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doi:10.15199/48.2023.10.12

# Analysis Of Energy Harvester Circuit for A Thermoelectric Energy Harvesting System (TEHs) At Asphalt Pavement

***Streszczenie.*** *Nadrzędne wyzwania naszych czasów obejmują zmiany klimatu, globalne niedobory energii, a nawet zanieczyszczenie środowiska. Poszukiwanie odnawialnych źródeł energii, które są ekonomiczne, wydajne i czyste, ma kluczowe znaczenie. W tym celu przemysł przyjrzał się przyjaznemu dla środowiska wykorzystaniu energii odnawialnej pod wieloma kątami, w tym podczas zbierania plonów z chodników. Ważnym elementem jest wybór odpowiedniego obwodu zarządzania energią do pozyskiwania energii z generatora termoelektrycznego. Jednak większość obwodów do pozyskiwania energii (EH) dostępnych na rynku jest zwykle zaprojektowana do zastosowań związanych z pozyskiwaniem energii słonecznej. Komercyjne obwody EH mają zazwyczaj współczynnik MPPT wynoszący 0,7-0,85 dla ogniw fotowoltaicznych i 0,5 dla TEG. W rezultacie, jeśli jest używany ze źródłem termoelektrycznym, nie można uzyskać stabilnej mocy wyjściowej. Dlatego ten projekt ma na celu analizę obwodu EH, który jest przeznaczony do zbierania energii termoelektrycznej na nawierzchni asfaltowej oraz analizę wydajności zimnego rozruchu obwodu zarządzania energią. Aby potwierdzić wykonalność projektu pozyskiwania energii z generatora termoelektrycznego, projekt został przetestowany w laboratorium z nawierzchnią asfaltową. W oparciu o symulację wyników, IC SPV1050 jest w stanie w pełni naładować do 4 V w czasie od 3 do 8 sekund. Jednak LTC3105 może ładować się szybciej niż SPV1050 w czasie od 0,19 s do 0,21 s, ale jest w stanie osiągnąć tylko 2,4 V. Jednak wyniki eksperymentu laboratoryjnego pokazują, że SPV1050 jest w stanie ładować 4,1 V przez około 1 godzinę, podczas gdy LTC3105 nie może ładować do 44mV. Wyniki te pokazują, że układy scalone z zimnym rozruchem typu pompy ładującej są w stanie zwiększyć i naładować napięcie znacznie szybciej niż układy typu transformatorowego. Podsumowując, różnica w pozyskiwaniu energii przez układ scalony pod względem zimnego rozruchu, wykorzystania komponentów, problemów technicznych z płytką drukowaną itp. może wpłynąć na pożądany odczyt napięcia i przyspieszyć proces ładowania, aby pomóc zwiększyć wydajność obwodu zarządzania energią.*

***Abstract***. *The overriding challenge of our time is manifold from climate change, global energy shortages, and even environmental pollution. The search for renewable energy sources that are economical, efficient, and clean is vital. For this purpose, industries have looked at the environmentally friendly usage of renewable energy from many angles including in pavement harvesting. Choosing the right power management circuit for harvesting energy with a thermoelectric generator is an important element. However, most of the energy harvesting (EH) circuits on the market are typically designed to meet solar harvesting applications. Commercial EH circuits typically have an MPPT ratio of 0.7-0.85 for PV cells and 0.5 for TEG. As a result, if it is used with a thermoelectric source, a stable output cannot be obtained. Therefore, this project aims to analyze, an EH circuit that is designed for thermoelectric energy harvesting on asphalt pavement and to analyze the cold-start performance of the power management circuit. To confirm the feasibility of the energy harvesting project with a thermoelectric generator, the project has been tested in the laboratory with asphalt pavement. Based on the result simulation, IC SPV1050 is able to fully charge to 4V between 3 to 8s. However, LTC3105 is able to charge faster than SPV1050 between 0.19s to 0.21s but is only able to reach 2.4 V. However, the results in laboratory experiment show SPV1050 is able to charge 4.1 V for about 1 hour, while LTC3105 unable to charge to 44 mV. These results show that ICs with a charge pump type of cold start are able to boost and charge the voltage much faster than the transformer type. In conclusion, the difference in IC energy harvesting in terms of cold start, component use, technical issues from the circuit board and etc can influence the desired voltage reading and make the charging process faster to help increase the performance of the power management circuit.* (***Analiza obwodu zbierania energii dla systemu pozyskiwania energii termoelektrycznej (TEH) na nawierzchni asfaltowe****j*)

