



Modeling And Simulation of An Advanced Step Up Converter For Low Voltage Energy Harvesting By Using Fuzzy Logic Controller

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Abstract

This paper presents a direct AC-DC power electronic converter topology and it is proposed for efficient and maximum energy harvesting from low voltage inertial micro generators. To process the positive and negative half cycles of the ac input voltage, this power converter consists a boost converter and a buck-boost converter respectively. The analysis of this AC-DC step up converter is to obtain the relations between power, circuit parameters, and duty cycle of the converter. The ac-dc step up converter using PI-controller should not give the better THD value. For better performance the present model is proposed with the fuzzy logic controller. Using this converter maximum energy harvesting is implemented effectively. Simulation results by using MATLAB software are found to be quite satisfactory to suppress the total harmonic distortions with improvement in performance.

Keywords-AC-DC conversion, chopper, energy harvesting, FLC

I.INTRODUCTION

The late advancement of reduced and effective semi conveyor advances has empowered the improvement of low-power remote gadgets. Reaping energy from nature has gotten to be doable alternative, for low-control prerequisite of a couple milli watts.

The prominent approach to extricate the electrical energy from nature is Vibration based energy gathering. Electromagnetic miniaturized scale generators take a shot at the guideline of faraday's law of electromagnetism. The measure of reaped energy can be controlled by changing the heap resistance associated with the curl. Numerous sorts of small scale

generators, utilized as a part of the self-controlled gadgets, are accounted for in the writing for collecting distinctive types of encompassing energies [1], [2]. The force level of the inertial - smaller scale generators is low extending from few microwatts to many factory watts. The inertial miniaturized scale generators can be ordered predominantly into three sorts taking into account energy transformation standard: electromagnetic, piezoelectric, and electrostatic [5], [6], among these three, the electromagnetic smaller scale generators have the most elevated energy thickness [7].

The electromagnetic generators are ordinarily spring-mass damper-based reverberation frameworks as appeared in Fig.1 in which the little sufficiency surrounding mechanical vibrations are opened up into bigger abundancy translational developments and by electromagnetic coupling the mechanical energy of the movement is changed over to electrical energy. An electromagnetic force generator comprises of a copper loop, a perpetual magnet (additionally going about as a mass), and a spring, the lasting magnet is joined to the curl through the spring.

The yield force of the force generator is sinusoidal AC and low, extending from couple of miniaturized scale watts to many factory watts, a energy gathering interface circuit with high power exchange productivity need to revive and store the electrical force into the energy stockpiling components.

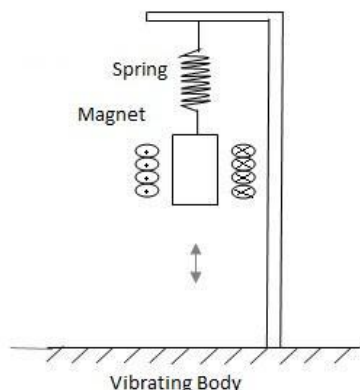


Fig .1 Schematic graph of an inertial small scale generator.

In the electromagnetic miniaturized scale generators, because of commonsense size restrictions, the yield voltage level of the generators is low (couple of several plant volts), though the electronic burdens require much higher dc voltage (3.3V). The routine force converters, reported for energy reaping [2], [6] Consist of two phases; a diode span rectifier and a standard buck or help dc-to-dc converter. To condition the yields of the electromagnetic small scale generators there are real disservices in utilizing the two-phase power converters. For low-voltage electromagnetic miniaturized scale generators, by the utilization of customary diodes amendment is not doable. On the off chance that correction is practical voltage drop in diode will bring about a lot of misfortunes. Direct AC to DC converter is proposed to address the issues of the ordinary two phase converters.

