

Designing A Boost Converter to Maintain PV Output Under Different Irradiance Levels

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Abstract

The photovoltaic (PV) system is one of the most widely utilised renewable energy sources in the process of producing electricity. The incompatibility of the PV panels' performance as a result of climate change is a disadvantage of the system. Predicting the PV system's ideal power output at various irradiance levels is essential. The goal of this project is to improve the efficiency and stability of photovoltaic (PV) panels in renewable energy systems by designing and evaluating boost converter designs for it. The project describes the issue of variable irradiance levels and their effect on PV production, which demands the construction of adjustable boost converters. Two designs are investigated: one using a MOSFET driven by a pulse generator and the other using an IGBT controlled by PWM. Through simulation and analysis, the MOSFET arrangement shows excellent performance, constantly reaching high efficiency and nearly matching expected to power outputs. This finding emphasises the importance of component selection and control methods in booster converter design. The study closes by selecting the MOSFET arrangement as the ideal choice for practical implementation, opening the door for future hardware integration and enhancing efficiency and dependability in renewable energy systems.

1. Introduction

One of the most important sources of energy in the world is electricity, which is often generated via conventional approaches. However, traditional energy sources such as coal, oil, natural gas, and biomass contribute to global warming. When standard energy production technologies are employed, greenhouse gases and carbon dioxide are released [1] [2]. Renewable energy sources such as solar, wind, hydropower, biomass, and geothermal energy should be highlighted as additional clean, limitless, and competitive energy sources [2]. Malaysia is one of the countries transitioning to a zero-energy strategy [3]. Malaysia has committed to low-carbon development with the objective of altering the economic environment to make it more sustainable. In order to transition Malaysia's energy systems from fossil fuel-based to cleaner, low-carbon systems, the National Energy Transition Roadmap (NETR) has created the Responsible Transition (RT) Pathway 2050 [4] [11].

A rise of concerns about environmental issues such as global warming and energy security are leading to an increase in the number of photovoltaic (PV) producing systems being built. Step-up converters, also known as boost converters, are critical components of photovoltaic (PV) systems that optimize energy extraction and overall system efficiency [5]. PV systems may work successfully in a range of locations because of boost

converters, which ensure that the energy produced is efficiently harnessed and put to use for a variety of purposes [6]. They are especially crucial when the PV panels' output voltage is lower than the load or storage system's requirements.

Renewable energy systems rely greatly on photovoltaic (PV) technology, and PV cells must be precisely calculated to optimum their performance [7]. This review of the literature examines the state-of-the-art in parameter estimation for PV cells, with a focus on evolutionary approaches. The selected work under evaluation used evolutionary algorithms to identify open circuit, short circuit, and maximum power spots on the I-V characteristic curve and estimate parameters at those locations [7] [8]. In [9], the researcher discusses how to design and test the input capacitor of a DC-DC boost converter for solar-powered devices. To acquire the maximum power from a photovoltaic (PV) source, systems must be efficient. A DC-DC converter and the maximum power point tracking (MPPT) algorithm are used to achieve this [10].

2. Methodology

This section describes the methodology that is carried out through this paper, which consists of an overview of the project and the software and operating system needed to perform the project. This methodology describes the approach that will be taken to build the project, including the instruments, apparatus, procedures, and processes that are involved in the development and execution of the simulation. The DC-DC boost converter, which is made in the MATLAB application, is the method used to simulate sustaining the PV output under different irradiance levels.

2.1 Solar Irradiance and Temperature

Solar irradiation and temperature have a considerable impact on photovoltaic (PV) system performance. The study included data from a wide range of sun irradiation levels from 1000 W/m^2 to 100 W/m^2 and temperatures ranging from $35 \text{ }^\circ\text{C}$ to $26 \text{ }^\circ\text{C}$ as shown in Table 1. Tests were also done under standard test conditions, including 1000 W/m^2 irradiance and $25 \text{ }^\circ\text{C}$ temperature as shown in Table 1.

Table 1 Generated data of solar irradiance and temperature

Solar Irradiance (W/m^2)	Column B (t)
1000	25
1000	35
900	34
800	33
700	32
600	31
500	30
400	29
300	28
200	27
100	26

2.2 Boost Converter

A DC-DC boost converter circuit must be designed and simulated using certain parameters defined by mathematical calculations and power electronics knowledge. This section shows the parameters needed to create the DC-DC boost converter. Table 2 contains the specifications for the DC-DC boost converter that will be utilised in the simulation with MATLAB.

