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Review of Power Converters with Smart Control Strategies for Piezo Electric Energy Harvesting System

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***Abstract*—Power converter is to process and control the flow of electrical energy by supplying voltages and currents in a form that is optimally suited for user loads. Process controllers maintain the output of process variables such as temperature, pressure, flow, or level within a pre-set range. They use feedback from sensors to identify any deviation from a setpoint and automatically adjust output until parameters are back within range. Piezoelectric energy harvesting is a very convenient mechanism for capturing ambient mechanical energy and converting it into electric power. This paper presents the review of power converters with smart control strategies for piezo electric energy harvesting system.**

***Keywords*—Power, Converter, Controler, Energy, Harvesting,Piezo.**

I. INTRODUCTION

In all fields of electrical engineering, power conversion is the process of converting electric energy from one form to another. A power converter is an electrical or electro-mechanical device for converting electrical energy. A power converter can convert alternating current (AC) into direct current (DC) and vice versa; change the voltage or frequency of the current or do some combination of these. The power converter can be as simple as a transformer or it can be a far more complex system, such as resonant converter. The term can also refer to a class of electrical machinery that is used to convert one frequency of alternating current into another. Power conversion systems often incorporate redundancy and voltage regulation.

Power converter are classified based on the type of power conversion they do. One way of classifying power conversion systems is according to whether the input and output are alternating current or direct current. Finally, the task of all power converters is to process and control the flow of electrical energy by supplying voltages and currents in a form that is optimally suited for user loads.[1]

A converter is an electrical circuit which accepts a DC input and generates a DC output of a different voltage, usually achieved by high frequency switching action employing inductive and capacitive filter elements.

A power converter is an electrical circuit that changes the electric energy from one form into the desired form optimized for the specific load. A converter may do one or more functions and give an output that differs from the input. It is used to increase or decrease the magnitude of the input voltage, invert polarity, or produce several output voltages of either the same polarity with the input, different polarity, or mixed polarities such as in the computer power supply unit.

The DC to DC converters are used in a wide range of applications including computer power supplies, board level power conversion and regulation, dc motor control circuits and much more.

The converter acts as the link or the transforming stage between the power source and the power supply output. There are several kings of converters based on the source input voltage and the output voltage and these falls into four categories namely the AC to DC converter known as the rectifier, the AC to AC cycloconverter or frequency changer, the DC to DC voltage or current converter, and the DC to AC inverter.

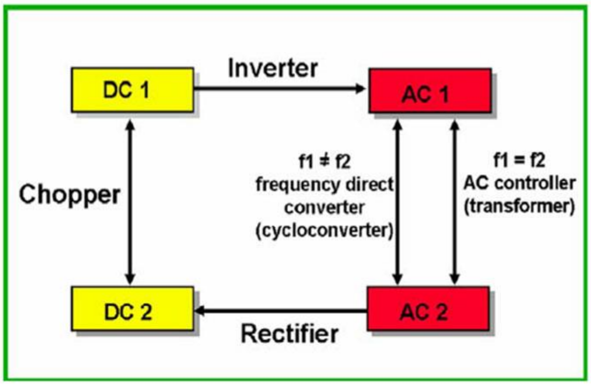

Figure 1: Power converter specifications

The converter uses non linear components such as the semiconductor switches, and linear reactive components such as the inductors, transformers and capacitors for intermediate energy storage as well as current and voltage filtering. The size, weight and cost of the converter are largely determined by these components.

Piezoelectric energy harvesting is a very convenient mechanism for capturing ambient mechanical energy and converting it into electric power since the piezoelectric effect is solely based on the intrinsic polarization of the material and it does not require a separate voltage source, magnetic field.

During vibration energy harvesting, piezoelectric materials convert mechanical strain into an electrical charge or voltage via the direct piezoelectric effect. The power output of a particular piezoelectric energy harvester depends upon intrinsic and extrinsic factors.

II. LITERATURE SURVEY

M. Edla et al.,[1] describes the design and practical application of a dual-stage H-Bridge (DSHBR) circuit to reduce the rectification losses and mitigate ripples in piezoelectric energy harvesting. The proposed DSHBR circuit integrates both AC-DC and DC-DC conversion processes using bidirectional switches and a step-up DC-DC converter, which applies to both positive and negative half cycles. One additional feature is that it does not require external power to turn on the bidirectional switches (V_{th} <; 0.3 V). Such feature facilitates active rectification at very low AC voltages (V_{ac} <; 0.5) generated by the piezoelectric device (PD). To validate the performance of the proposed circuit, a series of experimental tests were conducted. Firstly, the performance of circuit on rectifying the PD output was investigated using a shaker to generate high and low frequency excitations.