An immediate air conditioning to-dc converter is appeared in Fig. 2, it comprises of a support converter (inductor L1, switch S1, and diode D1) in parallel with a buck- help converter (inductor L2, switch S2, and diode D2). In this converter, the negative yield to information voltage addition of a buck-boost converter is used to venture up the negative half info voltage of the miniaturized scale generator to a positive high-dc yield voltage. The yield capacitor is charged by the help converter in the positive half cycle and by the buck-boost converter in the negative half cycle. Accordingly,

it determines the issues present in a double extremity help converter.

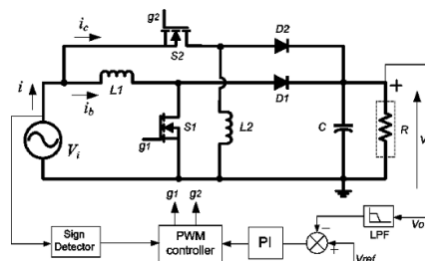


Fig. 2. Direct ac-to-dc converter with PI controller.

. The ac-dc step up converter using PI-controller will not give the better THD value. This Problem can be overcome by using FLC (fuzzy logic controller). The Proposed ac-dc converter with FLC is shown in figure.3.

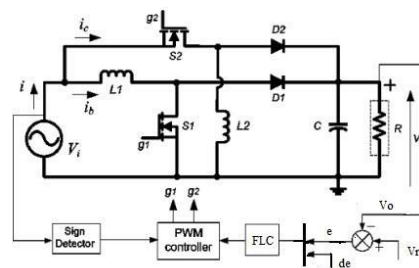


Fig 3. Direct ac-to-dc converter with Fuzzy logic controller.

II. DIRECT AC/DC CONVERTER

The proposed direct ac-to-dc power conditioning circuit, as shown in Fig. 3, has one boost converter and one buck-boost converter. These two converters are in parallel. The boost converter (comprising inductor L1, switch S1, and diode, D1) and the buck-boost converter (comprising inductor L2, switch S2, and diode D2) charges the output capacitor C of this converter during the positive half cycles and the negative half cycles of the sinusoidal ac input voltage (V_i), respectively. To understand the switches S1 and S2 N channel MOSFETs are used. It can be noticed that the MOSFETs are subjected to turn around voltage by the air conditioner yield of the small scale generator. To obstruct the converse conduction, the forward voltage drop of the body diodes of the MOSFETs is been higher than the crest of the information air conditioning voltage. Two Schottky

diodes (D1 and D2) with low forward voltage drop are utilized as a part of the help and the buck–boost converter circuits for low misfortunes in the diodes. It can be specified that the diodes can be supplanted by MOSFETs to assist enhance the effectiveness of the converter.

To diminishes the switch turn ON and turn OFF misfortunes, the proposed converter is worked under intermittent mode (DCM).The DCM operation likewise lessens the diode reverse recuperation misfortunes of the support and buck–boost converter diodes. The simple usage of the control plan has been empowered by DCM operation. The info current is corresponding to the information voltage at each exchanging cycle when the obligation cycle quality is consistent; in this way, the general information current will be in-stage with microgenerator yield voltage. There is 4 methods of operations in DCM operation of force converter. Amid positive half cycle of the info voltage Boost converter is worked in Mode-1 and Mode-2. The help switchS1 is ON and the current in the support inductor works Under Mode-1. Amid Mode-2, the switch is killed and the yield capacitor is charged. The other two modes: Mode-3 and Mode-4 are for the buck–boost converter operation amid the negative half cycle of the info voltage. Under Mode-3, the buck–boost switchS2 is ON and current in the buck–boost inductor assembles. Amid Mode-4, the buck–boost switchS2is killed and the put away energy of the buck–boost inductor is released to the yield capacitor.