Table 2 The specification of the DC-DC boost converter

Parameter	Value
Input voltage, V_{in} (V)	18
Output voltage, V_{out} (V)	36
Output current, I_{out} (A)	3
Output power, P_{out} (W)	108
Switching frequency, f_{sw} (kHz)	25
Voltage ripple factor, r (%)	1

2.2.1 Duty Cycle

According to Table 2, the initial value of the voltage, V_{in} and the output voltage, V_{out} is 18V and 36V respectively. Therefore, by using the formula [13] from Equation (1), to calculate the duty cycle, D as shown below.

$$\text{Duty cycle, } D = 1 - \frac{V_{in}}{V_{out}} \quad (1)$$

2.2.2 Resistance

The resistance is calculated using Equation (2) [13] based on the provided power, P_{out} and output voltage, V_{out} :

$$P = \frac{V^2}{R} \quad (2)$$

2.2.3 Minimum Capacitance

By given the voltage ripple factor of $r = 1\%$ and the switching frequency, $f_{sw} = 25\text{kHz}$, the capacitance of the DC-DC boost converter is calculated using the formula [13] from Equation (3).

$$C = \frac{D}{rRf} \quad (3)$$

2.2.4 Minimum Inductance

Based on the switching frequency, $f_{sw} = 25\text{kHz}$ and the resistance of, $R = 12\text{ohm}$, the minimum inductance can be calculated using the formula [13] from Equation (4).

$$L_{min} = \frac{D(1-D)^2}{2f} \quad (4)$$

2.3 Software Simulation

Using MATLAB Simulink, software simulation has been done to finish the design project's functioning. A component included with MATLAB numerical computing software called Simulink is primarily used as a graphical programming tool. It is made up of several modular libraries that may be customized, offering a large deal of design flexibility for the system. Depending on how they work, each block has a certain function. The usage of this simulation software's primary goal is to create a dc-dc boost converter.

Moreover, in Fig. 1, the DC-DC boost converter design includes one MOSFET and one pulse generator. The parameter of the DC-DC boost converter is referred to in Table 2 as shown in the previous section. The pulse generator has a period set to $4\text{e-}5$ seconds with an initial pulse width of 50%. A more detailed explanation of the simulation results will be discussed in the next chapter. Furthermore, in Fig. 2, the DC-DC boost converter design includes one IGBT and one PWM. The parameter of the DC-DC boost converter is referred to in Table 2 as shown in the previous section. The PWM pulse is configured to have an initial pulse width of 50%.

