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A Survey on Novel method of Efficient Boost Rectifier using Fuzzy Logic Controller

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Abstract: A single stage ac-dc power electronic converter is proposed to efficiently manage the energy harvested from electromagnetic generators. The conventional ac-dc converters for energy harvesting system with diode rectifiers suffers considerable voltage drop results increase in power loss of circuitry and complexity. The proposed topology combines a boost converter and buck boost converter to condition the positive and negative half portions of the input ac voltage, respectively. The proposed converter avoids the use of bridge rectifier and converts the ac input to the required dc output. By using Fuzzy compensator we can increase the dc output voltage compare to PI compensator system. The simulation is done with the help of MATLAB using simulink.

Keywords: Bridgeless, Boost, AC/DC conveter, Fuzzy compensator.

I. INTRODUCTION

PI Controller: The combination of PI term is important to increase the speed of the response and also to eliminate the steady state error. Integral mode has a negative effect on speed of the response and overall stability of the system. The PI controller will not increase the speed of response. PI controller discharges benefits and facility of implementation. A very common method of Ziegler-Nichols. This method gives a good response when the process to be controlled has a pair of dominant poles, but for more complex systems it is not recommended. The best way to fit the controller's parameters is via a heuristic manual variation. The linearity of the system, in this case, is not recommended, since the operation point usually changes constantly.

It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future & thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when:

a) Fast response of the system is not required
b) Large disturbances & noice are present during operation of the process
c) There is only one energy storage in process(capacitive & inductive)
d) Disadvantage: The PI controllers can work well for high and medium speeds but not for low speed. Because in this zone the linearity is not fulfilled according to the set of PI parameters chosen.

PID Controller**:** PID controller has all the necessary dynamics, fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease integral time constant Ti, which increases speed of the controller.

PID controller is used when dealing with higher order capacitive processes (process with more than one energy storage) when their dynamic is not similar to the dynamics of an integrator (like in many thermal processes). PID controller is often used in industry, but also in the control of mobile objects (course and trajectory following included) when stability and precise reference following are required. Conventional auto pilot is for the most part PID type controller.

Disadvantage: PID controllers are designed for nonlinear unstable systems.

Fuzzy Controller: Fuzzy logic is widely used in a machine control. The term "Fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "True" or "False" but rather as "Partially true".

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input maps sensors or other inputs, such as switches, thumb wheels, and so on, to the appropriate membership functions and truth valves. The processing stage involves each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output valve

Now systems are getting complicated day by day introducing higher order plants which increases the dead time so resulting the unstability in the system. There is drastic change in the performance of controllers with the introduction of Fuzzy controllers has been designed and tuned for third order system with such a high dead time which if difficult to control by the use of conventional

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controllers. FLC has been widely used of nonlinear and high dead time plants.

II. PROPOSED MODEL

A general diagram of an electromagnetic generator is demonstrated in Fig. 1, where k is spring stiffness constant; m is the proof-mass; DE and DP represent electrical and parasitic dampers, respectively. Essentially, the energy harvesting system consists of a spring, a proof mass, and an electrical damper. The extrinsic vibrations excite the internal oscillation between the proof mass (magnet) and electrical damper (coils). The internal oscillation produces a periodically variable magnetic flux in the coil, which induces a corresponding alternating output voltage.

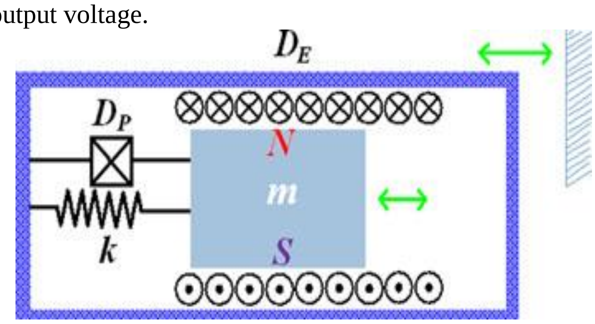

Fig. 1. General diagram of an electromagnetic microgenerator.