**Keywords:** energy harvester circuit, asphalt pavement, thermoelectric harvesting, SPV1050, LTC3105
**Słowa kluczowe**: obwód zbierania energii, nawierzchnia asfaltowa, zbieranie termoelektryczne, SPV1050, LTC3105

## Introduction

Thermoelectric generators (TEGs) are one of the harvesters that harvests electrical energy from heat energy based on the Seebeck effect. TEGs have numerous advantages, including design simplicity, the absence of moving parts, a long lifetime, long service life, and environmental friendliness. In a study by Jaziri et al., (2020) TEG is made of thermopiles that are connected to increase the power output. A voltage is generated when a temperature difference is established between the hot and cold ends of the semiconductor material [1]. Riffat & Ma, (2003) this voltage is referred to as the Seebeck voltage, and it is proportional to the temperature differential [2]

A power management integrated circuit (PMIC) is a circuit that controls power on electronic devices or in modules on devices that operate at different voltages. The PMIC is in charge of controlling battery charging and sleep modes, as well as DC-to-DC conversion and voltage scaling up and down. On PMICs, users can find low-dropout regulators (LDO), pulse-frequency modulation (PFM), pulse-width modulation (PWM), power FETs, and real-time clocks (RTC). A typical PMIC contains one or more switching DC-to-DC converters, such as buck or boost converters, and linear regulators, such as LDO. According to Twaha et al., (2016), the output voltage from the thermoelectric generator is low, so designing a circuit must have a power management circuit. It is made comprised of a DC-DC step-up converter. Several methods are mentioned that can be used to stabilize the voltage generated by the TEG to improve the system's overall performance. The selection of a DC-DC converter affects the overall performance of the system, so a proper criterion must be followed to select the best converter [3]. A DC-DC converter is a power electronic circuit designed to convert a direct current source from one voltage level to another. A DC-DC converter is required. to increase the output voltage obtained in the TEG. The Maximum Power Point Tracking (MPPT) algorithm can be integrated as well within the DC-DC converter to become a power management circuit [4][5][6][7]. These power management circuits (PMCs) are widely available in the market. However, most PMCs are designed to cater to solar harvesting where the MPPT ratio was set at 0.7-0.85 for PV cells. Other than that, cold start also plays an important role in a PMCs circuit where it is a start-up time to power on the IC for the boost converter [8] .

The important point in a boost converter system is the start-up voltage. To achieve a low start-up voltage, the transistor's threshold voltage must be low. The low threshold voltage, on the other hand, contributes to high transistor off-state leakage loss. The transient response of output voltage to reach a steady state is influenced by the start-up voltage. If a low start-up voltage can be achieved, the boost converter can be triggered in less time. The start-up time is the time interval for the transient period. According to Bose et al., (2019), the cold-start or start-up time is defined as the time it takes to turn on and start the primary boost converter by determining the ability of the low-power start-up voltage multiplier to power the inductive boost converter's start-up control circuits. While the rise time of the final output depends on the inductor current and the output load cap, most of the start-up time is consumed by the slow, low-voltage cold start. A cold-start circuit is needed to drive the voltage booster with a depleted storage element [9]. Another researcher by Scheidl & Pott, (2021) the cold-start circuit powerful way to boost the system, allowing it to self-sustain. The simplest implementation would be to drive the booster using the source signal. However, the supply frequently produces insufficient voltage to power the booster in the first place. One alternative is to use a mechanical switch. The mechanical switch, which is activated by random motion, is used for the initial cold start. For its higher impulse capability, a different energy domain (the mechanical domain) is used here from a theoretical viewpoint. However, after a cold start, the mechanical switch remains in the circuit and can prevent operation. Furthermore, this method is only applicable to inductive boost converters, which are typically not integrated. Following that cold-start method uses transformers, which have the advantage of achieving high efficiency after a cold-start with the same transformer. Inductors and transformers, on the other hand, generate magnetic fields that can interfere with other chip components and build large components that are incompatible with the desired form factor. Next, charge pumps are switched capacitor circuits that can provide very efficient conversion and are easily integrated. Charge pumps provide a method of boosting that uses only integrated parts and has a high achievable efficiency [8].

According to Yahya et al., (2020) thermoelectric generator can operate in electrical power generation mode, where TEG in power generation mode can create a voltage when there is a temperature difference (ΔT), where the side of TEG follows the seebeck effect [10]. The Seebeck effect occurs when there is a temperature difference that passes through a conductor and produces a voltage at the end of the conductor. Rohit et al,(2017) stated that the amount of power generated by the TEG is determined by the temperature difference between the TEG different sides ($\Delta T = T_{hot} - T_{cold}$). Heat is transferred to the other when one surface is kept at a higher temperature, reducing the temperature difference [10][11].

