A Sustainable Alternative To The Batteries Used In IOT Devices

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Abstract—A lot of studies have shown that the synchronous switch energy producer solutions increase the rate of energy production from vibration (i.e.) piezoelectric ones which comes with capacitive output impedance. These ones use inductive branch to compensate capacitive source. Some studies have done the reciprocal (i.e.) to compensate inductive source they use capacitive branch. In these, the controllers are very bulky which is not a desired ones for making sustainable energy for the IOT devices. This synchronous switch method will work with two rounds of ON/OFF actions in each vibration cycle. By this method we can improve the power factor, thus the energy production is increased. This method uses very less amount of switching actions than other methods we use just like pulse width modulation ac-dc rectifier designs. The detailed working is given in this article. It also shows the result proving that this synchronous switch method outperforms the diode-bridge rectifier energy converting methods by 62.1%-96.4%.

Keywords—diode-bridge rectifier, synchronous switch, EM Generator, Microcontroller, WSNs

I. INTRODUCTION

The Internet of Things (IoT) era has grown rapidlyin recent years. There will be numerous wireless sensor networks (WSNs) deployed in our surroundings in the future .One of the elements confining the distribution variety and operation life of WSN is sustainable power supply. The working time of batteries is very less. Energy harvesting technology is a promising power solution to relieve the dependence on batteries. It explores a way to scavenge kinetic energy in different forms from the environment and convert it into useful electricity, such that to offer independent energy to WSNs.With the improvement of EH technology, battery dependency can be alleviated. More WSNs are expected to become self-powered in the coming future. The electromagnetic (EM) transducer, sometimes just called a generator, is one of the most classical and widely used electromechanical transducers for kinetic energy harvesting .

An EM generator may be modelled as an ac voltage source in series with the coil's self-inductance and resistance. This electrical model was modelled with the well-known Faraday's law of induction. When the
magnetic flux through the coil changes, an electromotive force may be induced within the coil.

II. LITERATURE SURVEY

A. Zhiwu Xie et.al "Self-Powered Synchronous Switch Energy ExtractionCircuit for Electromagnetic Energy Harvesting Enhancement"IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 38, NO. 8, AUGUST 2023:

The SSEE circuit can recover 182.5% more energy than the diode-bridge rectifier and reduce braking time by 35.1% compared to the short-circuit braking case. - Compared with the standard energy harvesting diode-bridge rectifier, SSEE can harvest up to three-fold energy. - The SSEE circuit significantly reduces braking time and enhances the energy harvesting capability of an electromagnetic machine. They summarized -The SSEE circuit significantly improves energy harvesting and reduces braking time in motor regenerative braking, providing a promising energy extraction mechanism for electromagnetic inductive machines.

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B. J. Liang, C. Ge, and Y.-C. Shu, "Impedance modeling of electromagnetic energy harvesting system using full-wave bridge rectifier," in Proc. Act. Passive Smart Struct. Integr. Syst., 2017, Art. no. 101642N.

The synchronous switch energy extraction (SSEE) solutions can enhance the energy harvesting capability of vibration energy harvesters with capacitive output impedance. The SP-SSEE circuit outperforms the benchmark standard energy harvesting diode-bridge rectifier by 62.1%-96.4% under different excitation frequencies, in terms of harvested power. The proposed SP-SSEE circuit can harvest up to two-fold energy, under the same mechanical excitation, compared with the benchmark diode bridge SEH interface circuit. They summarized- The paper proposes a self-powered synchronous switch energy extraction (SP-SSEE) circuit for inductive electromagnetic energy harvesting sourcesand demonstrates its outperformance compared to the benchmark standard energy harvesting diode-bridge rectifier. It also highlights the rarity of related studies for electromagnetic transducers in the context of synchronous switch technique for power enhancement.

