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Different Step up Choppers for Photovoltaic Panel

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ABSTRACT—*India ranks among top ten countries that generate electrical energy. This electrical energy is generated with the help of renewable and non-renewable energy sources. But in today's scenario energy crisis is observed at domestic level. There are various reasons of energy crisis like increase in population, lack of space, traditional method of development and unbalance consumption of electrical energy. This problem can be overcome by step up chopper system along with photovoltaic panel (PV). The PV panel is used as energy source which is environment friendly, economic and infinite source of energy. This paper concentrates on selection of highly efficient chopper system with low cost and less complexity. The features of different step up choppers along with comparative study of circuit diagram, advantages, disadvantages and applications are proposed in thispaper.*

Keywords—*Voltage gain, conduction losses, leakage inductance, equivalent series resistance, efficiency, isolation.*

I. INTRODUCTION

Electrical energy appliances are useless without electrical energy whether it is home appliances or industrial appliances. Therefore electrical energy is necessary in today world. Various scientist and engineers work together and individually as well, spending most of their life in inventing various methods to generate electricity which can fulfill the arising need of electrical energy. The "Fig.1," classified generating method of electricity.

The electricity generated by non-renewable sources creates numerous problems. Firstly Non-renewable energy is a resource that does not renew itself at in sufficient time period. Secondly it creates pollution due to its consumption. The nuclear plant is costly and need to take precautions because nuclear effect is not only harmful for human body but also on soil and Eco cycle.

On other hand renewable energy resources are very eco-friendly, cheap and infinite. The voltage level of non-renewable energy sources is higher than renewable energy, except energy sources like wind turbines and hydro power (dam). But it's not easy to install at any place but also some time impossible. So for domestic application PV panels are used [1]. The output voltage level of PV panel is low depending on size and power capacity. To increase output voltage of PV panel no of method is given in literature. Simple one, the PV panels are connected in series to increase the voltage level [2].

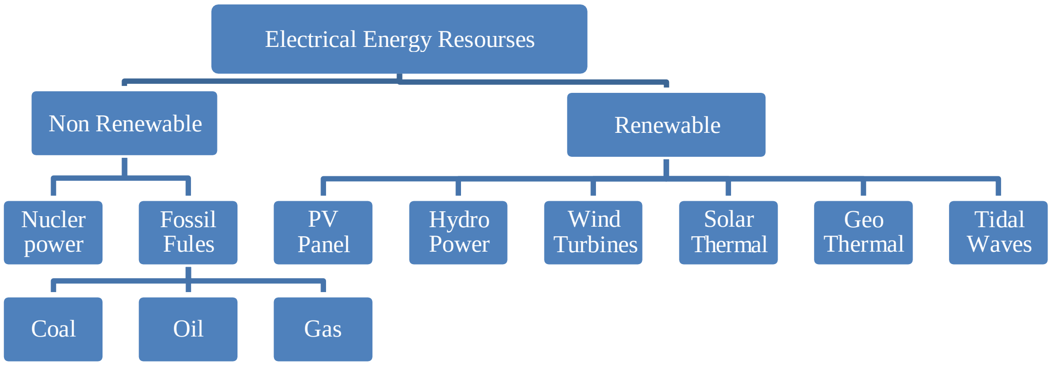


Fig.1. Methods of electrical energy generation.

When PV panels are connected in series the system becomes more costly as well as its required large area and probability of shading is also increase. So to overcome this problem step up chopper system is used to increase voltage level of PV panel before applying to an inverter system.

The “Fig. 2,” indicate complete system which is divide into four stages. Stage one consist of PV panel which converts sun light into electrical energy of 20-40 DC volts. Stage two consists of battery bank which provide constant voltage to step up chopper system. Third stage is step up chopper system to boost the DC voltage level and last stage consists on inverter stage which converts DC voltage into AC voltage.

The content of this paper is organized as follows. In Section II, different configuration of choppers is described in detail. In Section III, operational analysis of the proposed chopper is given. In Section IV, steady-state analysis of the proposed chopper is described. The performance comparison of different choppers are representing in SectionV.

II. DIFFERENT CONFIGURATION OFCHOPPERS

At present, PV panel based dc-to-dc converter is extensively used in space applications and also used for water pumping system at domestic level. In such converters, an adjustable dc voltage is obtained from a fixed dc voltage source. A dc-to-dc converter is also called as dc-chopper. The main dc-to-dc converter was developed in the early 1960s when semiconductor switches were available. Switched systems such as dc-to-dc converters are a challenge to design since its model depends on whether a switch is opened or closed. The R. D. Middlebrook from Caltech in 1977 published the models for dc-to-dc converter in market. He averaged the circuit configurations for each switch state in a technique called state-space average modeling. This simplification resulted in reduction of two systems into one [3].

The number of step up chopper circuits such as boost, buck-boost, flyback, forward, boost-sepic and quasi Z-source based are given in literature. All this configurations of step up chopper with its different drawbacks like high conduction losses, low voltage gain, leakage inductance recovery, equivalent series resistance (ESR) of the capacitor, low efficiency, complexity, and non-isolated circuit. These drawbacks can be overcome by proposed chopper up to maximum level.

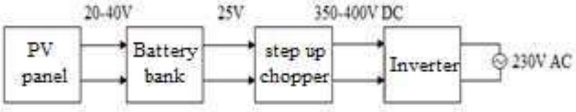


Fig.2. Block diagram of electrical energy generation.

A. Boostchopper

In a boost chopper, the output voltage is greater than the input voltage, hence the name “boost “chopper. The “Fig. 3,” indicate boost chopper circuit using a power MOSFET as switch (S). The functions of boost chopper are divided into two modes, Mode 1 and Mode 2. Mode 1 begins when S is switched ON, the input current rises and flows through inductor L and S. Mode 2 begins when S is switched OFF, the input current now flows through L, diode D, load and C. The inductor current falls until the next cycle. The energy stored in inductor L flows through the load, which will enhance the output voltage.