Therefore, these studies aim to analyze between two IC SPV1050 & LTC3105 in terms of time taken of charging voltage, and voltage boost output. These two IC also has different cold start method, charge pump, and transformer. By comparing these two cold start IC, the most suitable one to be used for thermoelectric energy harvesting at asphalt pavement. For the IC SPV1050 is an ultralow-power, high-efficiency energy harvester and battery charger that implements the MPPT function and integrates buck-boost converter switching elements [12]. The SPV1050 device allows for the charging of any battery or supercapacitor, including thin film batteries, by monitoring the end-of-charge and minimum battery voltages to prevent over-discharge and long-term battery life. Thus, LTC3105 is a boost converter optimized for high impedance, very low voltage input power source and allow for relatively high impedance, very low voltage input power sources. It allows to quick evaluate the LTC3105 boost converter and LDO regulator [13]. These two ICs will be used to improve low input voltage to the high output voltage of the energy harvesting system. This power management circuit will operate if the TEG input reaches up initial start-up to 0.5V for (SPV1050) and 0.25V for (LTC3105).

**Methodology**

This experiment was conducted in the Laboratory, the data readings for Temperature, open circuit voltage ($V_{oc}$),and voltage charging supercapacitor ($V_{CAP}$) will be monitored for 14400 seconds equal to 4 hours and the data readings were taken every 60 seconds (1 minute) by using Picolog (data for Temperature) and NI-DAQ data for $V_{oc}$ and $V_{CAP}$. Figure 1 shows the project setup that will be used in completing this project.

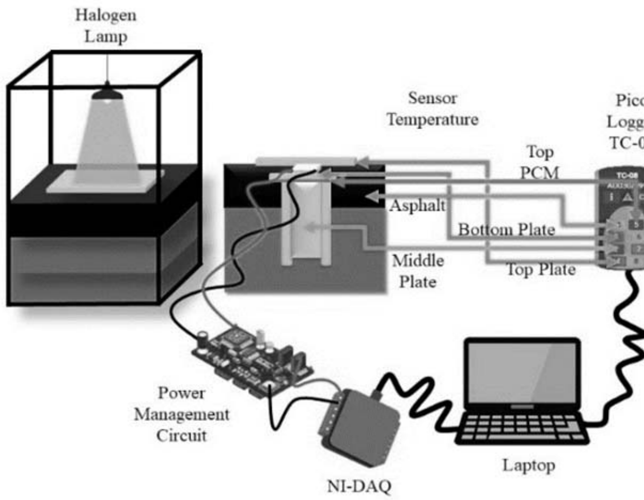


Fig. 1. Project Setup

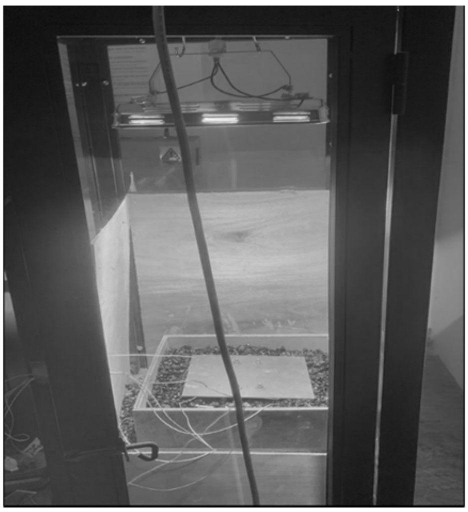

Fig. 2 Simulator box setup for the experiment

Figure 2 shows a simulator box was designed (500 mm x 1500 mm) that resembled the design of road construction by using 1000 W halogen lamps as a heat source. By using an aluminium type of size 150 x 200 mm (Top Plate) with a thickness of 2 mm, it works to absorb heat (top plate) from the temperature of the asphalt, the plate at the top used must be larger than the plate at the bottom so that it can touch the surface asphalt and can give a high-temperature difference. According to Khamil et al., (2020), the asphalt influenced the top plate (Temperature Hot), and the soil will remain constant. While the bottom plate measuring 100 mm x 200 mm will be welded together with the H-Shape to cool the TEG's cold part. This is due to the reason that the cold part of the TEG will work to cool and disperse the heat. The bottom of the plate will also be protected with foam to keep it from being in contact with the asphalt [14].

Three TEG type APH-127-10-25-S are cascaded in module on top another module in this project. According to Khamil et al., (2019), by cascading TEG in this manner provides a higher output temperature difference compared to cascaded side-by-side and single modules. And it can also provide a higher output value when connected with a power management circuit but on the condition that it needs to reach the start-up value of each IC to work [15]. This experiment also uses three TEGs connected in series. According to Yusop et al., (2014) series connection will allow the current to be high compared to a parallel connection and the TEG cascade connection allows an increase in voltage because the thickness of the TEG can affect the value of the voltage. So, the TEG module will be placed in the middle between the Top and bottom plate and clamped like a sandwich [16].