C. J. Bito, R. Bahr, J. G. Hester, S. A. Nauroze, A. Georgiadis, and M. M. Tentzeris, "A novel solar and electromagnetic energy harvesting system with a 3-d printed package for energy efficient Internet-of-Things wireless sensors," IEEE Trans. Microw. Theory Tech., vol. 65, no. 5, pp. 1831–1842, May 2017

This paper discusses the design of a novel dual (solar + electromagnetic) energy harvesting powered communication system, which operates at 2.4 GHz ISM band, enabling the autonomous operation of a low power consumption power management circuit for a wireless sensor, while featuring a very good "cold start" capability. The proposed harvester consists of a dual port rectangular slot antenna, a 3-D printed package, a solar cell, an RF-dc converter, a power management unit (PMU), a microcontroller unit, and an RF transceiver. Each designed component was characterized through simulation and measurements.They summerized- The paper discusses the challenges of relying on primary batteries for autonomous devices, the interest in ambient energy harvesting technologies for self-sustainable systems, efforts to improve the performance of RF energy harvesters, and the investigation of multiple energy harvesting systems for cold start and perpetual operation of low-power wireless sensor motes.

D. G. D. Szarka, S. G. Burrow, and B. H. Stark, "Ultralow power, fully autonomous boost rectifier for electromagnetic energy harvesters," IEEE Trans. Power Electron., vol. 28, no. 7, pp. 3353–3362, Jul. 2013.

Boost rectifier circuits can operate successfully without a discrete inductor down to 141 µW of available harvester power. - Full-wave boost rectifier circuits can achieve over 90% harvester utilization at 6 m•s -2 source excitation, presenting a near optimum damping condition for the energy harvester. - The half-wave boost rectifier topology has a utilization range of 75%, compared to the full-wave circuit, but offers improved power conversion efficiencies in the range of 80-90% near 1 mW input power level, when gate switching losses and gate drive and control circuit power overheads are ignored.They summerized- The paper focuses on the design and performance of boost rectifier circuits for microscale electromagnetic energy harvesters, emphasizing the trade-offs between harvester utilization and power conversion efficiencies for different circuit topologies.

E. G. D. Szarka, S. G. Burrow, and B. H. Stark, "Ultralow power, fully autonomous boost rectifier for electromagnetic energy harvesters," IEEE Trans. Power Electron., vol. 28, no. 7, pp. 3353–3362, Jul. 2013.

Energy harvesting provides a promising solution to the replacement or recharging of batteries for microscale devices; The proposed input-powered energy-harvesting interface achieves a maximum efficiency of 60% with 1.5 V ac input amplitude and 3 V regulated dc output, delivering 3.9 mW of output power; Mechanical vibration is identified as one of the main sources of energy for harvesting, and recent research has produced remarkable advances in power efficiency, scaling, and low-voltage capabilities for energy harvesting interface circuits. They summerized- The paper presents an energy-harvesting interface circuit that operates with input sine waveforms ranging from 1 V to 3 V and frequencies from 1 Hz up to 100 kHz, achieving a maximum efficiency of 60% with 1.5 V ac input amplitude and 3 V regulated dc output, and entering standby mode when the input drops below 600 mV with zero standby power consumption.

F. E. Arroyo and A. Badel, "Electromagnetic vibration energy harvesting device optimization by synchronous energy extraction," Sens. Actuator A-Phys., vol. 171, no. 2, pp. 266–273, 2011.

It investigates a new application of nonlinear techniques for vibration energy harvesting. The Synchronous Electric Charge Extraction (SECE) energy harvesting technique for piezoelectric generators is extended and adapted to electromagnetic generators. This new circuit, which is the dual of the SECE circuit, is named SMFE for Synchronous Magnetic Flux Extraction. A theoretical model is developed, and the harvested power is simulated. Comparisons with a classical energy extraction approach show that between 2.5 more power and 10% less power can be harvested, depending on the generator characteristics. It also allows the maximum power to be harvested whatever the value of the load. Finally, the SMFE circuit was embedded and tested on a simple centimeter-scale electromagnetic harvester. Measurements confirm the theoretical operating principle of the circuit. They summerized- The paper discusses the development and testing of a new extraction technique (SMFE) for electromagnetic generators, comparing its theoretical performances with the classical extraction technique and performing experiments to confirm its operational principle. The SMFE technique efficiently addresses two main difficulties introduced by the energy extraction for an electromagnetic generator: reducing the dependency on the load, settling the impedance matching issues, and directly producing usable DC voltages regardless of the generator parameters, allowing a focus on power maximization.