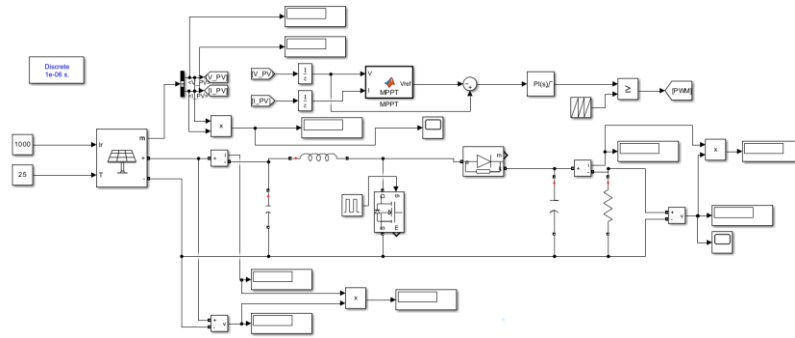


Fig. 1 Simulation of the DC-DC boost converter in MATLAB/Simulink using MOSFET

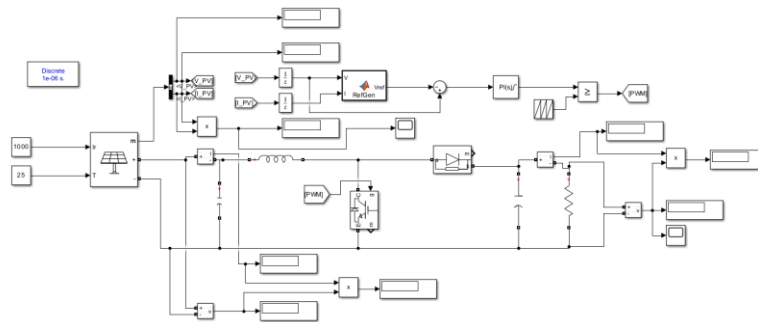


Fig. 2 Simulation of the DC-DC boost converter in MATLAB/Simulink using IGBT

A common boost converter does not use an input capacitor. However, when connecting a boost converter to a photovoltaic (PV) module, which operates similarly to a current source, the inclusion of an input capacitor is critical. This is important because the current from the PV module might fluctuate greatly, making it difficult to accurately determine the maximum power point (MPP). Furthermore, the boost converter is widely used for the MPPT converter, as described in the study [12]. To achieve best performance, an input capacitor must be connected in parallel with the boost converter's input source for the MPPT converter. According to research [12], without the input capacitor, the boost converter cannot work at the PV module's maximum power point, resulting in a lower power output. While an input capacitor is often included in an MPPT boost converter, it is sometimes removed, resulting in a substantial PV voltage ripple.

In order to regulate and filter out these oscillations, an input capacitor (C_{in}) is used. This capacitor serves to smooth the input current, minimising ripple and allowing for steadier and more precise MPP tracking, whereas the output capacitor (C_{out}) manages the voltage ripple at the boost converter's output.

2.3.1 User-defined PV Array in MATLAB/Simulink Software

The MATLAB/Simulink programme lacks prepared models for the precise rating and requirements needed for solar panels. As a result, it is necessary to explicitly define the properties of the 100W solar panel utilized in the simulation. The simulation will run under typical test settings, including $1000W/m^2$ irradiance and a temperature of $25^{\circ}C$. These circumstances correspond to the industry-standard test conditions (STC) for solar panels, allowing for a consistent and comparative evaluation of the panel's performance.

Furthermore, Fig. 3 depicts the precise configuration and layout of the solar panel module in the MATLAB/Simulink environment. This includes establishing the corresponding circuit characteristics, such as series and parallel resistances, which are required for properly replicating the solar panel's electrical behaviour. The solar panel's performance under normal test settings is assessed by illustrating the current-voltage (I-V) and power-voltage (P-V) characteristics. These graphs, illustrated in Fig. 4, give critical information about how the solar panel works. The I-V curve depicts how the current output varies with voltage, highlighting critical points such as the open-circuit voltage and maximum power point. The P-V curve, on the other hand, shows how the power output fluctuates with voltage, showing the panel's maximum power output under the given conditions.

Module data

Module:

Maximum Power (W)

Cells per module (Ncell)

Open circuit voltage Voc (V)

Short-circuit current Isc (A)

Voltage at maximum power point Vmp (V)

Current at maximum power point Imp (A)

Temperature coefficient of Voc (%/deg.C)

Temperature coefficient of Isc (%/deg.C)

Fig. 3 User_defined 100W module data

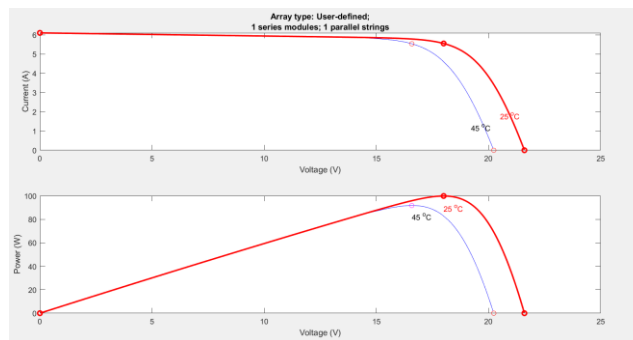


Fig. 4 I-V and P-V characteristics of the performance of the solar panel generated by MATLAB/Simulink software

3. Result and Discussion

Two setups of boost converters linked to photovoltaic panels are compared in here, one utilising an IGBT with PWM and the other utilising a MOSFET with a pulse generator.