The output voltage of boost chopper is low as compared to other chopper. Therefore used for low voltage application. The output voltage is increase with increase in duty cycle, but for high dutycycle on time conduction losses is increase. Output efficiency of chopper is low due to parasitic resistance of inductor and equivalent series resistance of capacitor. It is a non-isolated type of chopper with low cost [4].

B. Buck-Boostchopper

The buck-boost type chopper gives the output voltage, both more than as well as less than the input voltage level. It is depend on duty cycle. However, the output voltage has opposite polarity that of the input voltage. The “Fig. 4,” indicate circuit topology. When the switch S is turn ON, the diode D is reversed biased. The input current rises, inductor L stores energy from the supply. When switch S turnsOFF,theinductor current generatesanegativevoltage(□□=−□□/□□)acrosstheinductorL.It makes the cathode of the diode D negative and provides another path of current through the capacitor C and the load. During the off period, the stored energy is transferred to the capacitor C and theload.

In buck-boost type of chopper output voltage is more than input voltage when duty cycle is above 50%. It will increase on time conduction losses and produce high reverse recovery problem on diode. The parasitic resistance of inductor and equivalent series resistance of capacitor decrease efficiency of chopper. It is also used for low voltage application. The buck-boost type of chopper is also non- isolated type of chopper with low cost [4],[5].

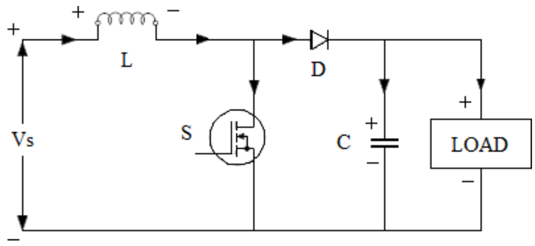


Fig.3. Circuit diagram of Boost Chopper.

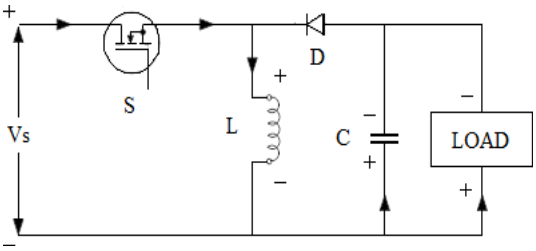


Fig.4. Circuit diagram of Buck-Boost Chopper.

C. Flyback chopper

Themaincomponentsofcircuitaretransformer T and switch S. Thetransformer T providesisolationbetweeninputandoutput.The"Fig.5,"indicatecircuitdiagramofflybackchopper.WhenswitchS is turns ON. The source voltage Vs is appearing across the primary winding $N_p$of transformer. According to mutual inductance lawe.m.f is induced in the secondary winding N_s. The voltage polarity depends on dotted terminal. Diode D2 is reverse biased so current does not flow in secondary winding N_s. The primary winding N_p behaves like inductor and store energy in its magneticfield.WhenswitchSisturnedOFF.The negativevoltage(□□=−□□ □□)inducedacross secondary winding N_s. So Diode D2 is forward bias and conducts the current. The stored energy transferred to load during offperiod.

In this chopper high voltage gain can be obtain by adjusting the turn ratio of transformer. But leakage inductance generates high voltage stress on power devices. This effect can be overcome by snabber circuit, which will increase complexity, size and cost of the circuit. This chopper have moderate efficiency and used for SMPS system [4],[5].

D. Forwardchopper

In forward chopper isolating transformer consist of three windings wound on common core i.e. the primary winding N_p, secondary winding N_s and feedback winding N_f. The "Fig. 6," indicate circuit diagram of forward chopper. When switch S is ON. The supply voltage Vs appears across primary winding N_p which induced voltage in secondary win-

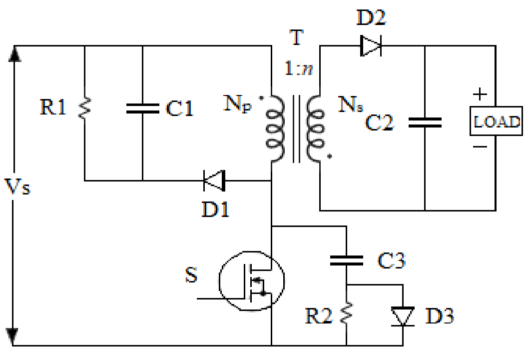


Fig.5. Circuit diagram of FlybackChopper.

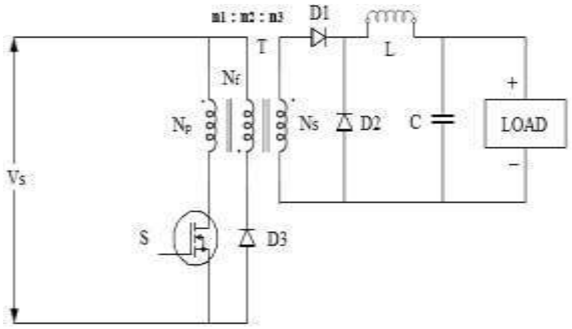


Fig.6. Circuit diagram of ForwardChopper.

ding N_s and feedback winding N_f. The diode D1 becomes forward biased. The energy transferred to load through diode D1 and inductor L. The inductor L stores the energy. During on time diode D3 is reversed biased. When switch S is turns OFF. The primary winding N_p generates negative voltage([illegible]=−[illegible]/[illegible])across it. Thus the diode D1 is reverse biased and energy send to load by inductor. The diode D3 is forward bias due to induced voltage in feedback winding Nfwhich is greater than the supply voltage so diode D3 start conducting. It stops conducting when all store energy is return back to source.