The boost converter is the common power conditioning interface due to its simple structure, voltage step-up capability, and high efficiency. The buck-boost converter has ability to step up the input voltage with a reverse polarity; hence, it is an appropriate candidate to condition the negative voltage cycle. The boost and buck-boost topologies could share the same inductor and capacitor to meet the miniature size and weight requirements.

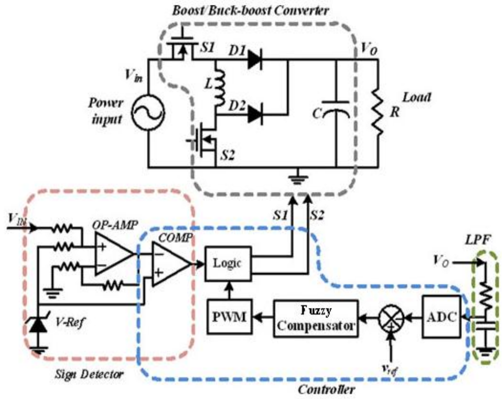

Fig. 2. Control circuit for the proposed converter.

A new bridgeless boost rectifier, shown in Fig. 2, which is a unique integration of boost and buck-boost converters, is proposed in this paper. When the input voltage is positive, S1 is turned ON and D1 is reverse biased, the circuitry operates in the boost mode. As soon as the input voltage becomes negative, the buck-boost mode starts with turning ON S2 and reverse biasing D2. MOSFETs with bidirectional conduction capability work as two-quadrant switches to ensure the circuitry functionality in both positive and negative voltage cycles.

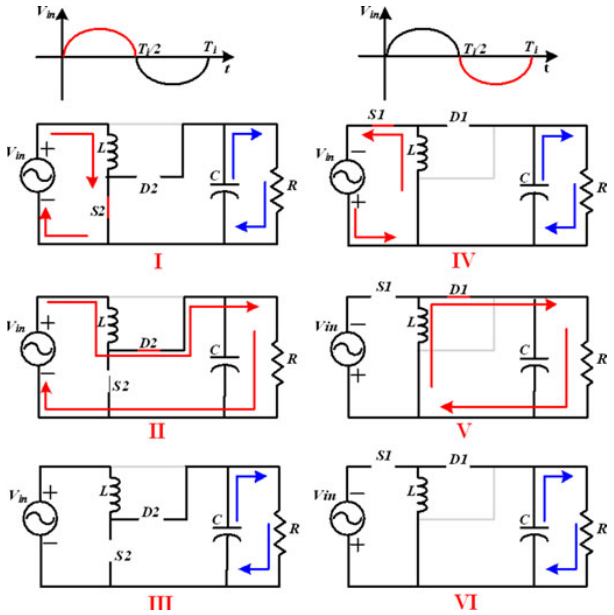

Fig. 3. Operating modes of the proposed boost rectifier.

III. PRINCIPLE OF OPERATION

The DCM operating modes of the proposed boost rectifier are shown in Fig. 3. Each cycle of the input ac voltage can be divided into six operation modes. Modes I–III illustrate the circuit operation during positive input cycle, where S1 is turned ON while D1 is reverse biased. The converter operates as a boost circuit during Modes I–III, while switching S2 and D2. The operation during negative input cycle is demonstrated in Modes IV–VI, where S2 is turned ON while D2 is reverse biased. In these modes, the converter operates similar to a buck-boost circuit.

Mode I: This mode begins when S2 is turned ON at t0. The inductor current is zero at t0. The turn on of S2 is achieved through zero current switching (ZCS) to reduce switching loss. Inductor L is energized by the input voltage as both S1 and S2 are conducting. Both diodes are reverse biased. The load is powered by the energy stored in the output filter capacitor C.

Mode II: S2 is turned OFF at t1 , where $t1 - t0 = d1Ts$, d1 is the duty cycle of the boost operation, and Ts is the switching period. The energy stored in the inductor during Mode I is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of diode D2.

Mode III: D2 is automatically turned OFF as soon as the inductor current becomes zero at t2 ($t2 - t1 = d2Ts$). This avoids the reverse recovery loss of diode. The load is again powered by the stored energy in the capacitor. The converter would return to Mode I as soon as S2 is turned ON, if the input voltage is still in positive cycle.