A. Converter Analysis:

Fig. 4(a). shows the input current waveform of the converter. It can be noticed that amid the help converter operation, the info current I and the support inductor current (iL1) are equivalent, yet amid the buck–boost converter operation, the information current I and the current in buck–boost inductor (iL2) are not equivalent. This is on account of; in the buck–boost converter the info current gets to be zero amid the switch turn OFF period (TOFF). Hence, in an exchanging cycle, the energy exchanged to the yield by a buck–boost converter is equivalent to the energy put away in the inductor, though, in the help converter, the energy exchanged to the yield is more contrasted with the energy put away in the inductor. In this area,

examinations of the converters are completed and the relations between the control and circuit parameters of the support and the buck–boost converters relating to the information power and the yield force are gotten. Consider any kth exchanging cycle of the support and the buck– help converter as appeared in Fig. 4(b), where Ts is the time of the exchanging cycle, Db is the obligation cycle of the support converter, dfTs is the help inductor current fall time (or the diodeD1 conduction time),Dc is the obligation cycle of the buck– support converter, vi is the information voltage of the generator with plentifulness Vp, and Vo is the converter yield. Expecting the exchanging time period (Ts) of the converter is much littler than the time of the information air conditioning cycle (Ti), the top estimation of the inductor current (ipk) in the boost converter can be obtained from the following equation

$$V_{ik} = L_d \frac{d_i}{d_t} = L_d \frac{i_{pk}}{T_{on}}$$

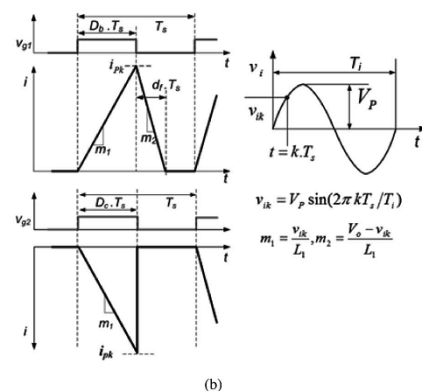
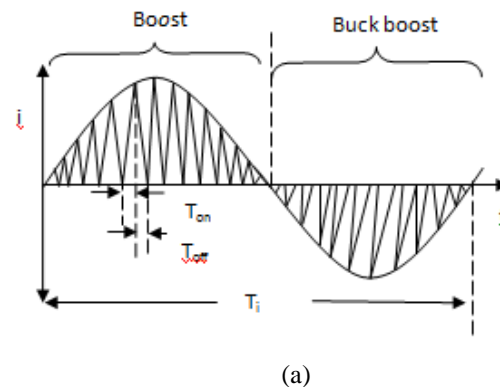


Fig.4. (a) Input current waveform of the converter.(b) Input currents, gate drive signals and input voltage

during a switching cycle of boost and buck–boost converter.

Therefore,

$$i_{pk} = m_1 D_b T_s = \frac{v_{ik} D_b T_s}{L_d} \quad (1)$$

Where

$$v_{ik} = v_p \sin(wkT_s)$$

Consider the input current waveform of the converter and various variables as defined in Fig 4. The average input power, P_{ib} , of the converter can be obtained as :

$$P_{ib} = \frac{v_p^2 D_b^2 T_s}{4L_1} \Delta \quad (2)$$

Where

$$\Delta = \left(\frac{1}{\pi} \right) \int_0^\pi \frac{1}{1 - (V_p/V_o) \sin \phi} d\phi$$

And

$$\phi = wt$$

It can be noted that in (2), Δ is constant for fixed values of V_p and V_o . Also, it is seen that for large switching frequency of the converter, the average power is independent of the micro generator output voltage frequency. In steady state, the average input power of the converter is equal to the sum of the average output power and the various converter losses. Hence, by defining the converter efficiency as η for a load resistance R , the input power and the output power can be balanced as in (3) $\frac{v_p^2 D_b^2 T_s}{4L_1} \Delta = \frac{v_o^2}{R} \cdot \frac{1}{\eta}$ (3)

From(3),the duty cycle of the boost converter (D_b)can be obtained as

$$D_b = \frac{2V_o}{V_p} \sqrt{\frac{L_1}{RT_s \eta} \Delta} \quad (4)$$

Further, consider the operation of the buck– boost converter; in this case the input power is supplied only during the ON period of the switch S2 (see Fig. 2).

