

Research Article

Effect of temperature on power output between floating and conventional PV systems

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ABSTRACT

Background: Photovoltaic (PV) solar power systems are gaining traction worldwide and represent a promising alternative for renewable energy generation. However, many studies have highlighted some disadvantages of installing and operating conventional solar power plants. Consequently, floating photovoltaic (FPV) systems have emerged as a new solar energy concept aimed at reducing the negative environmental impact caused by traditional photovoltaic system configurations. The floating photovoltaic (FPV) market has experienced impressive growth over the past decade, with global installed capacity doubling year-on-year.

Methods: The method of this study involves identifying each case and presenting its related mathematical model. The study aims to compare the performance of conventional photovoltaic modules and FPV systems. The principle is based on how the mathematical model directly influences global performance, with the relevant parameters integrated into the equation.

Results: This research employs the MATLAB Simulink platform to simulate the entire system and adapts the standard photovoltaic power generation model to the float-ing solar photovoltaic scenario. Based on the provided power and curves, it becomes straightforward to identify the best and most profitable PV system concerning the simulation conditions.

Conclusion: The results indicate that it is possible to achieve greater efficiency with the float-ing PV system due to the climatic conditions specific to the area where the PV system was installed.

Introduction

In the realm of renewable energy, photovoltaic (PV) systems stand out as a promising solution to meet the escalating global energy demand while mitigating environmental impacts (1-3). Two predominant configurations of PV systems have gained considerable attention: floating PV (FPV) and conventional PV (CPV) installations. Each presents unique advantages and challenges, catering to diverse environmental and spatial contexts.

FPV systems, a relatively recent innovation, involve installing solar panels on bodies of water such as reservoirs, lakes, or even the open sea (4). This concept not only maximizes land use efficiency but also offers additional benefits such as reduced water evaporation and improved water quality through decreased algae growth (5). According to recent statistics, floating PV installations have witnessed exponential growth, with an estimated cumulative capacity exceeding 2.6 GW globally by 2020. Countries like Japan, South Korea, and China, spurred by environmental consciousness and land scarcity, have spearheaded the adoption of floating PV technology, accounting for a significant portion of the installed capacity (6, 7).

On the other hand, CPV systems, characterized by ground-mounted or rooftop installations, have been the staple of solar energy deployment for decades. These systems are typically deployed on open land or built structures, offering flexibility in location and scalability. As of 2022, conventional PV installations had dominated the solar energy landscape, boasting a cumulative capacity of over 800 GW worldwide. Countries like Germany, the United States, and India have embraced conventional PV technology as a cornerstone of their renewable energy transition, leveraging its mature infrastructure and proven reliability to drive substantial reductions in carbon emissions and fossil fuel dependency (8).

In this discourse, the focus is on the comparative analysis of floating and conventional PV systems, exploring their respective merits, challenges, and socio-economic implications of their widespread adoption. By elucidating the distinctive attributes of each approach

and contextualizing them within the broader energy landscape, the aim is to inform strategic decision-making towards a sustainable and resilient energy future.

The remainder of the paper is structured as follows: Section 2 covers the methodology implemented; Section 3 presents the results obtained, and Section 4 discusses these results. Finally, the concluding section presents the conclusions drawn from the study.

Method

Floating photovoltaic system

The FPV systems represent a transformative approach to solar energy deployment, capitalizing on underutilized water bodies to harness solar power. These systems offer several distinct advantages over conventional PV installations, making them an increasingly attractive option for governments, utilities, and project developers worldwide. The following are a few of the main advantages of floating solar PV:

Land conservation

FPV systems effectively address the challenge of land scarcity, especially in densely populated areas or regions where suitable land for solar installations is limited. By utilizing water surfaces such as reservoirs, ponds, or even coastal areas, FPV systems circumvent the need for large tracts of land, thus preserving valuable terrestrial ecosystems and agricultural land (9).