The forward type of chopper gives high voltage gain by adjusting the turning ratio of transformer. But due to leakage inductance high voltage stress on power device. This can be overcome by snabber circuit. The output of forward chopper has bad spike effect. The forward type of chopper efficiency is higher than other chopper. Due to special transformer size and cost of circuit are increases. The forward type of chopper is used for high power application[5].

Overall choppers circuit which are present in literature have a most common problem is low output voltage gain and recovery of leakage inductance. The problem of voltage gain can be overcome by voltage lifter, switch inductor and switch capacitor [5] etc. But circuit becomes complex and efficiency of chopper will reduce. Conduction loss can be overcome by using resonant tank circuit [6]. The quesi z-source chopper has high voltage gain along with isolated transformer. But it's used four switches which will reduce the efficiency of circuit and increase complexity. Therefore z-source based high step-up chopper with coupled inductor is used to overcome the drawback of all choppers up to the maximum level [7].

II. OPERATIONALANALYSISOFTHEPROPOSEDCHOPPER

The "Fig. 7," indicate proposed step up chopper system. This system is basically consisting on Z- Source topology with the help of coupled inductors,

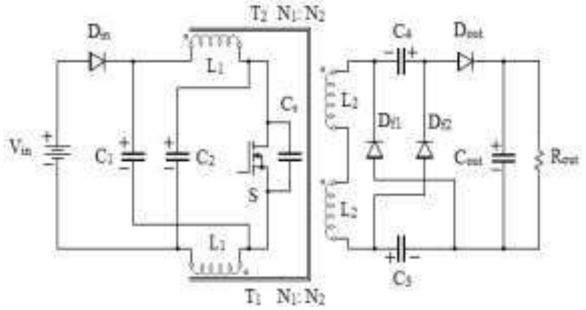


Fig.7. Z-Source based high step-up chopper with coupled inductor.

coils$L_1$and $L_2$and capacitors C_1 and C_2. These coils are wound on core $T_1$and T_2, in actual all coils are wound on same core T with turn ration N_1:N_2. Coupled inductors provide isolation between input and output as well as its form resonance tank circuit with capacitor $C_1$and C_2 which will reduce stress on switch S. The circuit is controlled by single MOSFET switch S. So the controlled circuit is simple. The leakage inductance can be recovered by freewheeling diodes $D_{f1}$and D_{f2}. The $D_{in}$is used for blocking the reverse voltage at input side and D_{out} is used for unidirectional flow of current. The capacitor C_{out} provides constant voltage to load[8].

The operational analysis of proposed chopper can be simplified with the help of some assumption such as; all devices are ideal one except stray capacitance of MOSFET (C_s). The equivalent model of coupled inductor is represented by magnetizing inductance (L_{m1}= L_{m2}= L_m), leakage inductance (L_{lk1}, L_{lk2}) and ideal transformer on the basis of cantilever model. Coupling co-efficient ($K_1 = K_2 = K$) and turn ratio $N_1/N_2 = n$. The value of capacitors (C_{out}, C_1, C_2, C_3 and C_4) and magnetizing inductance (Lm) are too large for providing constant voltage and current during over one switching period. The “Fig. 8,” is shown Simplified circuit diagram. The operational analysis is dividing into two modes, the continuous conduction modes (CCM) and discontinuous conduction mode (DCM).

A. Continuous conduction mode(CCM)

In CCM operation, the working of circuit is dividing into seven intervals. The “Fig. 9,” and “Fig. 10,” indicates equivalent circuit for each interval and their waveforms respectively. For CCM operation assumes that capacitor C1, C2, C3 and C4 is charged initially.

Interval [t_0-t_1]: It is a short time interval. In this interval switch S is ON at t=t_0, the stray capacitance Cs of S is discharge quickly. The Capacitor C_1 and C_2 start discharging though magnetizing L_m and leakage L_{lk1} inductors. The L_m and L_{lk1} are charged by Vcvoltage. The I_{Lm} and I_{L1} current increase linearly. The leakage inductance L_{lk2} discharges its energy through capacitor C_3 and C_4 along with diode D_{f1} and D_{f2}. The “Fig. 9(a),” indicate equivalent circuit for this interval. The Capacitor C_{out} is discharge through load. In this interval D_{in} and D_{out} is off. This interval is end at t=t_1 when I_{Df1} = I_{Df2} = 0.

Interval [t_1-t_2]: It is also short time interval. In this interval switch S is ON. The capacitor C_1 and C_2 discharge linearly through magnetizing L_m and leakage inductance L_{lk1}. The I_{Lm} and I_{L1} current increase linearly. The “Fig. 9(b),” indicate equivalent circuit for this interval. The capacitor C_3 and C_4 discharge through D_{out}, load and C_{out}. In this interval D_1, D_{f1}, D_{f2} remain OFF. This interval is end at t=t_2 when Vl2 = nVl1.

Interval [t_2-t_3]: It is main and longtime interval. In this interval switch S is ON. The diodes D_1, D_{f1}, D_{f2} remain off and diode D_{out} conduct. All devices keep their state as in interval [t_1-t_2]. The magnetizing inductor L_m transfers the storage energy to secondary side coupled inductors. These coupled inductors are in series with capacitor $C_3$and C_4. They pass energy to load through diode Dout. The “Fig. 9(b),” indicate equivalent circuit for this interval. This interval is ends at t=t3 when switch S is turnOFF.

Interval [t_3-t_4]: It is also short time interval. When switch S is OFF. The stray capacitor C_s charge quickly. The all other devices keep their state as in interval [t_2-t_3]. This interval is ends at t=t_4 when diode D_{in} starts conducting. The “Fig. 9(c),” indicate equivalent circuit for this interval.

Interval [t_4-t_5]: It is also short time interval. In this interval energy store in $L_m$and L_{lk1} is discharge through source to capacitor C_1 and C_2. The I_{Lm} current decrease linearly. The leakage inductance L_{lk2} discharges its energy through capacitor C_3, C_4, D_{out} and load. The “Fig. 9(d),” indicate equivalent circuit for this interval. The capacitor C_{out} is charged. In this interval diode D_{in} and D_{out} is conduct and diode $D_{f1}$and D_{f2} is off. This interval is ends at t=t_5 when diode D_{out} ifoff.