During the OFF period of the switch S2, the input current is zero [see Fig. 4(a)]. Hence, for any k^{th} switching cycle, the average power supplied by the buck–boost converter P_{ic} can be obtained as

$$P_{ic} = \frac{v_p^2 D_b^2 T_s}{4L_1} \quad (5)$$

The Duty cycle D_c can be obtained as in (6)

$$D_c = \frac{2V_o}{V_p} \sqrt{\frac{L_2}{RT_s \eta}} \quad (6)$$

B. Converter Control Scheme:

Using (4) and (6), the duty cycle of the boost converter D_b and the duty cycle of the buck–boost converter D_c can be related as

$$\frac{D_b}{D_c} = \sqrt{\frac{L_1}{L_2 \Delta}} \quad (7)$$

Two different control schemes are proposed for the boost and buck–boost-based converter to deliver equal average input power based on equation (7). In scheme 1, the values of the inductors are kept to be equal ($L_2=L_1$) and the converters are controlled with different duty cycles such that it satisfies the condition: $D_c = D_b \sqrt{\Delta}$. In scheme 2, both the boost and the buck–boost converters are controlled with same duty cycle ($D_b = D_c$), whereas the inductor values are chosen to satisfy the condition: $L_1 = \Delta L_2$.

III. FUZZY CONTROLLER

The inner structure of the control circuit is appeared in figure 6. The control plan comprises of Fuzzy controller, limiter, PWM Controller and era of exchanging signs. The genuine capacitor voltage is contrasted and a set reference esteem. To produce gating beats of attractive heartbeat width to MOSFETS in the AC-DC Step up converter, this fuzzy controller takes mistake and change in blunder as inputs; the yield of fuzzy controller is given to PWM controller.

(a) Definition of a fuzzy set: Assuming that X is a gathering of articles, a fuzzy set A_n in X is characterized to be an arrangement of requested sets:

$$A = \{(X, \mu_A(X)) / X \in X\}$$

Where $\mu_A(x)$ is called the membership function of x in A . The numerical interval X is called Universe of Discourse. The membership function $\mu_A(x)$ denotes the degree to which x belongs to A and is usually limited to values between 0 and 1.

(b) **Fuzzy set operation:** Based on membership functions corresponding fuzzy set operators have been defined. Operations like AND, OR, and NOT are some of the most important operators of the fuzzy sets. It is assumed that A and B are two fuzzy sets with membership Functions $\mu_A(x)$ and $\mu_B(x)$ respectively.

A fuzzy controller changes over a phonetic control procedure into a programmed control system, and fuzzy principles are built by master experience or information database. Firstly, enter voltage V_{dc} and the information reference voltage V_{dc-ref} have been set of the precise speed to be the information variables of the fuzzy rationale controller.

To change over these numerical variables into semantic variables, the accompanying seven fuzzy levels or sets are picked as: NL (negative substantial), NM (negative medium), NS (negative little), ZE (zero), PS (positive little), PM (positive medium), and PL (positive Large) as appeared in Fig.6.

The fuzzy controller is portrayed as takes after:

- 1) Seven fuzzy sets for every info and yield;
- 2) Fuzzification utilizing ceaseless universe of Talk;
- 3) Implication using Mamdani's 'min' operator;
- 4) De-fuzzification using the 'centroid' method.

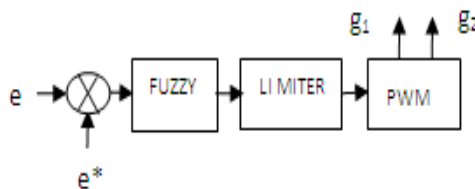


Fig.5 Conventional fuzzy controller

Fuzzification: Fuzzification is only the procedure of changing over a numerical variable (genuine number) to a semantic variable (fuzzy number)

De-fuzzification: The guidelines of FLC create required yield in an etymological variable (Fuzzy Number), as indicated by true necessities, semantic variables must be changed to fresh yield (Real number).