Mode IV: During the negative input cycle, Mode IV starts as soon as S1 is turned ON at t_0 . ZCS condition can also be achieved by ensuring the converter operation in DCM. The energy is transferred to the inductor L again, while the output filter capacitor C feeds the load.

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Mode V: At t_1 , S1 is turned OFF, where t_1 − t_0 = d_1 Ts, d_1 is the duty cycle of the buck-boost operation. The energy stored in the inductor during Mode IV is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of the diode D1.

Mode VI: When the inductor current decreases to zero at t_2 (t_2 − t_1 = d_2Ts), D1 is turned OFF at zero current. The load is continuously powered by the charge stored in the output capacitor. The converter would return to Mode IV as soon as S1 is turned ON, if the input voltage is still negative.

According to the analyses of operation modes, the switches are turned ON with ZCS and the diodes are turned OFF with ZCS. Due to the DCM operation, the input current sensor can be eliminated and switching loss can be reduced. Moreover, the control scheme of DCM operation is relatively simpler. Since the circuit size can be reduced and the efficiency can be enhanced, DCM operation is more suitable than continuous conduction mode (CCM) operation.

The output filter capacitor C is large enough to keep the output voltage Vo constant. The input is a sinusoidal voltage source. The switching frequency is much higher than the input voltage frequency. During each switching cycle, the input voltage could be treated as a constant voltage source.

The boost ratio is defined according to the specific application, while the load resistance R is dependent on the output power level. With the specified power and voltage demands, the inductance is designed according to the desired range of duty cycle and switching frequency. The larger the switching frequency is, the smaller the inductance would be.

Both the boost and buck-boost operations of the converter provide the same inductor current ripple. The voltage ratings of the MOSFETs and diodes are normally chosen higher than Vo with an appropriate margin for safe operation.

For a dynamic EM energy harvester system, if the external excitation frequency is different from the intrinsic resonance frequency, the PEI should be able to match its input impedance with the internal impedance of the harvester so that maximum power point (MPP) could be tracked.

This new topology has the maximum power point tracking (MPPT) capability. The main objective of the new introduced circuit topology, which is capable of satisfying the voltage requirement (4V) of an electronic load. Thus, a voltage feedback control loop is utilized to regulate the load voltage.

The converter is designed to operate in DCM (Discontinuous conduction mode). The output voltage is filtered by a passive low-pass filter and then fed to the analog-to-digital converter (ADC) of the controller.

The difference between the ADC output and the desired voltage is calculated and compensated through the **Fuzzy** algorithm to generate an adjustable duty cycle signal. The switching signals of S1 and S2 are dependent on the polarity of the input voltage. A sign detector is used to determine the input voltage polarity. The Atmel Mega 16 A is selected as the controller, which has both on-chip analog comparator and integrated ADC and can be integrated with the sign detector.

The sign detector is composed of a voltage reference, an opamp, and the on-chip analog comparator. The op-amp operates as an analog adder, where a dc bias (voltage reference) is added to the input voltage. The signal summation is compared with the voltage reference to detect the polarity.

The component design details and electrical parameters are summarized in Table

TABLE I: COMPONENTS AND PARAMETERS IN THE PROTOTYPE.

COMPONENT	PARAMETERS	Part Number
V_{in} (Input voltage)	0.4 V, 100 Hz	N/A
V_o (output voltage)	3.3 V	N/A
Switching frequency	50 kHz	N/A
Power Inductor L	4.7 μH, 3.34 A, 25.4 mΩ	DR74-4R7-R
Filter Capacitor C	100 μF, 6.3 V	C3225Y5V0J107Z
MOSFETs	20 V, 8 A, 22 mΩ@2.5 V	SI9926CDY
Schottky Diodes	20 V, 0.36 V@1 A	DFLS120L-7