Result and Data Analysis

*i. Simulation Result*

The simulations are set to 30s and the input voltage was set to 500mV to evaluate how fast it can boost and charge the battery.

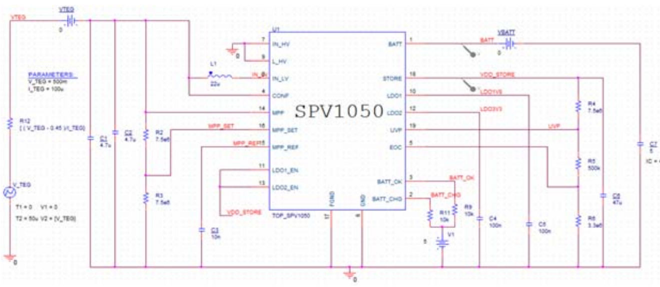


Fig. 3. Circuit Diagram for SPV1050

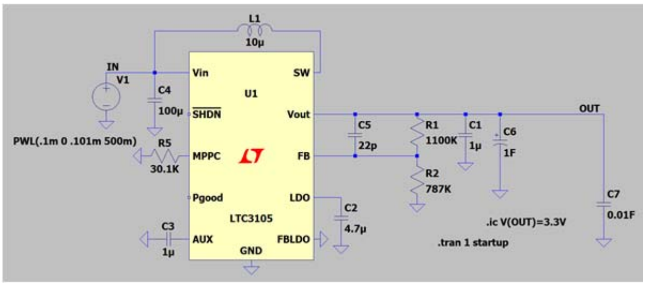


Fig. 4. Circuit Diagram for LTC3105

The current value of 100uA used for the simulation are taken from the real experiment value of Khamil et al., (2021) and the circuit used are shown in Figure 3 and Figure 4 [17].

Table 1. Comparison of IC SPV1050 and LTC3105 in simulation

| | | SPV1050 | | LTC3105 | |
|---|---|---|---|---|---|
| V TEG | Super capacitor | Voltage Output ($V_o$) | Time step to reach ($V_o$) | Voltage Output ($V_o$) | Time Step to Reach ($V_o$) |
| 500mV | 0.01F | 4V | 8s | 2.4V | 0.19s |
| 500mV | 0.1F | 4V | 4s | 2.4V | 0.20s |
| 500mV | 5F | 4V | 3s | 2.4V | 0.21s |

The output shows that the power management IC SPV1050 can reach 4V if employing 3 supercapacitors of 0.01F, 0.1F, and 5F when the TEG input is set to 500mV. The result show LTC3105 requires 1ms to reach a steady state to charge 0.1F, 0.01F, and 5F of supercapacitors in comparison to SPV1050. In transient analysis, the two very important parameters are the print step and final time. Hence, the time steps here in the simulation is not indicating the real-time in an experiment [18]. For use in small electronic devices, 3.3 V is required for the electronic device to operate. Based on the simulation circuit between the power management circuit (PMC) LTC3105 and SPV1050 shown in Table 1, it was found that the SPV1050 circuit has a higher charging voltage reading of 4V, compared to the LTC3105 IC which is only capable of 2.4 V [19]. For IC SPV1050, the pump charging method is used for the initialization of the power management circuit and will be in active mode when it reaches a value of 0.5V from the TEG source. According to Lee J et al., (2006), the charge pump circuit uses a capacitor to increase the low input voltage to get the higher output voltage. Because the TEG voltage is insufficient to start a simple electrical device, the boost converter can be started when the capacitor is charged up until the voltage level changes. Hence, the utilization of a charge pump in the power management circuit for energy harvesting TEG helps to make it possible for the start-up of a boost converter in a short interval of time [20].

While the LTC3105's initial start-up input is 0.25 V when using the cold start method transformer. According to Scheidl A et al., (2021), the use of a transformer will give the advantage of being able to achieve high efficiency after a cold-start process with the same transformer, by using a transformer it can control and stabilize the voltage transmission and transformers provide highly efficient and long-distance power transmission, which helps to step up the voltage to a higher level on the output [9] Hence, the cold start charge pump is much more suitable for environmental sensing. With that, the simulation results will be used as guidance for the next experimental investigation.