III. CIRCUIT AND BLOCK DIAGRAM

A. Synchronous Switch Interface Circuits

An EM source has an inverted internal structure to the piezoelectric case. Because, in case of piezoelectric ones it uses a capacitive source and current source is parallel with it and thus the voltage source will be in series with an inductance in the EM source.Even though the negative power is observed in some intervals when using simple bridge rectifier circuits. So that the concept of PEH is converted to the Electromagnetic energy Harvesting source by interfacing the synchronous switch circuit for Enhancement. The improvement is more significant when reactive components is more used than the resistive components. It means that when an AC source has a Large Quality Factor. Therefore, this method will be very useful when EM Generator operates in high speed or has more windings or core is made of high-permeability material

Many methods were proposed for the PEH Cases during the last 10 years.But for EMEH cases there were None and all of them used the PC-based controllers which use more power and they are very big compared to ours.The circuit Diagram was shown in the Fig.1

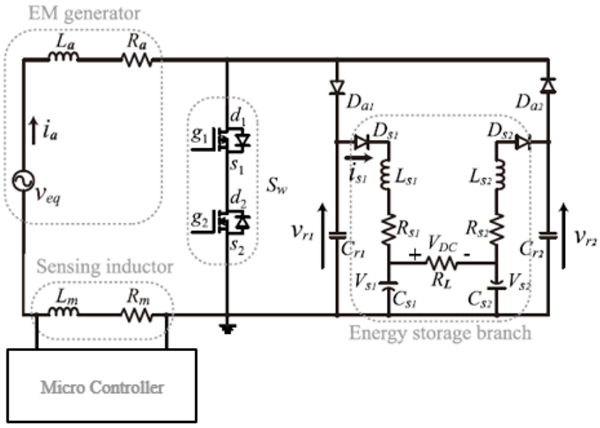

Fig. 1. Schematic diagram of the Synchronous Switch Circuit diagram

B. Block Diagram of Synchronous Switch

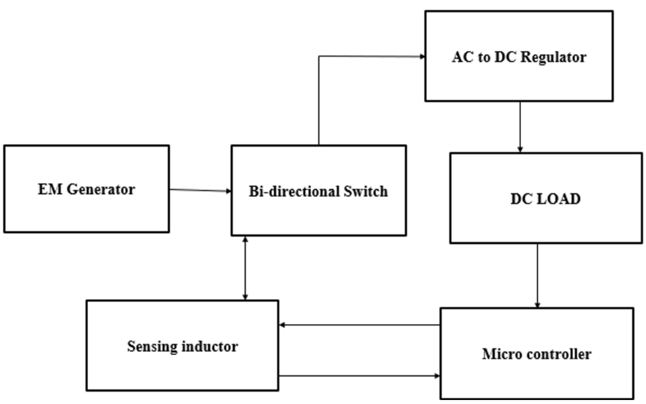

Fig. 2. Block Diagram of Synchronous Switch.

1) EM Generator:

In electricity generation, a generator is a device that converts motion-based power (potential and kinetic energy) or fuel-based power (chemical energy) into electrical power for use in an external circuit. Mechanical energy sources include steam turbines, gas turbines, water turbines, internal combustion engines, wind turbines, and even hand cranks. The first electromagnetic generator, the Faraday disk, was invented by British scientist Michael Faraday in 1831. Generators provide almost all the power of the grid.In addition to electricity and motion-based designs, solar photovoltaic generators and fuel cell generators use solar energy and hydrogen-based fuels, respectively, to produce electrical output.The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators are very similar. Many motors can generate electricity from mechanical energy.