Interval [t_5-t_6]: It is also short time interval. In this interval energy store in L_m and L_{lk1} is still discharge through source to capacitor C_1 and C_2. The I_{L2} current is flow through capacitor C_3, C_4 and diode D_{f1}, D_{f2}. The “Fig. 9(e),” indicate equivalent circuit for this interval. The capacitors C1, C2, C3, and C4 are charged. The capacitor C_{out} discharges its energy through load. This interval ends at t=t_6 when Vl2 = nVl1.

Interval [t_6-t_7]: It is main and longtime interval. In this interval switch S is OFF. In this interval all devises are in same state as in interval [t_5-t_6]. The magnetizing inductor L_m transfers the storage energy to secondary side coupled inductors. The capacitor C_3 and C_4 charged. The capacitor C_{out} still discharges its

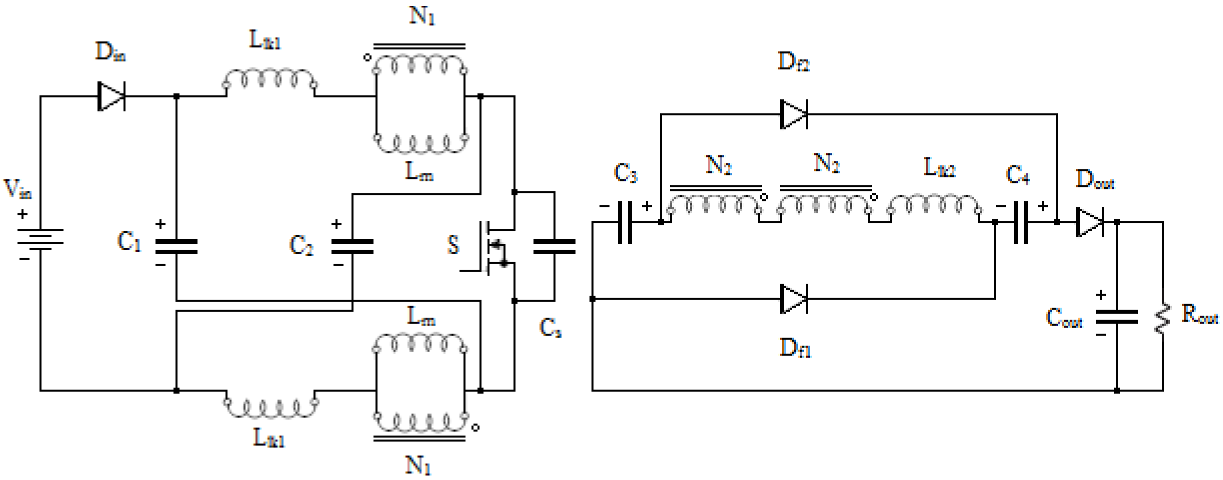


Fig.8. Simplified circuit diagram.

energy through load. This interval is ends at t=t_7 when switch S is turn ON. The “Fig. 9(e),” indicate equivalent circuit for this interval.

B. Discontinuous conduction mode(DCM)

In DCM operation, the working of circuit is dividing into eight intervals. The “Fig. 11,” and “Fig. 12,” indicates waveforms and their equivalent circuit of chopper in each interval respectively. For DCM operation assumes that capacitor $C_{1,}$ C_2, C_3 and $C_4$is charged initially.

Interval [t_0-t_1]: In this interval switch S is ON at t=t_0. The stray capacitor Cs discharge quickly. The “Fig. 12(a),” indicate equivalent circuit for this interval. The capacitors C_1 and C_2 are discharge through magnetizing inductor $L_m$and leakage inductor $L_{lk1}$and charge by Vc. The Capacitor C_3 and C_4 are discharge through load. In this interval diodeD_{out} is conduct and D_{in}, $D_{f1}$and D_{f2} are off. It is a short interval ends when Vl2 =nVl1.

Interval [t_1-t_2]: In this interval switch S is ON. The diodes $D_{out,}$ D_{in}, D_{f1} and D_{f2} are in same state as given in previous interval. The “Fig. 12(a),” indicate equivalent circuit for this interval. The magnetizing inductor $L_m$transfers the stored energy to the secondary. The capacitor C_3 and C_4 are in series with secondary coupled inductor and send store energy to the load. The capacitor C_{out} is start to charged. This interval is ends when switch is turnOFF.

Interval [t_2-t_3]: In this interval switch S is OFF at t=t_2. It is a short interval. In this interval stray capacitor Cs start to charge quickly. The “Fig. 12(b),” indicate equivalent circuit for this interval. The all devices like diodes $D_{out,}$ D_{in}, D_{f1} and D_{f2} are in same state as give in previous interval. This interval ends when diode D_{in} start to conduct at t=t_3.

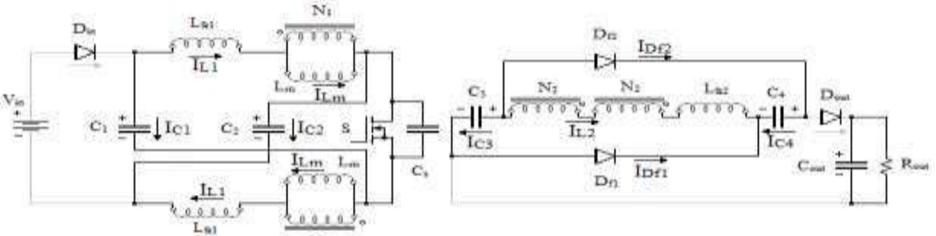
Interval [t_3-t_4]: In this interval switch S is OFF. The diode D_{out} and D_{in} is conducting and diode D_{f1} and D_{f2} is off. The “Fig. 12(c),” indicate equivalent circuit for this interval. The energy stored in magnetizing and leakage inductors L_m and L_{lk1} discharge through capacitor $C_{1,}$ C_2 and source. The leakage inductor L_{lk2}discharges its energy through series capacitor C_3 and C_4 and load. This interval is ends when diode D_{out} isoff.