Enhanced energy generation

The cooling effect of water bodies on solar panels can enhance the efficiency of FPV systems compared to their land-based counterparts. Studies have shown that the lower operating temperatures achieved in floating installations can lead to a modest increase in energy generation, particularly in regions with high ambient temperatures (10, 11).

Synergies with water infrastructure

Floating PV systems can be integrated synergistically with existing water infrastructure, such as hydropower reservoirs or wastewater treatment ponds. Co-locating FPV arrays with water facilities offers dual benefits, including optimized land use, reduced water evaporation, and improved water quality management through shading, thereby enhancing the overall sustainability of water resources.

Environmental benefits

Beyond energy generation, FPV systems offer environmental co-benefits, including reduced carbon emissions, mitigation of water evaporation, and inhibition of algae growth in water bodies. Moreover, by repurposing idle water surfaces for renewable energy production, floating solar contributes to climate change mitigation efforts and supports biodiversity conservation (12).

Economic viability

While initial investment costs for FPV systems may be higher compared to conventional PV installations, the potential for cost savings in land acquisition and transmission infrastructure can make floating solar economically competitive, particularly in areas where land prices are prohibitively high. Additionally, FPV projects may qualify for incentives and subsidies aimed at promoting renewable energy deployment, further bolstering their financial attractiveness.

Global expansion

The adoption of floating PV technology has witnessed rapid global expansion, with projects proliferating across various geographical regions. Countries with abundant water resources and ambitious renewable energy targets, such as China, Japan, and the United States, have emerged as frontrunners in FPV deployment, driving innovation and scalability in the sector (13).

Technological advancements

Continued research and development efforts are driving technological advancements in floating PV systems, including improvements in float design, anchoring mechanisms, and system durability. Innovations such as dual-use platforms combining solar energy generation with aquaculture or water treatment further enhance the multifunctionality and economic viability of FPV installations.

Figure 1. gives the different floating PV system architecture.

Pure floats, on which photovoltaic modules are fixed directly; Modular rafts, in which the floater is attached to a structural framework that supports the panel; A buoyant tubular ring supports membranes, where panels are affixed to a reinforced membrane.

Conventional photovoltaic system

CPV systems, comprising ground-mounted and rooftop installations, have been the cornerstone of solar energy deployment for decades, offering proven reliability, scalability, and versatility (8). These systems leverage available land resources, urban spaces, and rooftops to harness solar energy efficiently. Key characteristics and advantages of conventional PV systems include:

Scalability and flexibility

Conventional PV systems offer unparalleled scalability, allowing for installations ranging from small residential rooftops to utility-scale solar farms covering vast expanses of land. This flexibility enables tailored solutions to meet diverse energy needs, whether for individual households, commercial buildings, or large-scale power generation projects.

Established infrastructure

With a mature and well-established supply chain, conventional PV systems benefit from readily available components, standardized installation practices, and a robust ecosystem of manufacturers, developers, and service providers. This infrastructure ensures reliable performance, ease of maintenance, and widespread accessibility, contributing to the mainstream adoption of solar energy technologies.

Geographic diversity

Conventional PV systems can be deployed across a wide range of geographical locations, from sun-drenched deserts to temperate climates and urban environments. This geographic diversity enables solar energy to be harnessed effectively across various regions, thereby diversifying energy sources, enhancing energy security, and reducing reliance on fossil fuels.

Rooftop potential

Rooftop solar installations offer a decentralized approach to energy generation, utilizing underutilized urban spaces to harvest solar energy closer to the point of consumption. By leveraging rooftops of residential, commercial, and industrial buildings, conventional PV systems can reduce transmission losses, alleviate grid congestion, and empower consumers to become prosumers, contributing to a more resilient and distributed energy infrastructure.

Cost competitiveness

Advancements in PV technology, coupled with economies of scale and declining manufacturing costs, have significantly enhanced the cost competitiveness of conventional PV systems. The leveled cost of electricity (LCOE) from solar photovoltaics has witnessed a steep decline, making solar energy increasingly cost-competitive with conventional fossil fuel sources in many parts of the world.