H. -C. Cheng et al.,[2] a reconfigurable capacitive power converter with capacitance redistribution for indoor light-powered batteryless Internet-of-Things (IoT) devices is presented. The proposed converter is capable of redistributing the capacitance among two charge pump stages to efficiently utilize the harvested energy and further powering milliwatt-powered loading circuits occasionally. Moreover, the proposed converter is capable of storing and reusing the harvested energy to cope with the power demand under different operating modes. The first charge pump stage stores the excessive energy produced by a photovoltaic (PV) cell to the storage capacitor using a maximum power point tracking (MPPT) technique under low-output power demand, whereas the second stage provides a regulated 1.5-V output voltage.

S. -H. Wu et al.,[3] proposes a boost converter with ultralow-voltage time-domain control for thermoelectric generators (TEGs). A subthreshold 0.3-V voltage supplied control system is constructed using time domain and constant on-time approach. The maximum power point tracking (MPPT) is realized using the fractional open-circuit voltage scheme. The proposed converter is implemented in a 0.13- μm CMOS process. The measured minimum TEG open-circuit voltage which can maintain harvesting is 80 mV. The power consumption of the control circuit is down to 840 nW. The peak end-to-end efficiency is 72.1% at 170-mV open-circuit voltage where the input power is 34.4 μW.

Z. Gao et al.,[4] presents an asynchronous AC-DC boost converter with a high power conversion efficiency (PCE) and a low start-up voltage. The converter consists of a self-powered rectifier with unbalanced comparator, followed by a hysteresis DC-DC boost converter with an `event-driven' regulation loop, enabling boost conversion and output regulation without the need for a system clock, leading to significant reduction of the driving power loss and thus improvement of the PCE. The converter can be started up from an input AC voltage with 500 mV amplitude, achieving a maximum PCE up to 94% with reduced chip-to-chip variation as low as 4%, delivering 103 μW output power. The chip has been fabricated in 180 nm standard CMOS process with a 0.11 mm^2 core area, targeting on the low-frequency electromagnetic (EM) energy harvesting.

J. Maeng et al.,[5] presents a high-voltage (HV) dual-input buck converter with a bidirectional inductor current (IL) and a fully integrated maximum power point tracking circuit for triboelectric (TE) energy-harvesting applications. The proposed converter regulates HV inputs through a single shared inductor, and HV inputs can be isolated without using an additional HV protection circuit. In addition, the proposed diode-based HV sampling circuit can accomplish high ac voltage sampling and peak detection to perform the fractional open-circuit voltage method without any external components. Fabricated using a 180-nm bipolar-CMOS-DMOS (BCD) process, the proposed system with a self-manufactured polytetrafluroethylene (PTFE)based TE nanogenerator can regulate two HV inputs up to 70 V and achieve a power conversion efficiency of 84.7% and an endto-end efficiency of 75.6%, which are 30.2% and 22.7% better than prior work, respectively.

J. Park et al.,[6] a buck-boost converter is described which harvests energy from a solar cell and performs dc-dc conversion with only one inductor. If the harvested energy is larger than the system load, the buck-boost converter charges a battery with the residual energy, which is called the battery-charging mode. If system load is larger than the harvested energy, the load is supplied by both the harvested energy and the battery, which is called the battery-assisted mode. The optimum control scheme has been found to be the integral charging scheme for the maximized power efficiency (PE). The buck-boost converter implemented in a 180-nm complementary metal-oxide-semiconductor (CMOS) process operates at 97 kHz and shows the steady-state output ripple smaller than 25 mV with the maximum PE of 89.4% for 28-mW output power.

S. Kawar et al.,[7] proposes a discontinuous charging technique for switched-capacitor converters that improves the power conversion efficiency (PCE) at low power levels and extends the input power harvesting range at which high PCE is achievable. Discontinuous charging delivers current to energy storage only during clock non-overlap time. This enables tuning of the output current to minimize converter losses based on the available input power. Based on this fundamental result, an input power-aware, two-dimensional efficiency tracking technique for Wireless Sensor Network (WSN) nodes is presented. In addition to conventional switching frequency control, clock non-overlap time control is introduced to adaptively optimize PCE according to the sensed ambient power levels. The proposed technique is designed and simulated in 90nm CMOS with post-layout extraction. Under the same input and output conditions, the proposed system maintains at least 45% PCE at 4μW input power, as opposed to a conventional continuous system which requires at least 18.7μW to maintain the same PCE.