Interval [t_4-t_5]: It is a short interval. In this interval switch S is OFF. The magnetizing inductor L_m and leakage inductor L_{lk1} discharge through $C_{1,}$ C_2 and source. The “Fig. 12(d),” indicate equivalent circuit for this interval. In this interval capacitor C_3 and C_4 are charged through D_{f1} and D_{f2}. In this interval I_{L2} increase in reverse direction quickly. This interval is ends when Vl2 = nVl1.

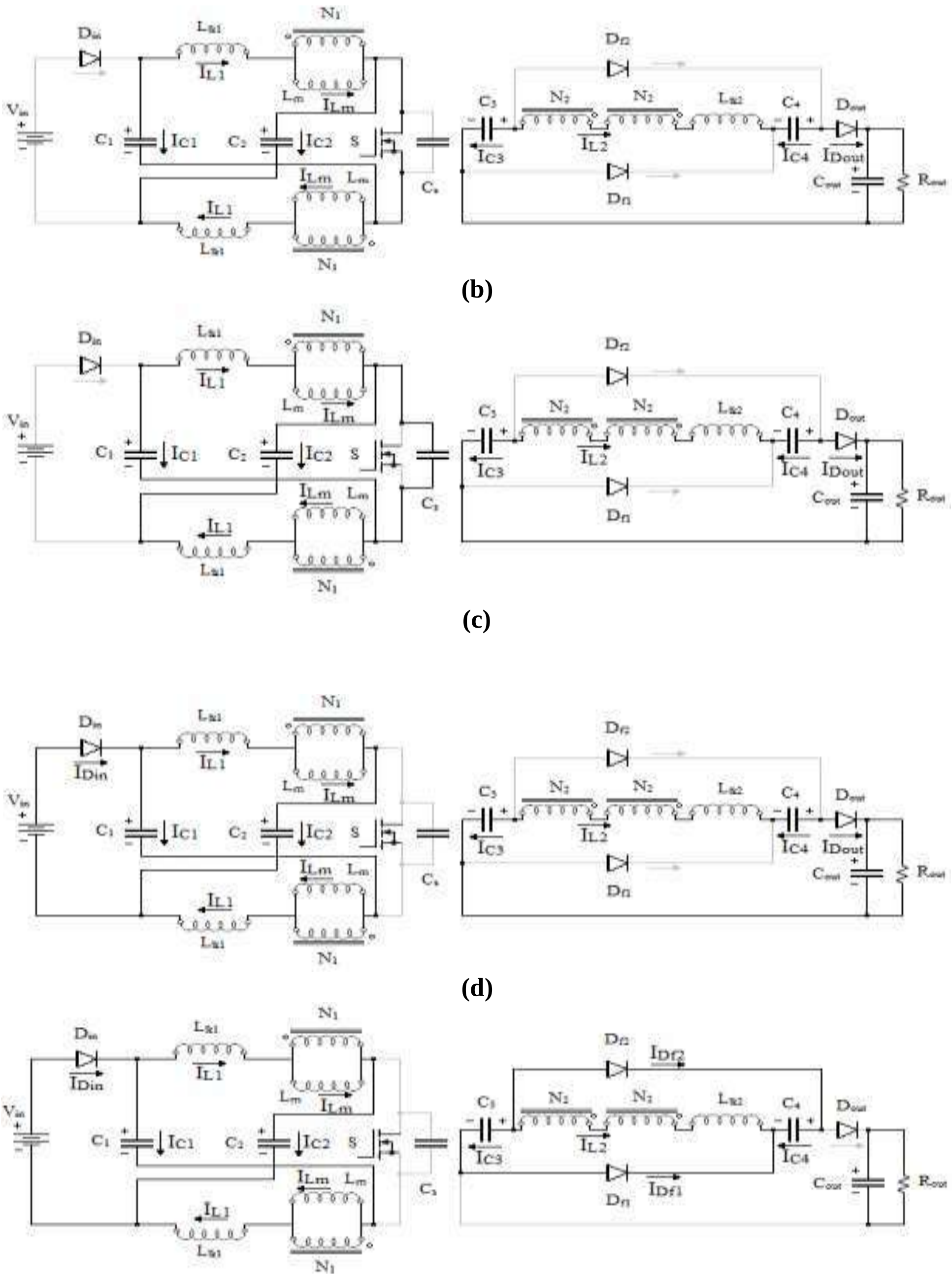
Interval [t_5-t_6]: In this interval $D_{out,}$ D_{in}, D_{f1}, D_{f2} and switch S are remain in same state present in previous interval. The store energy in magnetizing inductors L_m is transfer to secondary side. The “Fig. 12(d),” indicate equivalent circuit for this interval. In this interval capacitor C_3 and C_4 are charged with secondary inductor voltage through diode D_{f1} and D_{f2}. This interval is ends whenI_{L2}=0.

Interval [t_6-t_7]: In this interval only D_{in} diode is conducting and remaining all diode are off. The “Fig. 12(e),” indicate equivalent circuit for this interval. The capacitor C_1 and C_2 are charged. The energy store in C_{out} capacitor is discharge through load. This interval is ends when store energy in magnetizing inductor $L_m$is dischargecompletely.

Interval [t_7-t_8]: It is a discontinuous interval. In this interval all diodes $D_{out,}$ D_{in}, D_{f1}, D_{f2} and switch S remain off except capacitor C_{out}. The capacitor C_{out} discharges its energy through load. In this interval capacitor C_1, C_2, C_3 and $C_4$are charged with coupled inductor voltage. This interval is ends when switch S is turn ON. For high efficiency discontinuous conduction mode is avoided.