Job creation and economic growth

The widespread deployment of conventional PV systems has catalyzed job creation and economic growth across the solar value chain, from manufacturing and installation to operations and maintenance. As solar energy becomes an integral part of the global energy mix, it stimulates investments, fosters innovation, and generates employment opportunities, thereby contributing to sustainable economic development (15) Table 1.

Mathematical modeling

A photovoltaic (PV) module comprises multiple solar cells connected either in parallel or in series. These cells work to convert solar energy into electrical power. Various models of solar cells exist (16), with one of the most commonly used being a single diode model connected to a parallel resistor known as the shunt resistor (R_{sh}) and a serial resistor (R_s) Figure 2. This model is used in our study for evaluating the performance of the PV panel (17).

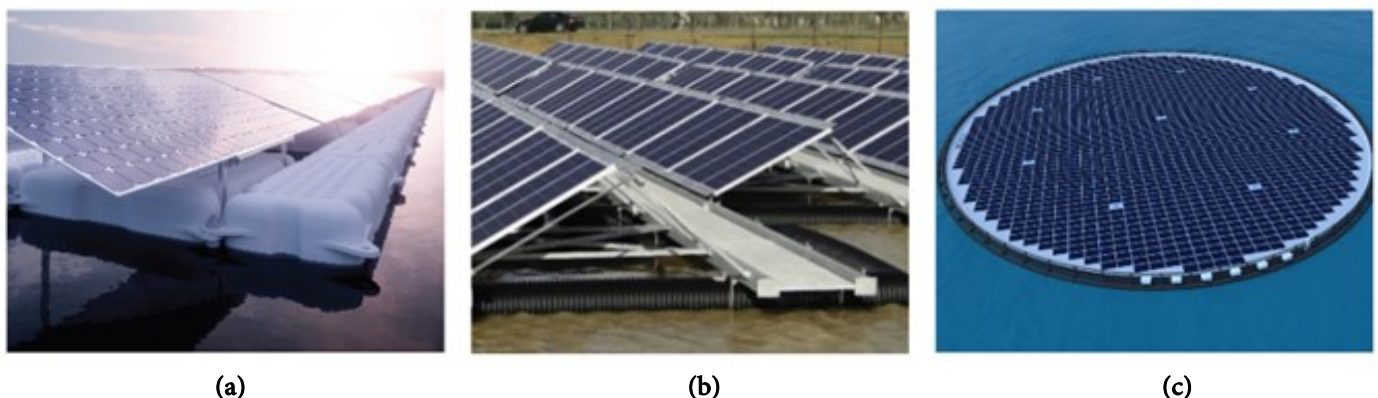


Figure 1. Different architectures of FPV systems: (a) pure raft, (b) modular float, and (c) membranes.

Table 1. the case of 100 KW needed power with the floating or the conventional PV

Aspect	Floating PV System	Conventional PV System
Efficiency	15-20%	16-22%
Robustness	Moderately robust	Highly robust
Prices	\$0.80 - \$1.20 per watt	\$0.60 - \$1.00 per watt

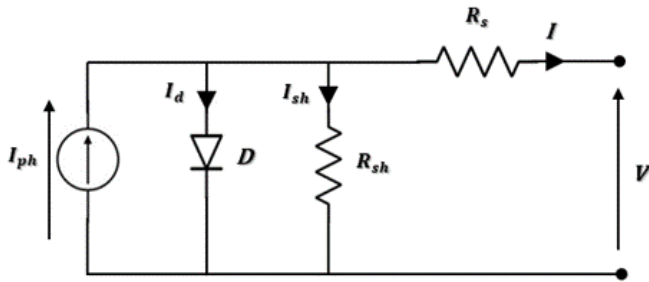


Figure 2. PV cell equivalent circuit.