*ii. Temperature Result*

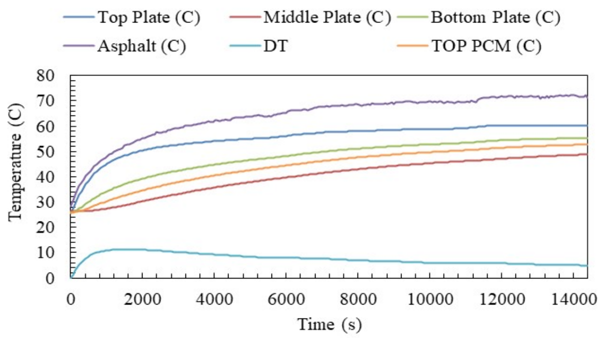


Fig. 5. Temperature profiles for a laboratory experiment.

As illustrated in Figure 5, the temperature during these 4 hours of the experiment increases continuously due to the effect of using the lamp as a heat source and in a controlled environment. The controlled environment was the simulator box as seen in Figure 2. Hence, the constant temperature.

Based on Table 2, the temperature on the Asphalt section increases rapidly when the lamp is turned on, which is close to 73 degrees Celsius for 4 hours, while the temperature between the top plate that is connected to the top of the TEG also increases by 61°C. The temperature difference between the top plate and the bottom plate influences the voltage increase in the TEG, during the experiment the temperature difference between the top plate and the bottom plate is only 12°C of DT. Due to the use of static lamps, it affects the temperature of the bottom plate, the Top PCM, and also the Middle plate. According to Khamil et al. (2021), the data from the paper show, if the experimental test in the field, the bottom of the Top PCM and the middle plate of the reading temperature will be lower than the TOP Plate and asphalt, and the DT will be higher than in the laboratory and it can affect the TEG voltage increase [20]. Figure 5 shows that the longer the time taken, the closer the temperature difference (DT).

Table 2. Temperature difference data TEHs in 4 hours

| SPV1050 & LTC3105 | | | | | |
|---|---|---|---|---|---|
| | Top Plate °C | Bottom Plate °C | Middle Plate °C | Asphalt °C | DT |
| Min | 25.252 | 25.712 | 26.382 | 25.123 | 0.015 |
| Max | 61.621 | 56.826 | 50.535 | 73.982 | 11.301 |
| Average | 56.272 | 49.289 | 41.887 | 65.641 | 7.007 |

*iii. Voltage Boost*

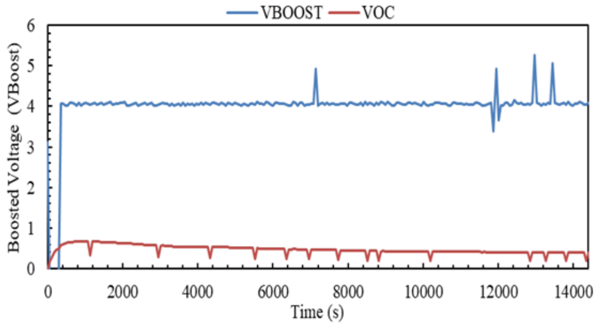


Fig. 6. Voltage Boost for IC SPV1050

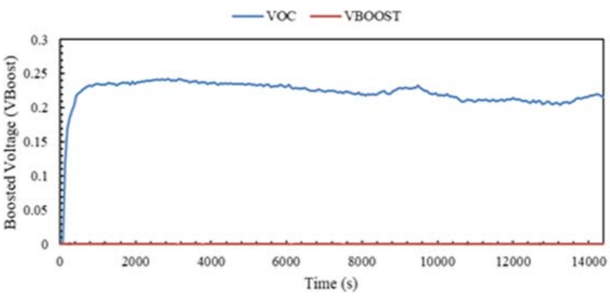


Fig. 7. Voltage Boost for IC LTC3105

Another function of the Power management Circuit is that it can step up and stabilize the output until the $V_{oc}$ is lesser than the minimum required [21]. As seen in Figure 6, from $V_{oc}$ has able to boost using SPV1050 to 4V, when $V_{oc}$ reached 500mV.While in Figure 7 illustrated the boost voltage using LTC3105 only reached 68mV when $V_{oc}$ is 0.25V.

Table 3. Comparison Voltage Boost between SPV1050 and LTC3105

| | SPV1050 | | | LTC3105 | | |
|---|---|---|---|---|---|---|
| | Min | Max | Ave | Min | Max | Ave |
| $V_{oc}$ (V) | -0.012 | 0.674 | 0.471 | 0.000 561 | 0.242 | 0.222 |
| Voltage boost (V) | -0.300 | 5.23 | 3.98 | - 0.000 41 | 0.001 | 0.000 68 |
| Time to Boost | 5 minutes | | | Not reached | | |

Table 3 shows the comparison voltage boost between SPV1050 and LTC3105. From that, IC SPV1050 can boost voltage until 5.23V for 5 minutes compared to IC LTC3105 which cannot boost at certain times.