(a)



(b)

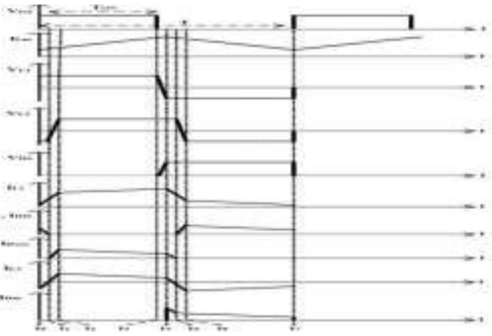
(c)

(d)

(e)

Fig.9. Operational analysis in CCM intervals.

Fig.10. Waveform for operation in CCM intervals.



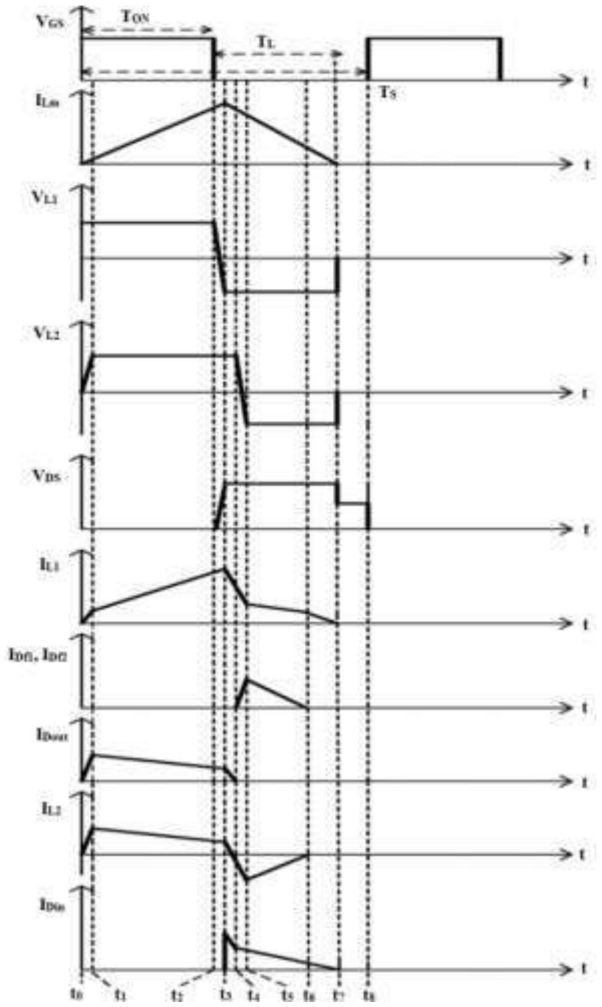
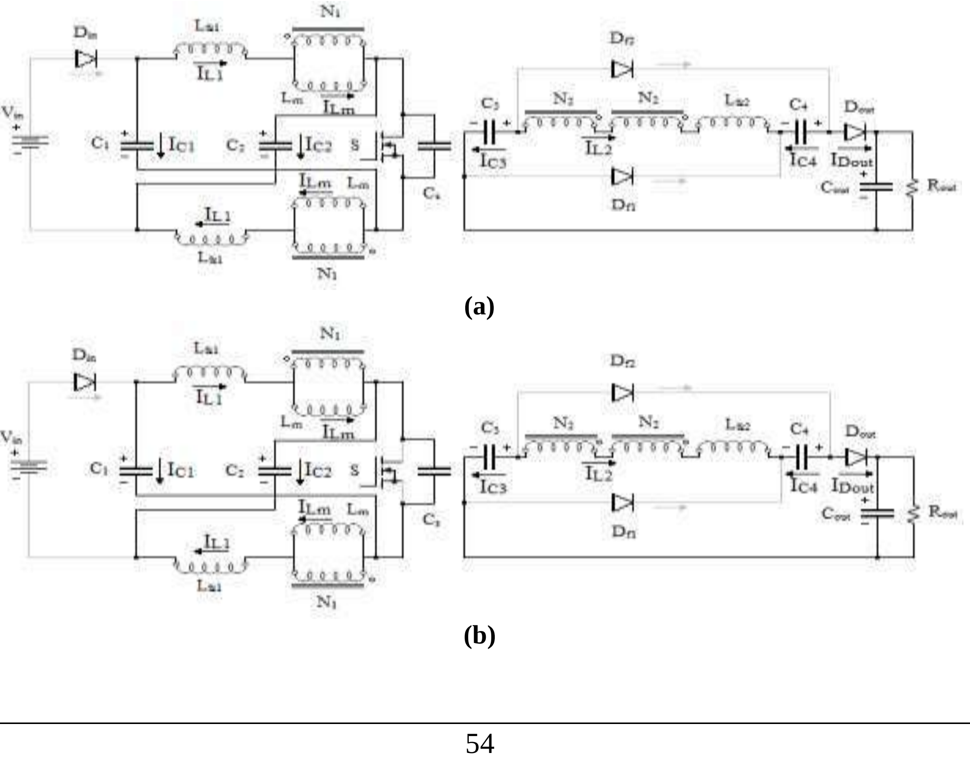
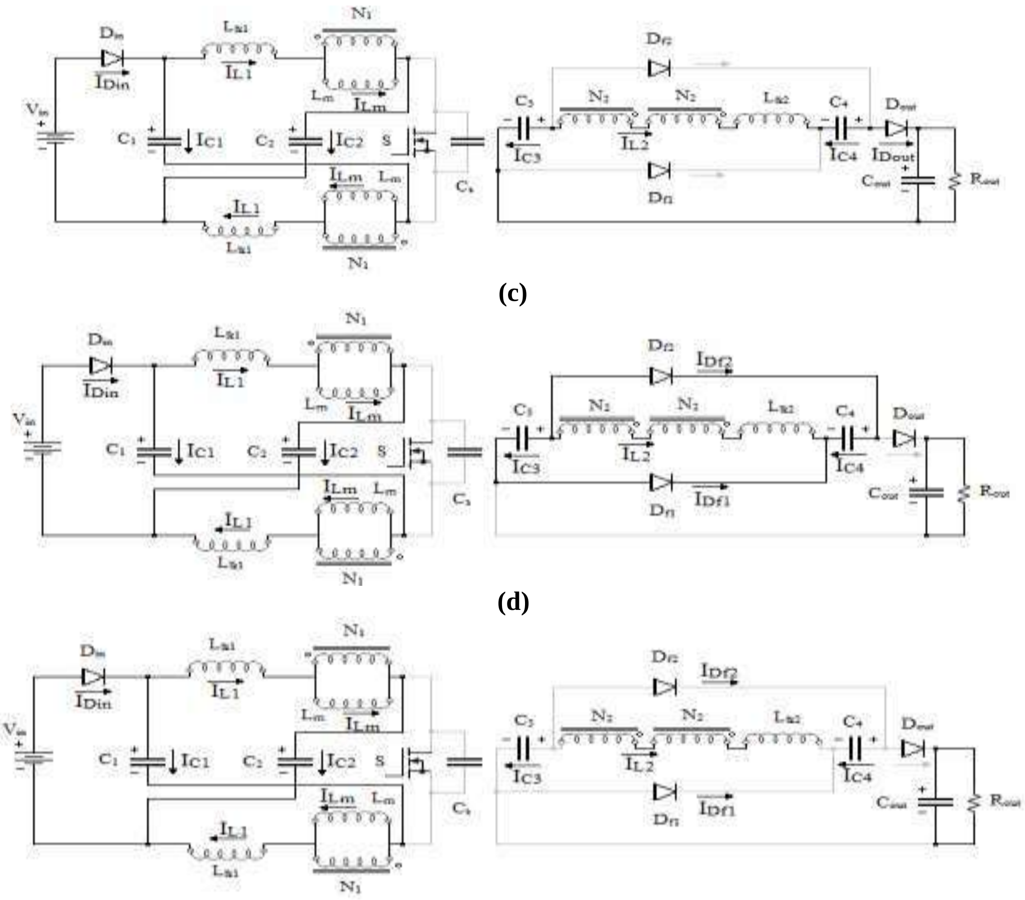