The output current of a solar cell is defined by equation 1, where I_{ph} represents the photocurrent and I_0 signifies the reverse saturation current of the diode.

These variables can be expressed using equations (2) and (3) respectively, where V and I denote the output voltage and current of the PV cell. I_{sc} denotes the short-circuit current at the reference condition, G and T represent irradiance (W/m^2) and temperature (K) respectively. I_{rs} represents the saturation current at the reference temperature, K_i stands for the short-circuit temperature coefficient, T_n denotes the nominal temperature (K), a is the diode ideality factor, E_g represents the band gap energy, K represents Boltzmann's constant ($1.38 \times 10^{-23} \text{ J/K}$), and q signifies the electron charge ($1.6 \times 10^{-19} \text{ C}$).

$$I = I_{ph} - I_0 \left(\exp \left(\frac{V + I R_s}{V_t} \right) - 1 \right) - \left(\frac{V + I R_s}{R_{sh}} \right) \quad (1)$$

$$I_{ph} = (I_{sc} + k_i \cdot (T - T_n)) \cdot \frac{G}{G_n} \quad (2)$$

$$I_0 = I_{rs} \left(\frac{T}{T_n} \right)^2 \exp \left(\left(\frac{q E_g}{a K} \right) \left(\frac{1}{T_n} - \frac{1}{T} \right) \right) \quad (3)$$

The mathematical model for a PV module, consisting of N_s cells in series and N_p cells in parallel (18), can be expressed as follows (4):

$$I = N_{pp} \cdot I_{ph} - N_{pp} \cdot I_0 \left(e^{\left(\frac{N_{pp} V + N_{ss} I R_s}{a V_t N_{ss} N_{pp}} \right)} - 1 \right) - \frac{N_{pp} V + N_{ss} I R_s}{N_{ss} R_{sh}} \quad (4)$$

Furthermore, the mathematical equation for calculating power generation from the floating PV is thus in equation (5):

$$P = P_{STC} \times (1 + k_p(T - 25)) \times F_g \quad (5)$$

Where:

P_{STC} is the total array power (kWp) at standard test conditions (STC at $G = 1000 \text{ W/m}^2$ and $T = 25^\circ\text{C}$); T is the PV module temperature; G is the irradiance value ($\text{kWh/m}^2/\text{day}$); k_p is the temperature coefficient; and with $F_g = \frac{G}{1000}$.

Results

In this section, the simulation results of the two systems are presented to verify their efficacy. The simulations are carried out using the MATLAB/Simulink platform, chosen for its precision and ease of use.

The parameters of the PV module employed in this research are detailed in Table 2.

The achievable generation power is 100 kW. According to MATLAB Simulink, the maximum power output of an ideal solar panel is 435,213W. So, to meet the required power output,

the total number of solar panels needed can be calculated as follows: $100,10^3 / 435,213 = 229.77$

$$\approx 230 \text{ Panels}$$

The characteristics of the PV module under various values of temperature and solar irradiation are illustrated in Figures. 3 and 4.

Table 2 PV panel specifications: SUNPOWER SPR-435NE-WHT-D

Parameters	Values
Voltage at MPP (V_{mpp})	72.9 (V)
Current at MPP (I_{mpp})	5.97 (I)
Open-circuit voltage (V_{oc})	85.6 (V)
Short-circuit current (I_{sc})	6.43 (I)
Maximum power (P_{mpp})	435.213 (W)
Ideality factor (a)	1.0252
Boltzmann constant (K)	$1,38 \cdot 10^{-23} \text{ J/K}$
Band gap energy E_g	1.2 eV
Temperature coefficient of I_{sc}	0.0193
Temperature coefficient of V_{oc}	-0.326
Number of cells	128
Internal series resistance of a cell (R_s)	0.36845 (Ω)
Internal parallel resistance of a cell (R_{sh})	395.6428 (Ω)