2) Sensing inductor:

An inductive sensor is a device that uses the principle of electromagnetic induction to detect or measure objects. When current flows through an inductor, a magnetic field is created. On the other hand, a change in the magnetic field through a circuit containing an inductor causes a current in that circuit. This effect can be used to detect metallic objects that interact with magnetic fields. Inductive

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sensors can work in wet or dirty conditions because non-metallic materials such as liquids or some types of dirt do not interact with magnetic fields.

3) Ac to Dc regulator:

AC to DC converters are one of the most important elements in power electronics. This is because there are many real-world applications based on these developments. An electrical circuit that converts an alternating current (AC) input to a direct current (DC) output is known as an AC-DC converter. They are used in power electronics applications with 50 Hz or 60 Hz sinusoidal AC voltage input that require power conversion for DC output.The process of converting AC current to DC current is known as rectification. The rectifier converts AC power to DC power at the load end connection. Similarly, transformers are commonly used to adjust AC power to lower the voltage level and extend the operating range of DC power.

4) Micro controller:

A microcontroller (MC, μC, or, due to confusion of ⟨μ⟩ with ⟨u⟩, UC) or microcontroller unit (MCU) is a small computer on a single integrated circuit. A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input and output peripherals. Program memory in the form of ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general-purpose applications consisting of various discrete chips.In modern terminology, a microcontroller is similar to, but less sophisticated than, a system on a chip (SoC). A SoC may include a microcontroller as one of its components, but usually integrates it with advanced peripherals like a graphics processing unit (GPU), a Wi-Fi module, or one or more coprocessors.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make digital control of more devices and processes practical. Mixed-signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems. In the context of the internet of things, microcontrollers are an economical and popular means of data collection, sensing and actuating the physical world as edge devices.

IV. WORKING PRINCIPLE

A. Topology

This synchronous Switch method basically consists of an equivalent model of an EM Generator, sensing inductor, controller, two synchronous switches (i.e.) MOSFETs, and two FW and storage branches. The induced voltage will be directly proportional to relative velocity between the zero-volt coil and the Magnet. The synchronous switch action takes place when equivalent voltage crosses the zero so that instantaneously current direction will also change.

The switching branch consists of two MOSFETs, two diodes and two resonant capacitors. The Underdamped RLC circuit helps to extract all energy in the EM Generator's self-inductance and the polarity of current will be changed at each switch. The capacitance at the energy storage branch is greater than the capacitance at the RLC circuit.

The Capacitance at the energy storage branch provide stable positive and negative voltage to power the controller circuits. The sensing Inductor in the controller circuit helps to find when the current derivative rise or fall across the zero line. A dc load is connected across the two capacitance of energy storage branch.

B. Working Phases

This synchronous switch is compared with the PWM-design which has low frequency switching strategy. It means that only two switch ON/OFF action is needed per vibration cycle.

While crossing the zero-crossing point from positive to negative, it supplies energy from the source inductance to the positive storage capacitor through the capacitor of RLC circuit. This process repeats reciprocally when change from negative to positive cycle of zero crossing point. This energy process can be divided into four phases.

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At first phase, keeping switch on state and the varying equivalent voltage magnetizes the source inductance and the sensing inductor. Current increases gradually from zero during this phase across this loop. The duration of this phase is half a vibration cycle.

At second phase, when voltage crosses zero from positive to a negative value. Switch is turned OFF for a short interval. This will enable a transient and sudden change in the polarity of the current. At this time, the capacitor at the RLC circuit will absorb most of the energy. But little dissipation occurs due to the joule heating. At about the quarter of the LC period which is shorter than a vibration cycle, current will drop to zero. The turn OFF interval of switch is longer than a quarter of the LC period used to demagnetize completely.

At third phase, in the next half cycle switch is turned ONandstartsthe magnetization of inductance of source inductance and the sensing inductance but with negative voltage. Meanwhile, the extracted energy stored in the capacitor of RLC circuit is transferred to the capacitance at the energy storage branch. We know energy storage branch capacitance is large, so it can provide a constant voltage source.