*iv. Charging voltage*

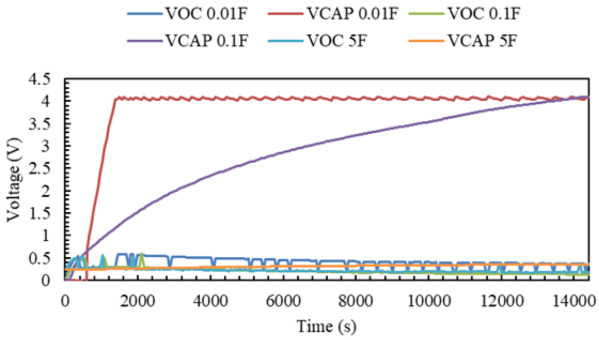


Fig. 8. Open circuit voltage from TEG and capacitor voltage for SPV1050

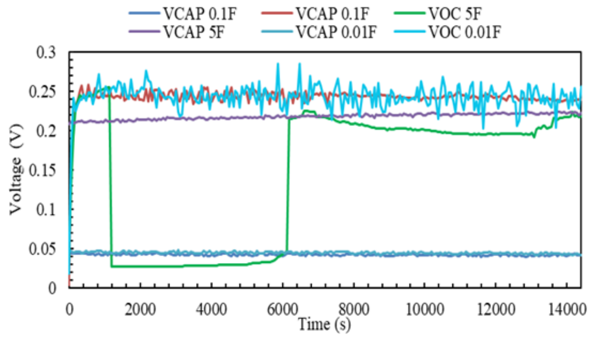


Fig. 9. Open circuit voltage from TEG and capacitor voltage for LTC3105

For this experiment, to investigate the charging capability between IC SPV1050 and LTC3105, 3 super capacitors were selected to be performed in this experiment. Among the supercapacitor, values are 5F, 0.1F, and 0.01F. Figure 8 and 9 shows the open circuit voltage ($V_{oc}$), and the charging voltage ($V_{cap}$),value according to the type of IC selected.

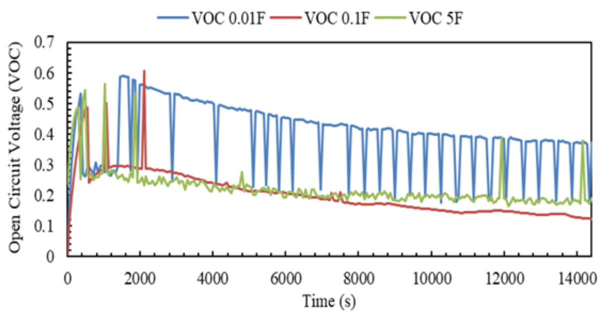


Fig. 10. Output voltage for SPV1050

Figure 10 above shows a graph for $V_{oc}$. For IC SPV1050, according to the datasheet when the $V_{oc}$ initial start-up reaches 500mV, the voltage drops and becomes unstable due to the supercapacitor, where the characteristic of supercapacitor will cause the voltage to change when the energy is delivered [22]. The supercapacitor will be in active mode and start the charging process until it reaches 4 V, and after the first start-up the input voltage from $V_{oc}$, can range between 150mV and 18V. The time taken for the charging process for IC SPV1050 is also 4 hours using a 0.01F supercapacitor [12].

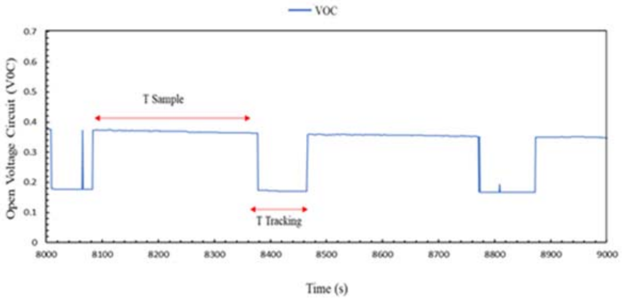


Fig. 11. Close-up view of the output open circuit voltage for SPV1050 MPPT (T-Tracking).

In addition, as can see from the graph Figure 11, when the MPPT mode is active, the SPV1050 IC will stop switching for 400 ms (sample time) every 16 seconds (tracking time). During the sample period, the IC SPV1050 will also reach a high impedance state and be stored on the $C_{REF}$ with a charging capacitor.