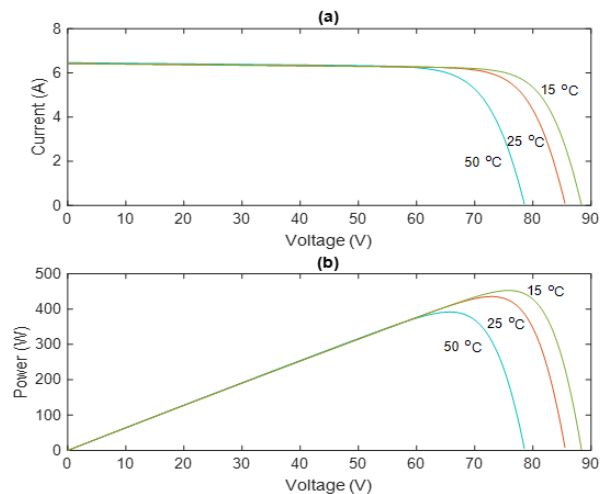


Figure 3. (a) I-V characteristic curves of the PV module under varying temperatures at an irradiance level of $G=1 \text{ kW/m}^2$. (b) P-V characteristic curves of the PV module under identical condition

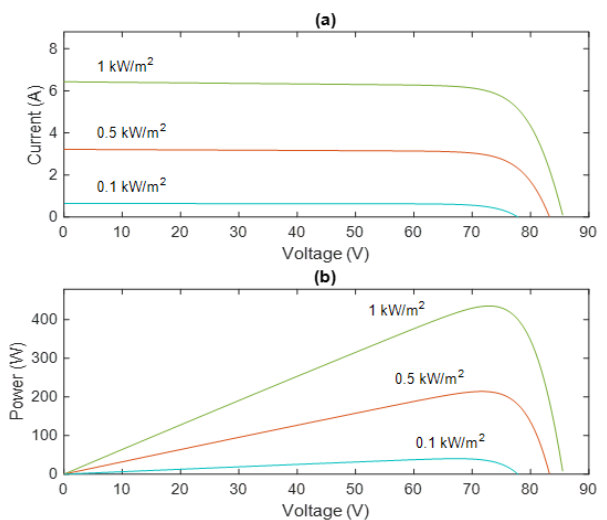


Figure 4. (a) I-V curves for various irradiation levels at a temperature of $T=25^\circ\text{C}$. (b) P-V curves under the same conditions.

Discussion

Based on the tests made through the simulation tool and by using the technical specifications cited in Table 2. The comparison results of the two types of PV were summarized in Table 3.

The measured temperature for the two locations was calculated as 28 °C and 29.3 °C. All tests were made in Tunisia, at the Djerba city location.

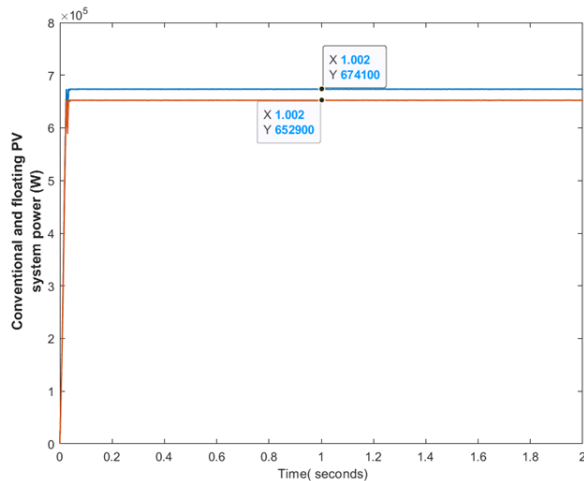


Figure 5. Output power of conventional PV and floating PV system.