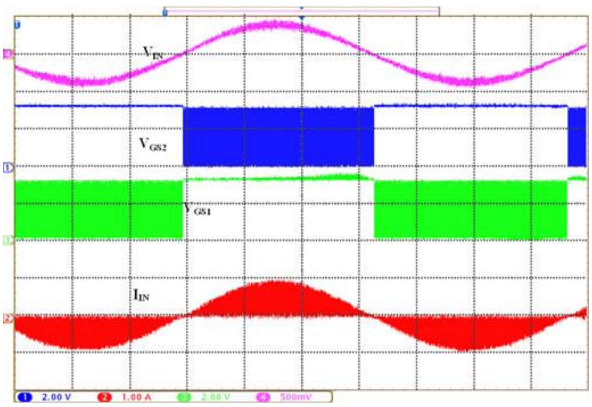

Fig. 4. From top to bottom: oscillograms of input voltage (0.5 V/div), boost gate pulse (2 V/div), buck-boost gate pulse (2 V/div), input current (1 A/div); time 4 ms/div, R = 200 Ω.

The energy harvester is emulated by a signal generator cascaded with a high-pass filter, and a high current voltage follower (OPA548).

The power source is programmed to have 0.4-V amplitude and 100-Hz frequency.

Fig. 4 shows the waveforms of input voltage, gate signals of both switches, as well as the input current.

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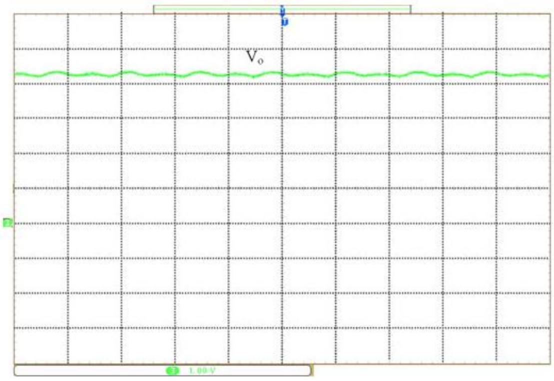

Figure 5: Oscillogram of output voltage, 1 V/div; time 20 ms/div.

R = 200Ω.Response of Conventional controller

During the positive input cycle, S1 is turned ON, while S2 is driven by the boost control scheme. When the circuit operates in the negative input cycle, S2 is turned ON, while S1 is controlled under the buck-boost conditioning strategy. As seen from Fig. 5, the output voltage is regulated at 4 V dc with approximately 0.2V (i.e., 7%) voltage ripple.

The conduction losses and switching losses of both active and passive components are estimated according to the experiment data and the parasitic parameters offered in Table I. Due to ZCS operation, the switching losses are minimized. The conduction loss dominates in the total conversion losses. Both the quiescent and dynamic losses of each IC are also estimated according to the provided corresponding data sheet. The estimated losses of individual component are listed in Table II, under 200-Ω

TABLE II. LOSS CALCULATION

Category	Component	Estimated Loss
Topology	Inductor	5.7 mW
	Filter Capacitor	0.06 mW
	MOSFETs	5.6 mW
	Diodes	6.3 mW
Controller	Mega 16A	1.98 mW
Sign Detector	Voltage Reference	0.33 mW
	OP-AMP	0.08 mW
Others	Trace and Contact resistances	2.0 mW
	Total Loss	22.05 mW

IV. CONCLUSION

A single stage ac–dc topology for low-voltage low-power energy harvesting applications is proposed in this paper. The topology uniquely combines a boost converter and a buck boost converter to condition the positive input cycles and negative input cycles, respectively. Only one inductor and one filter capacitor are required in this topology. This topology successfully boosts the 0.4-V, 100-Hz ac to 4.2-V dc. Output voltage is tightly regulated at 4.2 V through closed-loop voltage control. The measured conversion efficiency is 71% at 54.5mW. In comparison to state-of-the-art low-voltage bridgeless rectifiers, this study employs the minimum number of passive energy storage components, and achieves the maximum conversion efficiency.

With this work, the following conclusions can be reached: In spite of the easy implementation of traditional control "PI", its response is not so good for non-linear systems. The improvement is remarkable when controls with Fuzzy logic are used, obtaining a better dynamic response from the system. This is seem with clarity in the following figures.

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