configuration. Simulation results obtained are presented.

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