At fourth phase, after the full discharge of energy from the capacitor of RLC circuit, still there will some energy be left in the energy storage branch inductor. Therefore, it will be transferred to the energy storage branch capacitor. The major portion of the energy is transferred in this half cycle to the energy storage branch capacitor. Source inductance is only involved in the 2nd phase and the storage capacitor is only involved in the 3rd and the 4th phase. So, it means that source and load devices are not coupled.

V. EXPERIMENTS AND RESULTS

The circuit simulation is first built and runs in MATLAB Simulink software to examine the performance as shown in figure below.

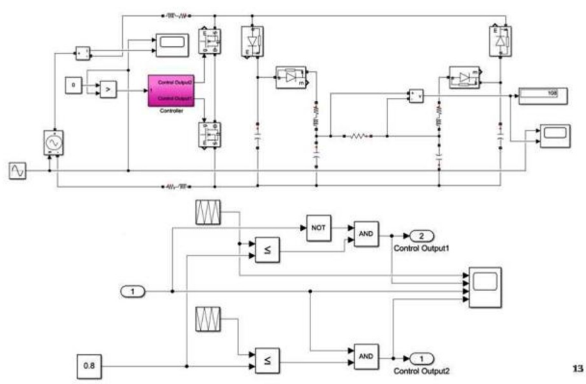

Fig. 3. MATLAB Simulation Diagram.

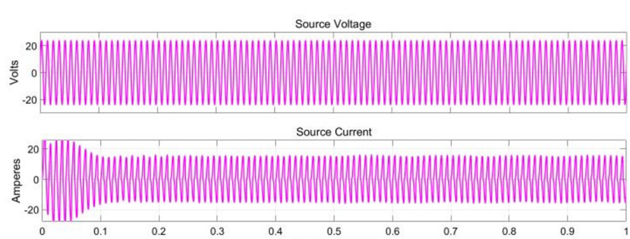

Fig. 4. Input Waveform

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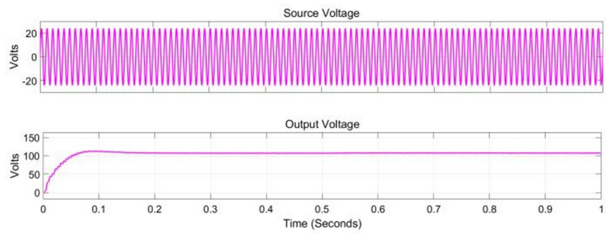

Fig. 5. Output Waveform

After that a experiment was built for practical examination. It includes a EM Generator which is actually a motor as prime mover which consists of circular magnets. When magnets rotate a emf is induced in the zero volt coil. The amplitude and frequency are controlled by varying the motor speed. If the frequency is higher, the power generated will be higher. In other words, more the reactive inductance more the frequency increases the speed.