P. Cao et al.,[8] presents a bipolar-input thermoelectric energy-harvesting interface based on boost/flyback hybrid converter (BFHC). Two-type ring oscillators are combined to form as a complementary group with bipolar-input voltage operating range for self-start. With the technique of combining the boost converter and flyback converter together, the system is able to convert the energy with bipolar-input voltages. The open-circuit voltage maximum power point tracking (MPPT) method is adopted in this harvester to extract as much energy as possible from the thermoelectric generator.

I. . -C. Chen et al.,[9] A single-inductor dual-input dual-output (SI-DIDO) dc-dc converter for photovoltaic and piezoelectric energy harvesting systems is proposed. The SI-DIDO dc-dc converter uses buck-boost topology. A new algorithm is proposed to share the single inductor between all the inputs and outputs in one switch cycle. Light-load or heavy-load mode is determined by current-mode pulse width modulation (PWM) control.

Q. Zhang et al.,[10] The cascaded H-bridge (CHB) is a good candidate to integrate multiple photovoltaic (PV) arrays into the power grid. However, due to the internal uncertain power supply of renewable sources, it is difficult to meet the power grid power command with only PV arrays. To overcome this limitation, a CHB converter with both PV arrays and energy storage units in the dc rails is proposed in this work. First, a two-layer hierarchical control is developed for independent PQ control and power distribution among each CHB cell.

M. Chen et al.,[11] a batteryless boost converter for thermal energy harvesting is presented. Only single off-chip inductor is employed through inductor sharing technique. A stepping-up architecture consisting of a startup converter and a main converter is adopted. The startup converter activates the chip with an input voltage as low as 190 mV. With zero-current switching and maximum power point tracking techniques, the main converter achieves a peak efficiency of 60% and outputs a maximum power of 400 µW. The converter is capable of maintaining its operation under a minimum input voltage of 50 mV over a wide temperature range from -30 °C to 80 °C.

M. Shim et al.,[12] presents a fully integrated energy harvesting (EH) system that even includes an input capacitor and a simplified ripple correlation control (RCC) maximum power point tracking (MPPT) method for low-power system-on-a-chip applications. The proposed system implements the RCC block with a charge pump (CP) that can be integrated into the chip, instead of the inductive switching converter that is commonly used for conventional RCC methods. The CP changes the input impedance by changing the size of the flying capacitor to ensure system reliability.

K. Yoon et al.,[13] presents a double pile-up resonance energy harvesting circuit that efficiently and simultaneously extracts energy from a piezoelectric transducer (PZT) and a thermoelectric generator. The proposed harvester operates in a double pile-up mode (DPM) to efficiently extract energy from PZT with the enhanced damping force, resulting in a 1452% improvement in power extraction, which is the best performance among the state-of-the-art works. The harvester also operates in a boost converter mode (BCM) without an additional power switch, achieving 75% conversion efficiency at 450-µW output power.

Y. Sun et al.,[14] Converter-less supply architecture is promising for energy harvesting sensor nodes, due to their high conversion efficiency, low cost, and easy integration. However, lack of a dc-dc converter precludes the electronic load operating under the voltage for optimal energy efficiency, since the output voltage of the energy harvester is set as the maximum power point tracking (MPPT) voltage. To mitigate efficiency loss of workload, we propose architecture to achieve maximum energy efficiency tracking for the overall sensor node. A theoretical analysis is given for the architecture and an efficiency-driven frequency controller is fabricated to validate the design methodology.

III. TYPE OF CONVERTER CIRCUIT & CONTROLLER

There are three basic converter circuits that are widely used in DC to DC converters are the buck, boost, and the buck and boost. These configurations are the most used topologies due to their simplicity and use of fewer components. Each has its advantages and drawbacks which determines the suitability for any specific application.