3.1 Simulation Results and Voltage Increment Analysis for MOSFET with Pulse Generator Configuration

Significant voltage increases are seen in the results of simulations across a range of temperature and sun irradiation conditions as shown in Table 3. The input voltage of 17.38V boosts to 34.02V at standard test conditions (STC) of $1000W/m^2$ and $25^\circ C$, as shown by the simulation results of the boosted voltage output displayed in Fig. 5. This is a tremendous 95.74% increment. Additionally, under all measured conditions, the voltage increase exceeds 90% and is consistently high at lower irradiance levels and greater temperatures. This illustrates how well the boost converter arrangement performs in preserving output voltage stability

Table 3 Voltage Increment Analysis based on the generated data for MOSFET with Pulse Generator Configuration

Solar Irradiance (W/m^2)	Temperature ($^\circ C$)	Input Voltage, $V_i(V)$	Output Voltage, $V_o(V)$	Percentage Increment, (%)
1000	25	17.38	34.02	95.74
1000	35	17.10	33.46	95.67
900	34	15.94	31.15	95.42
800	33	14.39	28.04	94.86
700	32	12.72	24.69	94.10
600	31	11.01	21.27	93.19
500	30	9.29	17.81	91.75
400	29	7.55	14.32	89.77

300	28	5.79	10.79	86.48
200	27	4.01	7.23	80.36
100	26	2.07	3.50	69.00

Overall, the voltage increment analysis shows how well the boost converter design maximises the PV panel's voltage output. The configuration's appropriateness for practical photovoltaic applications is demonstrated by the steady and appreciable voltage increases as well as the accurate control made possible by the pulse generator. These results confirm that pulse generator control combined with MOSFET-based switching can enhance improve PV system dependability and efficiency in a variety of environmental situations.

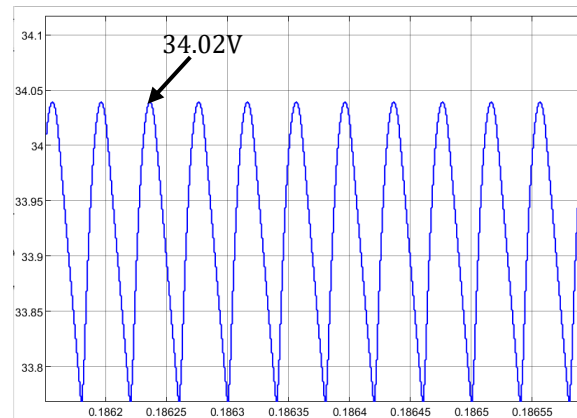


Fig. 5 Simulation of the output voltage for a MOSFET configured with a Pulse Generator under standard test conditions

3.2 Simulation Results and Voltage Increment Analysis for IGBT with PWM Configuration

Results from the simulation show significant voltage increases at all temperatures and solar irradiance levels as shown in Table 4, demonstrating the boost converter's capacity to sustain output voltage stability. The input voltage of 20.84V rises to 22.95V at standard test conditions (STC) of $1000\text{W}/\text{m}^2$ and 25°C , a significant 10.12% increase. The simulation results of the raised voltage output at STC are displayed in Fig. 6. In a similar way, the voltage increase maintains its high level at lower irradiance levels and greater temperatures, indicating the booster converter configuration's reliable performance under most conditions.

Table 4 Voltage Increment Analysis based on the generated data for IGBT with PWM Configuration

Solar Irradiance (W/m^2)	Temperature ($^\circ\text{C}$)	Input Voltage, V_i (V)	Output Voltage, V_o (V)	Percentage Increment, (%)
1000	25	20.84	22.95	10.12
1000	35	20.17	22.19	10.01
900	34	20.10	22.11	10.00
800	33	19.99	21.99	10.01
700	32	19.85	21.83	9.97
600	31	19.64	21.59	9.93
500	30	19.31	21.21	9.84
400	29	18.66	20.47	9.70
300	28	17.38	18.26	5.06
200	27	14.16	13.71	-3.18
100	26	7.60	6.99	-8.04

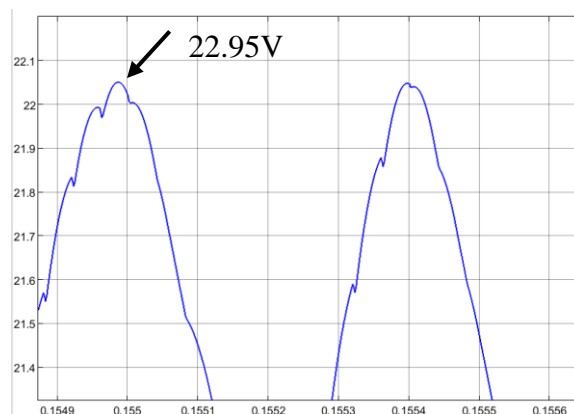


Fig. 6 Simulation of the output voltage for a MOSFET configured with a Pulse Generator under standard test conditions