Fig.11. Waveform for operation in DCM intervals.



(a)

(b)



(c)

(d)

(e)

Fig.12. Operational analysis in DCM intervals.

III. STEADYSTATEANALYSISOFPROPOSEDCHOPPER

A. Voltage gain in CCMintervals

The CCM divide into seven intervals, but only two intervals is for long time. The interval [t_2-t_3] when switch S is ON and interval [t_6-t_7] switch S is OFF. The remaining intervals assume as a transient states. The one switching period is represent by Tsand D is a duty cycle. The voltage gain equation can be obtained from "Fig. 9(b)," and "Fig. 9(e),".In CCM each capacitor voltage Vc1=Vc2=Vcand Vc3= Vc4 are remain constant (same for each intervals). The primary inductor voltage Vl1(on) and Vl1(off) represent for ON time and OFF time respectively. Similarly secondary inductor voltage Vl2(on) and Vl2(off) represent for ON time and OFF timerespectively.

Apply KVL on "Fig. 12(b)," for ON time period

At primary side

$$□□_1(□□)=□□ \qquad (1)$$

$$□□□1=□□−(□□) \qquad (2)$$

By voltage dividing principle

$$□□□(□□)=□□[\frac{□□}{□□+□□□1}]$$

Assume

$$[\frac{□□}{□□+□□□1}] = ⊔$$

$$(□□)=□□□ \qquad (3)$$

$$□□□1=(1−□)$$

$$□□_2(□□)=−□□□□(□□)$$

$$□□_2(□□)=−□□\ □□ \qquad (4)$$

Similarly,
At secondary side

$$□□=□□3+□□4−2□□_2(□□) \qquad (5)$$

Apply KVL on *"Fig. 12(e),"* for OFF time period

$$□□□−□□_1(□□□)=□□$$

$$□□_1(□□□)=□□□−□□ \qquad (6)$$

$$□□3=□□4=2□□_2(□□□) \qquad (7)$$

$$□□_2(□□□)=−□□□□(□□□) \qquad (8)$$

By applying voltage-second principle on primary inductor

$$\int_0^{□□□} □□_1(□□)□□+\int_{□□□}^{□□} □□1(□□□)□□=0$$

$$□□□□□_1(□□)+(1−□)□□□□1(□□□)=0$$

From (1) and (6)

$$\square\square\square = -(1-\square)(\square\square\square-\square\square)$$
$$\square\square\square = -\square\square\square+\square\square+\square\square\square\square-\square\square\square$$
$$(2\square-1) = \square\square(\square-1)$$
$$\frac{\square\square}{\square\square\square} = \left[\frac{1-\square}{1-2\square}\right]$$
$$\square\square = \square\square\square\left[\frac{1-\square}{1-2\square}\right] \tag{9}$$

By applying voltage-second principle on secondary inductor

$$\int_{0}^{\square\square\square} \square\square 2(\square\square)\square\square + \int_{\square\square\square}^{\square\square} \square\square 2(\square\square\square)\square\square = 0$$
$$\square\square\square\square\square 2(\square\square)+(1-\square)\square\square\square\square 2(\square\square\square)=0$$

From (4) and (8)

$$\square\square\square\square = -(1-\square)\square\square\square(\square\square\square)$$
$$\square\square\square(\square\square\square) = -\square\square\left[\frac{\square\square}{1-\square}\right] \tag{10}$$

From (8) and (10)

$$\square\square 2(\square\square\square) = \square\square\square\left[\frac{\square\square}{1-\square}\right] \tag{11}$$