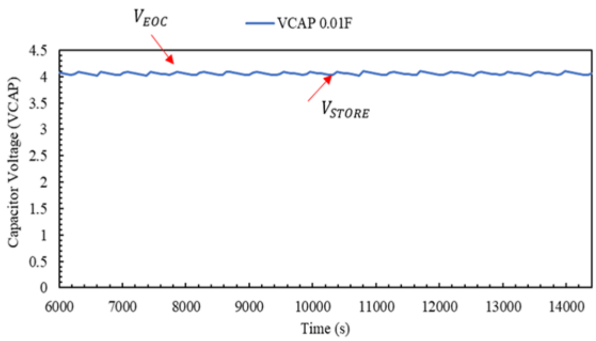


Fig. 12. Close-up view of the output voltage for SPV1050 when $V_{Eoc}$,pin trigger.

Figure 12 shows, DC-DC will therefore switch back after the sampling time has passed. The switching phase DC-DC converter also will be stopped once the voltage at the store pin triggers the $V_{Eoc}$ and continue until the $V_{Store}$ value drops below the internal hysteresis-defined threshold. It can be said that this process is a part of the MPPT algorithm.

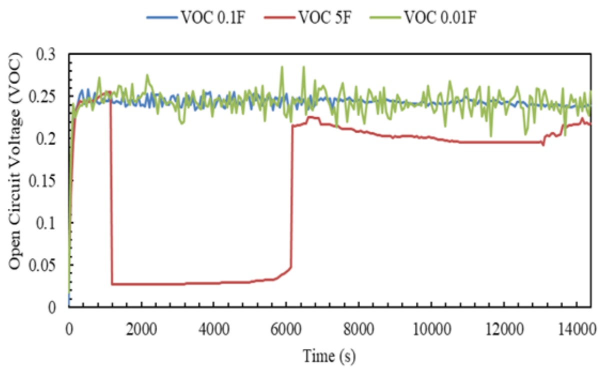


Fig. 13. Open circuit voltage, $V_{OC}$ for LTC3105

Table 4. Comparison between SPV1050 and LTC3105 in terms of Voltage Output ($V_O$)

| $V_{OC}$ (V) | SPV1050 | | | LTC3105 | | |
|---|---|---|---|---|---|---|
| | Min | Max | Aver | Min | Max | Ave |
| 0.01 F | 0.008 | 0.589 | 0.402 | 0.018 | 0.285 | 0.242 |
| 0.1 F | 0.012 | 0.605 | 0.204 | 0.003 | 0.258 | 0.242 |
| 5 F | 0.167 | 0.563 | 0.222 | 0.027 | 0.255 | 0.146 |

Figure 13 shows the result of $V_{oc}$, for LTC3105, just only able to reach 250mV. As the graph shows, due to process charging, the voltage seems unstable because of the effect of the supercapacitor.

Table 4 shows the comparison between the two IC in terms of voltage open circuit, As can be seen, the voltage open circuit for IC SPV can reach 500 mV, compared to IC LTC3105 which is only able to reach 250 mV. According to the datasheet of SPV1050, the open circuit voltage value is not stable due to the switching process of the charge pump. So, the experiments in the laboratory acquired the same result, that is why the $V_{oc}$ seems unstable.

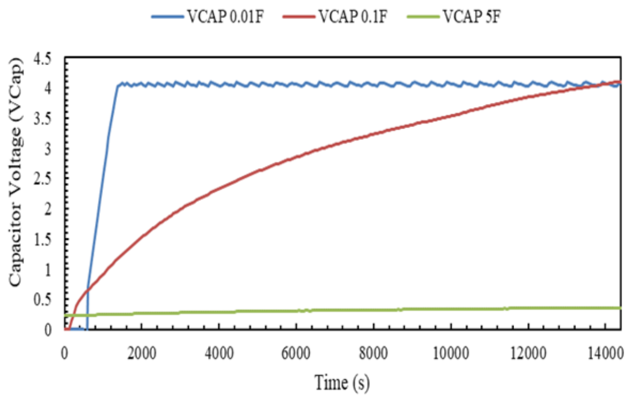


Fig.14 . Capacitor charging voltage for SPV1050.

As seen in Figure 14, from supercapacitor charging voltage has able to charge using SPV1050 to 4.1V when using 0.01F, and 0.1 F capacitors.

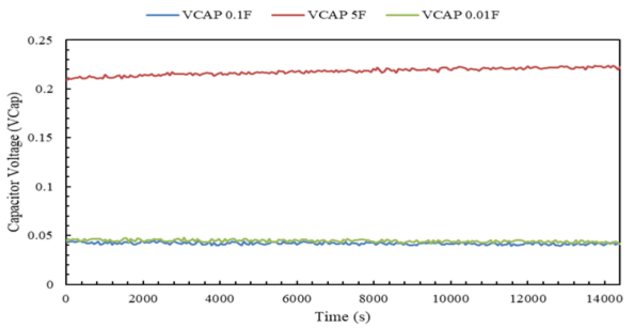


Fig.*15*. Capacitor charging Voltage for LTC3105.