However, at lower irradiance levels, namely $200W/m^2$ and $100W/m^2$, exhibit irregularities with the voltage increase displaying negative values of -3.18% and -8.04%, respectively. These variations point to difficulties in preserving voltage stability in particular environmental circumstances. Although these anomalies, the boost converter arrangement exhibits a general efficacy in enhancing voltage output throughout various circumstances, demonstrating its practical use in solar systems.

4. Conclusion

In conclusion, the study carried out went well in accomplishing its first objective, which was to develop a boost converter to maintain a steady output from a photovoltaic (PV) panel. The first arrangement, which used a MOSFET operated by a pulse generator, showed considerable voltage and power increases over a range of irradiance levels and temperatures. This setup regularly demonstrated good efficiency, with the simulated output power close to the expected maximum PV power output, resulting in a nearly 95% increase under standard test conditions (STC). This demonstrates that the design efficiently stabilizes and maximizes the power output from the PV panel, so achieving the project's primary objective. The project's next phase will involve developing the boost converter's hardware and ensuring that it can sustain PV production at all irradiance levels in the future. Furthermore, to ensure that the desired result will be achieved, the performance of the generated boost converter must be evaluated. Future work should focus on establishing this project's results into practice by implementing the preferred boost converter configuration in hardware. These initiatives, with continuing invention and improvement, can contribute to the larger objective of establishing sustainable and efficient energy solutions.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors are solely responsible for planning and designing the study, collecting data, analysing and interpreting results, and writing papers.

Appendix A: Data Sheet of Mono 100W PV Panel

柔性单晶太阳能电池组件规格书

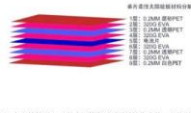
太阳能光伏组件材料来源：
 1.内部：晶硅太阳能电池片在P型硅片上生长N型硅片，2.表面采用0.2微米分子阻水剂膜材料透明导电膜ETC，3.背膜采用0.2微米分子阻水剂膜材料透明导电膜ETC，4.背面胶：我司提供的单晶硅太阳能电池片1年内输出功率不足，材料浪费(非人为损坏)情况，我司免费维修和更换。

MONO单晶数据	
Rated Cell (数量)	180cell
Maximum power (Pm) (最大功率)	100Wp
Maximum power voltage (Vmp) (最大功率电压)	18.0V
Maximum power current (Imp) (最大功率电流)	5.56A
Open circuit voltage (Voc) (开路电压)	21.6V
Short circuit current (Isc) (短路电流)	6.1A
Size of module (mm) (组件规格尺寸)	910*540*16mm
Weight per piece (kg) (单片重量)	2.4kg
Maximum system voltage (V) (最大系统电压)	600V
Temperature coefficient of Pm (%) (温度系数功率系数)	-0.46%/°C
Temperature coefficient of Voc (%) (温度系数开路电压系数)	-0.23%/°C
Temperature coefficient of Isc (%) (温度系数短路电流系数)	+0.51%/°C
Temperature coefficient of Pm (%) (温度系数功率系数)	-0.46%/°C
Temperature coefficient of Voc (%) (温度系数开路电压系数)	-0.23%/°C
Temperature coefficient of Isc (%) (温度系数短路电流系数)	+0.51%/°C
Temperature Range (工作温度范围)	-25°C~+65°C
Tolerance Voltage (e.g. ±5%) (容差电压)	±0.5%
Surface Maximum Load Capacity (组件表面承受最大负载力)	3600Pa(24mmHg)
Acceptable hail load (可接受冰雹)	soft ball fall down from 1m height (1.5米高度跌落)
Junction Box Type (接线盒类型)	ABC型(塑料)
Length of Cable (mm) (接线长度)	—
Cell Efficiency (%) (电池效率)	21.6%
Output tolerance (%) (输出功率公差)	±0.5%
Standard Test Conditions (标准测试条件)	AM1.5 1000W/m² 25°C
Warranty (产品质保)	5 years product warranty and 3 years 80% of power (5年质保, 功率在质保期内不低于80%)
Eff (%) (效率)	21.6%
Color (颜色)	option (选项, 蓝色)