Database: The meaning of the participation Function required by fuzzifier and defuzzifier is put away in database.

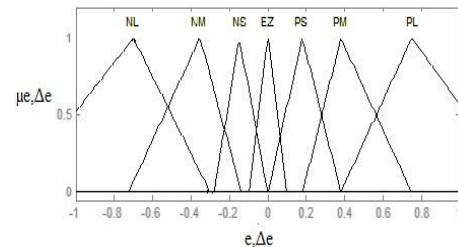


Fig.6. Membership functions for Input, Change in input, and Output.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with ' V_{dc} ' and ' V_{dc-ref} ' as inputs

e / Δe	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

Table-1: Rules table

IV. MATLAB MODELING AND SIMULATION RESULTS

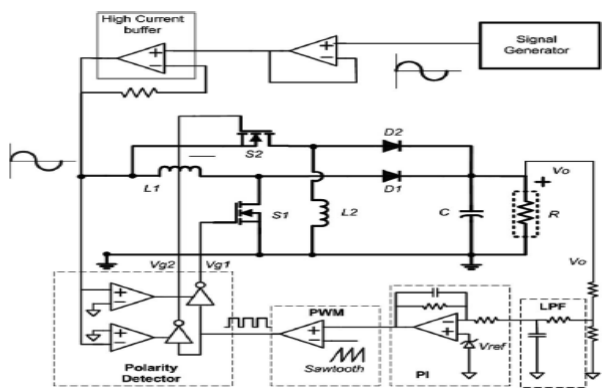


Fig. 7. Circuit diagram of the energy-harvesting converter using PI controller

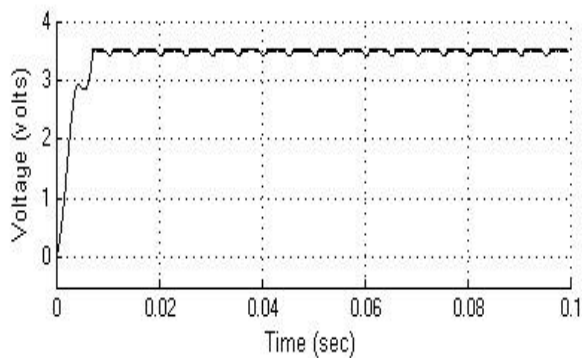


Fig.8. Output Voltage

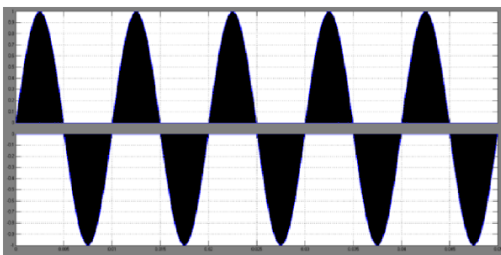


Fig.9.

Boost and buck-boost input current

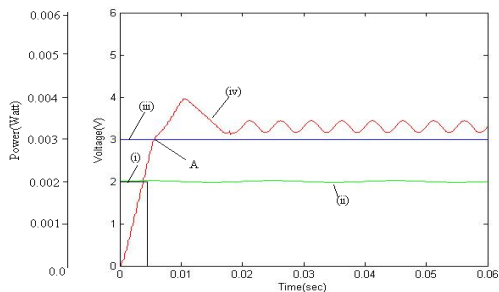


Fig.10. converter, battery power and voltages during self start-up. Curves (i), (ii), (iii), and (iv) shows

the power supplied by the battery, power draw from the converter output, battery voltage, and converter output voltage, respectively