Put value of (11) in (7)

$$\square\square 3 = \square\square 4 = 2\square\square\square\left[\frac{\square\square}{1-\square}\right] \tag{12}$$

By substituting value of (4) and (12) in (5)

$$\square\square = 4\square\square\square\left[\frac{\square\square}{1-\square}\right] - 2(-\square\square\square\square)$$
$$\square\square = 2\square\square\square\square\left[\frac{1+\square}{1-\square}\right] \tag{13}$$

Put value of (9) in (13) for CCM gain

$$\square\square = 2\square\square\square\square\square\left[\frac{1-\square}{1-2\square}\right]\left[\frac{1+\square}{1-\square}\right]$$
$$\square\square = 2\square\square\square\square\square\left[\frac{1+\square}{1-2\square}\right]$$
$$\square\square\square\square = \frac{\square\square}{\square\square\square} = 2\square\square\left[\frac{1+\square}{1-2\square}\right] \tag{14}$$

For perfect coupling K = 1,

$$\square\square\square\square = \frac{\square\square}{\square\square\square} = 2\square\left[\frac{1+\square}{1-2\square}\right] \tag{15}$$

B. *Voltage gain in DCM intervals*

In DCM intervals only four intervals is in steady state. The interval [t_1-t_2] is ON time interval. The intervals [t_5-t_6], [t_6-t_7] and [t_7-t_8] are for OFF time. The duty cycle Dl is equal to Tl/Ts. The voltage gain equation can be obtained from “Fig. 12(a),”, “Fig. 12(d),” and “Fig. 12(d),” of circuit diagram for DCM intervals. In DCM intervals leakage inductance assume to be negligible.

□□1(□□)=□□ (16)

□□2(□□)=−□□□1(□□)=−□□□ (17)

□□=□□3+□□4−2□□2(□□) (18)

Primary Inductor voltage during intervals [t_5-t_6] and [t_6-t_7] is represent as Vl1(6)Vl1(7) and respectively. Similarly, for secondary Vl2(6) and Vl2(7).

□□1(6)=□□1(7)=□□□−□□ (19)

□□3=□□4=2□□2(6)=2□□2(7) (20)

For interval [t_7-t_8]

□□1(8)=□□2(8)=0 (21)

By applying voltage-second balance principle on primary inductor

□□□ (□+□I)□□

∫ □□1(□□)□□+∫ □□1(6,7)□□=0

0

□ □□ □□□□□1(□□)+□□□□□1(6,7)=0

□□□+(□□□−□□)=0

□□/□□□ =[□□/□□−] (22)

By applying voltage-second balance principle on secondary inductor

□□□ (□+□I)□□

∫ □□2(□□)□□+∫ □□2(6,7)□□=0

0

□ □□ □□□□□2(□□)+□□□□□2(6,7)=0

□□□□=□□□□2(6,7)

□□2(6,7)=□□□□[□/□□−] (23)

So voltage of capacitors

□□3=□□4=2□□□□[□/□□−] (24)

Put value of (17) and (24) in (18)

□□=2□□□[(2□+□)/□□]

□ = □□/□□□ =2□[(2□ + □□)/(□□−□)] (25)

C. *Blocking voltage across switch anddiodes*

The blocking voltage *Vds*across switch S during OFF time is given as follow

$$\square\square\square=\square\square-\square\square_1(\square\square\square)$$
$$\square\square\square=\square\square-(\square\square\square-\square\square)$$
$$\square\square\square=\left[\frac{\square\square\square}{1-2\square}\right] \quad (26)$$

Similarly, blocking voltage value of each diodes *Vdin, Vdf*1, *Vdf*2, *Vdout*for diode D_{in}, D_{f1}, D_{f2}, D_{out}

$$\square\square\square\square=\square\square+\square\square_1(\square\square)-\square\square\square$$
$$\square\square\square\square=2\square\square-\square\square\square$$
$$\square\square\square\square=\left[\frac{\square\square\square}{1-2\square}\right] \quad (27)$$

$$\square\square\square 1=\square\square\square 2=\square\square\square\square\square=2\square\left[\frac{\square\square\square}{1-2\square}\right] \quad (28)$$

IV. PERFORMANCECOMPARISONOFDIFFERENTCHOPPERS

The circuit performance comparison between the Boost, buck-boost, flyback, forward and proposed chopper is given in Table I.

TABLE ICOMPARISON BETWEEN DIFFERENTCHOPPERS

Parameters	**Boost**	**Buck- boost**	**Flyback**	**Forward**	**Proposed Chopper**
Switch	1	1	1	1	1
Diode	1	1	3	3	4
Capacitor	1	1	3	1	5
Inductor	1	1	0	1	0
Coupled Inductor	0	0	1	1	2
Voltage Gain	$\frac{1}{1-\square}$	$\frac{-1}{1-\square}$	□□ □ [ ] □□ 1 − □	□□ □ □□	1 + □ 2□[ ] 1 − 2□
Switch Voltage Stress	□□ + □□	□□ + □□	□□ □□[1+] □□	□□ □□[1+] □□	□□□ [ ] 1 − 2□
Reverse Recovery Problem	Large	Large	Large	Large	Small
Isolation	Absent	Absent	Present	Present	Present
Efficiency	low	low	moderate	high	high

V. CONCLUSION

The Z-source based high step-up chopper is having high voltage gain. The duty cycle of chopper is less than 50%. So the conduction losses are decrease. The leakage inductance recovery is smooth i.e. no bad spike at output. The Z-source network form resonant tank circuit which will cause low voltage stress on switching device. The voltage gain can be increase by adjusting the turn ratio of coupled inductors. In the Z-source based high step-up chopper single switch is used with low voltage rating. Therefore circuit becomes simple and economic. Due to coupled inductor isolation is present between input and output. The overall efficiency of the proposed chopper circuit is higher than that of the existing topologies. These features allow using of this proposed chopper as step up chopper for PV panel energyapplications.

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