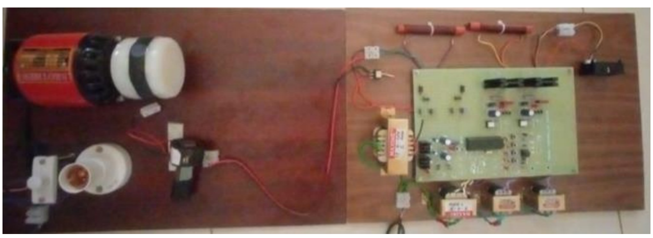

Fig. 6. Practical Model

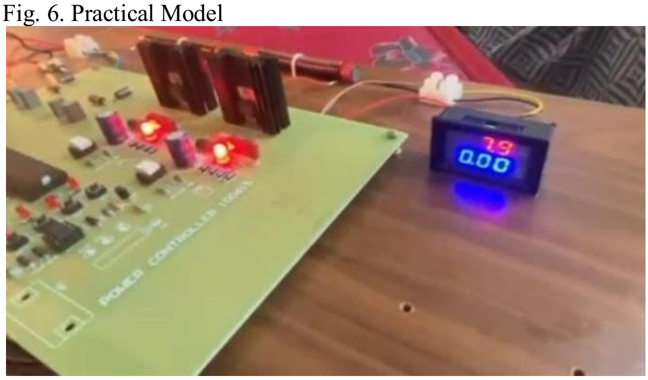

Fig. 7. Output voltage of weak source and strong source

In the start of supply given, the inductance part charges the storage branch capacitors. When that voltage reaches the required operating threshold voltage the synchronous switch circuit will operate. In this study 5V is the minimum threshold voltage. We can see an improvement after the switch involves in this process of capacitors charging speed in the storage branch.After load is connected, the storage branch gets steady state sometimes later.

The power obtained is calculated using the Joule's law. But this calculation will differ between the simulation and experimental results because the controller heat dissipation is not included in the experiment and parasitic resistance can't be measured either.

In this study we compare the produced power of synchronous switch method and the standard energy harvesting method. The ac sources which has string reactive impedance produce more efficient energy conversion.

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VI. COMPARISON TO PREVIOUS STUDIES

A. Compared to peizoelectric method

The current and voltage waveforms look very similar to each other. But each works in reciprocal way (i.e.) piezoelectric is capacitive source and in the synchronous switch it is a inductive source. It also better solutions for energy conversions using synchronous switch method

B. Compared to diode bridge rectifier method

In this study we use the power-controlled devices whereas in the diode bridge rectifier they did not use like that and uses only one-fold of switch actions and since it is controlled by a microcontroller. Sotherefore, the power factor is reduced so that power production is increase to an extent from 62.1% to 96.4%

C. Compared to pulse width modulation method

Most of electro magnetic energy enhancement uses the pulse width modulation. But this synchronous switch method uses the transient underdamped response method. In PWM switching frequency is higher and at this study we can use low switching frequency and also if we want to for a self-powered implementation synchronous switch method is easy.

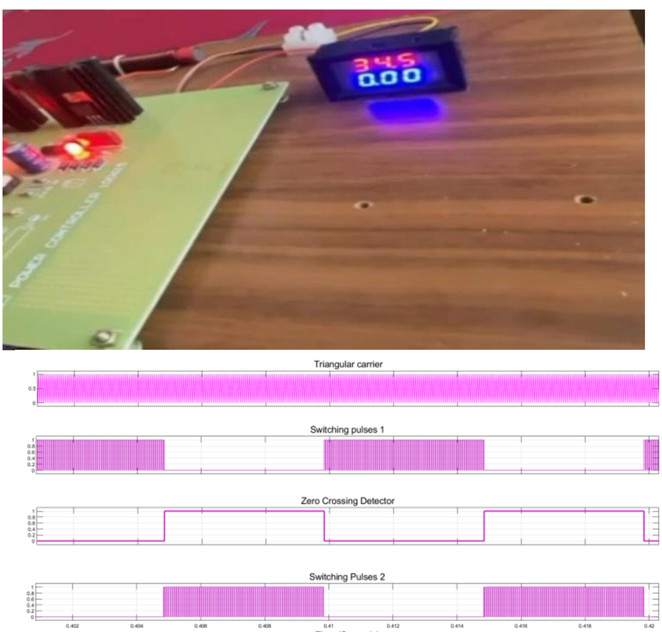

Fig. 8. Pulse Waveform

VII. CONCLUSION

This synchronous switch method was previously used in the piezoelectric ones which is capacitive source but rarely seen in the inductive way source. This study gives a self-powered solution for the EM based sources. The circuit diagram, working principle and results were discussed very clearly. Compared with the standard diode bridge rectifier method to this study and proved that this experiment produced more energy compared to the other. Power produced is independent to the load variation. The higher quality factor are very efficient for this technique. When the source parasitic resistance is very small, self-inductance is very high or EM source works at high frequency.

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