While in Figure 15 illustrated the capacitor charging voltage using LTC3105 cannot be able to charge when using 0.01F, 0.1F, and 5F capacitors. Moving on, another power management circuit such as BQ25505, compared to Khamil et al. (2021), this power management circuit is also unstable but, after the supercapacitor store reaches 1.8V, the Open circuit voltage ($V_{oc}$) value will become more stable. Therefore, the time taken to charge the supercapacitor at 4 V is approximately 12 000 seconds, within 3.5 hours [20].

Table 5. Comparison between SPV1050 and LTC3105 in terms of Voltage charging

| $V_{cap}$ (V) | SPV1050 | | | LTC3105 | | |
|---|---|---|---|---|---|---|
| | Min | Max | Ave | Min | Max | Ave |
| 0.01F | -1.743 | 4.103 | 3.79 | 0.041 | 0.047 | 0.044 |
| 0.1F | 0.008 | 4.097 | 2.827 | 0.039 | 0.044 | 0.042 |
| 5F | 0.231 | 0.358 | 0.311 | 0.208 | 0.223 | 0.217 |

Based on Table 5, all results were obtained after completing the experiment. These 3 parameters of the supercapacitor have been chosen to investigate the charging result. As can see, the supercapacitor of 0.01F and 0.1F for IC SPV1050 are able to charge until it reached $V_{Eoc}$ which is ~4V, but for 5F, it is not able to charge, and the result does not achieve the target. It is different in the LTC3105 IC shown in Figure 19, where the three supercapacitors used are not capable of charging until they reach a $V_{Eoc}$ value of 3.3V [13].

Table 6.Time taken to reach Max $V_{Eoc}$ within 4 hours of experiments.

| | Time to reach Max $V_{EOC}$ | |
|---|---|---|
| | SPV1050 max (4 V) | LTC3105 (3.3V) |
| 0.01F | 1 Hour | Not reached |
| 0.1F | 3.75 Hour | Not reached |
| 5F | Not reached | Not reached |

Throughout the experiment, the data shown in Table 6, time was also taken to study the ability of each IC for the charging process according to the type of supercapacitor used. For the 0.01F supercapacitor, the time taken to charge ~4V is less than 1 hour compared to 0.1F, only 3.75 hours and the 5F supercapacitor does not reach the value of the charge. While for the LTC3105 type IC, the three supercapacitors cannot charge at the specified time. In addition to that, each power management circuit energy harvesting circuit has a different cold start, which it can affect the results during the process experiment. the SPV1050 IC uses a charge pump as a method to start up, while the LTC3105 IC uses a transformer, this method will affect the overall performance of each circuit used.

According to Abdelaziz et al. (2012), because the output from the Thermoelectric generator is very low, less than 1V, it cannot be used for power up in electronic devices, so the cold start method can help in raising low voltage to high voltage [23]. For IC SPV1050, the type of cold start used is the charge pump type, according to Peng et al. (2014) a type of DC-DC converter called a charge pump circuit, uses a switched capacitor technique to either raise or lower the input voltage level [24]. The charge pump also uses a capacitor to achieve high voltage, since the charge pump also helps to start the circuit to achieve from low input to get a higher voltage. Meanwhile, during the experiment using LTC3105 the performance of the cold start transformer make the IC not achieve the voltage to charge and reached the high voltage.

**Conclusion**

In a conclusion, this paper shows two IC SPV1050 and LTC3105 have successfully done real data from thermoelectric energy harvesting at asphalt pavement by using 3 supercapacitors (0.01F,0.1F,5F) to see the ability of the two IC in term of boost and charging. As a result, IC with the charge pump cold method manages to charge ~4V by using a supercapacitor 0.01F within 1 hour. While the LTC3105 which uses a transformer as a start-up method is not able to charge even after using 3 supercapacitors Therefore, since most of low power application is typically at 3.3V, SPV1050 proves to be more practical than LTC3105. The difference in IC energy harvesting in terms of cold start, component use, technical issues from the board and etc can have an effect on the desired voltage reading process, this matter needs to be done carefully in order to obtain the desired result. Besides, by using a thermoelectric energy harvester system, it can help give energy to the world to be well controlled without wasting it. It is very necessary because it is an environmentally friendly material and very reliable in forming energy that is able to provide convenience to humans.

***Acknowledgement*** *The authors would like to thank Centre for Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) for sponsoring this work.*

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