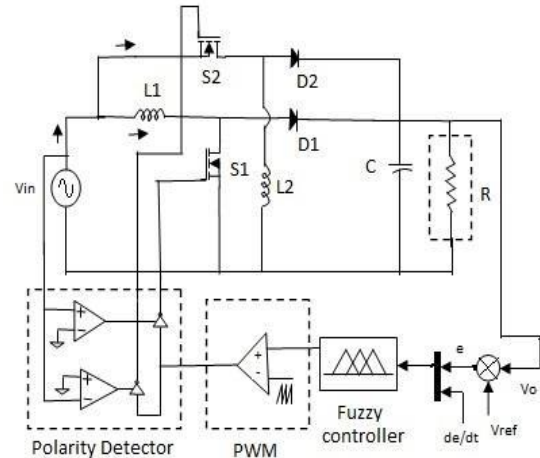


Fig.11. Circuit diagram of the energy-harvesting converter using Fuzzy controller

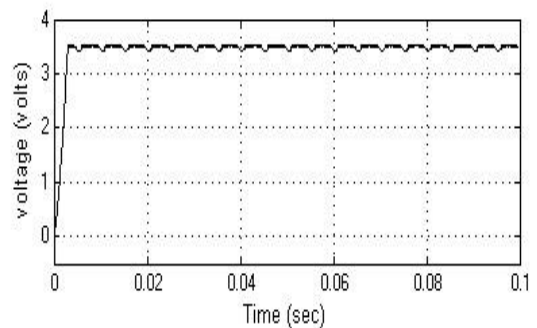


Fig.12. Output Voltage

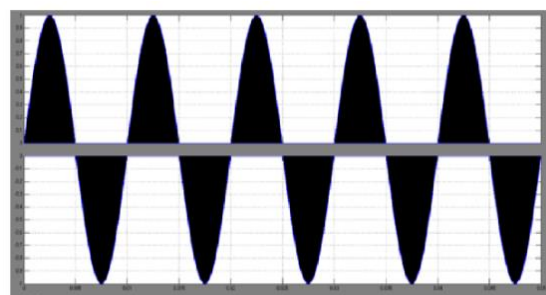


Fig13. Boost and buck-boost input current

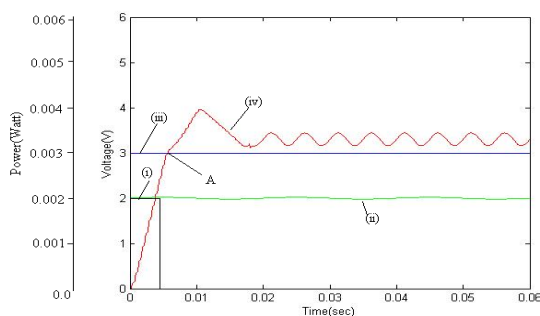


Fig.14. converter, battery power and voltages during self start-up. Curves (i), (ii), (iii), and (iv) shows the power supplied by the battery, power draw from the converter output, battery voltage, and converter output voltage, respectively

Comparison:

THD	Converter with PI controller	Converter with Fuzzy logic controller
	4.50%	1.75%

The harmonic ripples injected in line voltage will be decreases by using Fuzzy logic controller instead of PI controller in converter

V. CONCLUSION

Taking into account the human learning of framework conduct a straightforward fuzzy rationale control is developed by a gathering of tenets. To concentrate on the conduct of AC/DC converter and execution of proposed controllers, Matlab/Simulink recreation model has been manufactured. To enhance the strength of AC-to-DC converters fuzzy rationale controller has potential capacity. The exhibited direct AC-to-DC low voltage energy reaping converter evades the traditional extension amendment and accomplishes higher proficiency. The proposed converter comprises of a support converter in parallel with a buck–boost converter. To boost the voltage of the negative half cycle of the micro generator to positive dc voltage, the negative gain of the buck–boost converter is utilized. Here simulation is performed with PI controller as well as fuzzy controller. Fuzzy logic controller gets best output value, and total harmonic distortion will be reduces compare to PI controller.

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