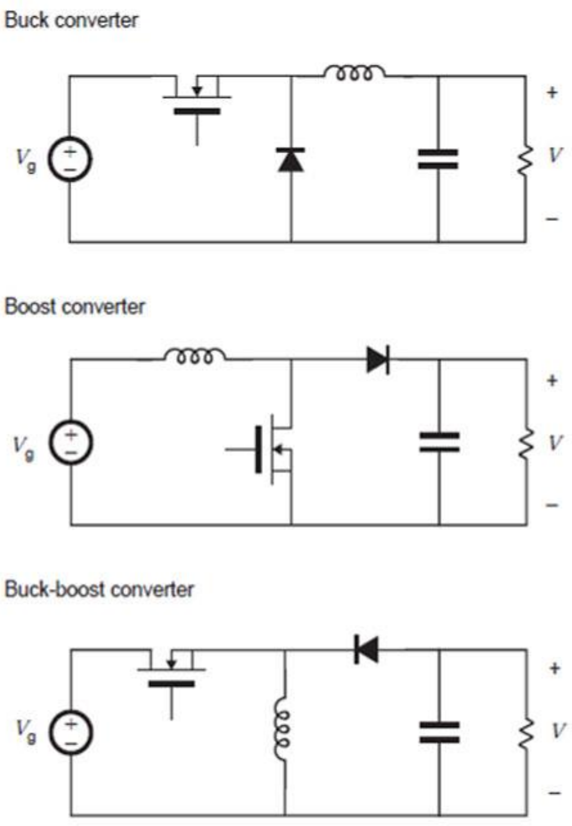

Figure 2: Non-isolated converter circuit arrangements

The buck converter is a step-down, the boost a step-up while the buck-boost is both step-up and step-down. All these are non-isolated and use the inductor as the energy transfer element and are mostly used in board level power conversion and regulation.

The isolated dc to dc converters use a transformer to provide the isolation, multiple outputs, a different voltage level, or polarity depending on the turns ratios and directions of the windings.

They are based on the non-isolated topologies but with the inclusion of a transformer. The commonly used types are, the full bridge, the half bridge, forward and the push pull converters, which are the isolated versions of the buck; and the flyback which is the isolated version of the buck-boost converter.

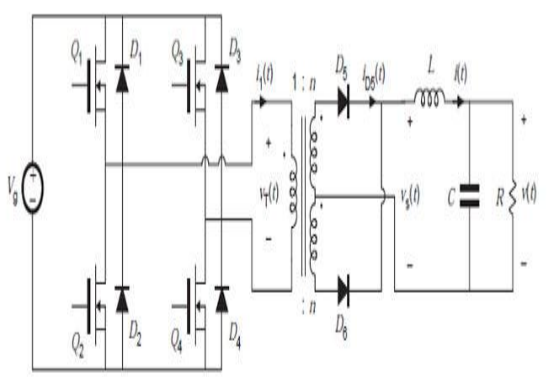

Figure 3: Full Bridge isolated buck converter

To improve performance, high frequencies and fast switching power semiconductor devices are used. The high frequencies increase the efficiency while reducing the physical sizes of the supplies since they allow the use of smaller components. The frequencies are usually above the audible range and in the range of between 20 KHz and 200 KHz. A feedback and duty cycle control circuit is usually used to adjust the turn-on and turn-off conditions to maintain a constant voltage at the output regardless of the load current or variations in the supply voltage.

Converters are widely used in the electronic equipment, in power supplies and other circuits requiring specific voltage and current levels other than the available raw supply energy. The converters provide any type of the required voltage at the desired magnitude. With a proper design and use of the almost ideal components, the available methods of conversion offer variety of reliable and efficient energy to power most of the electronic devices and components.

Smart Control techniques ensure that the electric power system is able to operate, without instability, under a wide range of system conditions.

Mainly three types of electrical control panels are used:

- Power control centres (PCC)
- Motor Control centres (MCC)
- Automation Panel (SCADA / PLC PANELS)
- Power Control Centers (PCC Panels)

The power control centres – It is extensively used in distribution of electricity from source to the use. The power control centres are generally placed near power source with high fault level of 50KA or 65 KA for 1 sec. The metallic bus bars are fitled to interlink incoming power outgoing feeders. The ample space for termination of cables is provided for easy handling of the system.

The power control centres are also provided with protection and safety devices for short circuit, overload earth fault, under over voltage etc.

Motor control center (MCC Panel)

The Motor Control Center Panels (MCC Panel) are used in large industrial and commercial application to control motors from a central location.

The motor control centers are combination of multiple enclosed sections having common busbars and each section containing power contactors, protective relays, isolators and other control and indication devices. The MCC are also fitted with VFD's, PLC's, metering etc. as required.

The motor control centre are also provided with protection safety devices such as motor protection preventers, earth fault relays, phase reversal relay etc.

Automation Panels (SCADA / PLC PANEL)

PLC Automation Control Panels have essentially made a niche in today's electrical distribution support system in generation, transmission as well as distribution of electricity from load to utility centres. PLC Automation Panels control the varying electrical load as per variable load demand periodic as well as intermittent and switching on sequential flow of programmable automated operation in assembly line of manufacturing as well as completion of operations.

IV. CONCLUSION

There are different types of the power converters with smart control strategies for piezo electric energy harvesting system. The efficient power converter achieves the better performance. The smart controller strategies is based on the soft computing and the artificial intelligence techniques. This paper review of the various research work on the design and analysis of power converter with controller for different applications.

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