外观规格标准

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- 无严重划痕、裂纹、气泡、异物、电池片错位;
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 1. AM1.5 1000W/m²
 2. 25°C
 3. 1000hPa
 4. 1000hPa
 5. 1000hPa
 6. 1000hPa
 7. 1000hPa
 8. 1000hPa

References

- Azhar, M., & Ullah, K. (2020, January 1). MCDM Analysis of Renewable and Conventional Energy Power Plants in Pakistan. *IEEE Xplore*. <https://doi.org/10.1109/iCoMET48670.2020.9073843>
- Bhatia, S. C., & Gupta, R. K. (2018). *Textbook of Renewable Energy*. In Google Books. Woodhead Publishing India PVT. Limited. https://books.google.com.my/books/about/Textbook_of_Renewable_Energy.html?id=i2NhwwEACAAJ&redir_esc=y
- C.-H. Shin, S. Lee, J. Kim, H. Nam, and Y. K. Jeong, "A Study on the Implementation of Economic Zero Energy Building according to Korea's Renewable Energy Support Policies and Energy Consumption Patterns," *IEEE Xplore*, Oct. 01, 2018. <https://ieeexplore.ieee.org/document/8539571>
- Transition of renewable energy policies in Malaysia: Benchmarking with data envelopment analysis. (2021). *Renewable and Sustainable Energy Reviews, 150*, 111456. <https://doi.org/10.1016/j.rser.2021.111456>
- Khatib, T. T. N., Mohamed, A., Amin, N., & Kamaruzzaman Sopian. (2010). An Efficient Maximum Power Point Tracking Controller for Photovoltaic Systems Using New Boost Converter Design and Improved Control Algorithm. *WSEAS Transactions on Power Systems, 5*(2), 53–63.
- Mena ElMenshawy, & Massoud, A. (2019). *Multimodule DC-DC Converters for High-Voltage High-Power Renewable Energy Sources*. <https://doi.org/10.1109/sgre46976.2019.9020690>
- Biswas, P. P., Suganthan, P. N., Wu, G., & Amaratunga, G. A. J. (2019). Parameter estimation of solar cells using datasheet information with the application of an adaptive differential evolution algorithm. *Renewable Energy, 132*, 425–438. <https://doi.org/10.1016/j.renene.2018.07.152>
- N., S., N., S., & B., I. R. (2020). Solar photovoltaic module parameter estimation with an enhanced differential evolutionary algorithm using the manufacturer's datasheet information. *Optik, 224*, 165700. <https://doi.org/10.1016/j.ijleo.2020.165700>
- Mostafa, H. H., & Ibrahim, A. M. (2019). Design and Analysis of DC-DC Converters with MPPT Controller based on Salp Swarm Algorithm for a Grid-Connected PV System. [https://doi.org/10.1109/mecon47431.20\(2\)19.9008173](https://doi.org/10.1109/mecon47431.20(2)19.9008173)
- Liu, Y., Liu, D., Chen, F., Liu, S., Xue, W., & Dang, H. (2021). Research on MPPT Control Method of IoT Terminal Photovoltaic Power Generation System Based on Disturbance Self-Optimization and Fuzzy Algorithm. *2021 IEEE Sustainable Power and Energy Conference (ISPEC)*. <https://doi.org/10.1109/ispec53008.2021.9735650>
- Standard Test Conditions (STC) of a Photovoltaic Panel*. (n.d.). Alternative Energy Tutorials. <https://www.alternative-energy-tutorials.com/photovoltaics/standard-test-conditions.html>
- Ayop, R., & Tan, C. W. (2018). Design of boost converter based on maximum power point resistance for photovoltaic applications. *Solar Energy, 160*, 322–335. <https://doi.org/10.1016/j.solener.2017.12.016>
- Hwu, K. I., & Yau, Y. T. (2014). High Step-Up Converter Based on Coupling Inductor and Bootstrap Capacitors With Active Clamping. *IEEE Transactions on Power Electronics, 29*(6), 2655–2660. <https://doi.org/10.1109/tpel.2013.2289387>