Table 3. Comparison of conventional and Floating PV

	Power production (W)	Average irradiation (kWh/m ² /day)	Medium Temperature	Location	Position of panels
Conventional PV	6,741. 10 ⁵	6415,2	28°C	Djerba (Tunisia)	First Floor
Floating PV	6,529. 10 ⁵	6655,2	29.3°C	Djerba (Tunisia)	Flat Water tank

Figure 5 shows the power outputs of the CPV and FPV systems. The output from the CPV is represented by the orange, and the FPV output corresponds to the blue.

From the above figure, it can be observed that the FPV has higher total power (6,741. 10⁵ kW) gain than the conventional PV (6,529. 10⁵ kW). When the temperature rises, the performance of the solar panels decreases. This is mainly due to the nature of photovoltaic cells, which are more efficient at lower temperatures. As the temperature increases, the output voltage of the cells decreases, reducing the overall power of the system.

Floating photovoltaic systems tend to be less sensitive to temperature rises than conventional systems. This is due to the natural cooling capacity offered by the water under the floating panels, which can help maintain a lower temperature compared to conventional panels exposed to air.

Conclusion

An FPV system is a solar photovoltaic application in which photovoltaic modules are designed and installed to float on a body of water. Today, FPV systems represent a new way of utilizing solar energy systems that overcomes the limitations of GPV systems, such as the need for land.

This study describes both conventional PV and floating PV systems in the MATLAB-Simulink environment. The simulation results show that the production capacity of the FPV system is higher than that of the GPV system.

In summary, although temperature has a negative effect on the output power of photovoltaic systems, floating systems can benefit from better heat dissipation compared to conventional systems, which can slightly mitigate this effect.

Competing interests

The authors declare no competing interest.

Authors contributions

A Flah, C. Saad, , developed the research concept; and designed the data collection process; analysis of the data, and drafted the study reports. A. Flah provided academic guidance and continuous supervision, reviewed the study.

Data information

No data to be share

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References

- Ateş AM. Unlocking the floating photovoltaic potential of Türkiye's hydroelectric power plants. *Renew Energy* [Internet]. 2022;199:1495–509. Available from: doi: 10.1016/j.renene.2022.09.096
- Masenge IH, Mwasilu F. Modeling and control of solar PV with battery energy storage for rural electrification. *Tanzania Journal of Engineering and Technology* [Internet]. 2020;39(1):47–58. doi: 10.52339/tjet.v39i1.518
- Praveen kumar B, Prince Winston D, Pounraj P, Muthu Manokar A, Sathyamurthy R, Kabeel AE. Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method. *Desalination* [Internet]. 2018;435:140–51. doi: 10.1016/j.desal.2017.11.007
- Hafeez H, Kashif Janjua A, Nisar H, Shakir S, Shahzad N, Waqas A. Techno-economic perspective of a floating solar PV deployment over urban lakes: A case study of NUST lake Islamabad. *Sol Energy* [Internet]. 2022;231:355–64. doi: 10.1016/j.solener.2021.11.071
- Chowdhury R, Aowal MA, Mostafa SMG, Rahman MA. Floating solar photovoltaic system: An overview and their feasibility at kaptai in rangamati. In: 2020 IEEE International Power and Renewable Energy Conference. IEEE; 2020.
- Micheli L, Talavera DL, Marco Tina G, Almonacid F, Fernández EF. Techno-economic potential and perspectives of floating photovoltaics in Europe. *Sol Energy* [Internet]. 2022;243:203–14. doi: 10.1016/j.solener.2022.07.042
- Abid M, Abid Z, Sagin J, Murtaza R, Sarbasov D, Shabbir M. Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries. *Int J Environ Sci Technol (Tehran)* [Internet]. 2019;16(3):1755–62. doi: 10.1007/s13762-018-2080-5
- Allouhi A, Rehman S, Buker MS, Said Z. Up-to-date literature review on Solar PV systems: Technology progress, market status and R&D. *J Clean Prod* [Internet]. 2022;362(132339):132339. doi: 10.1016/j.jclepro.2022.132339
- Justo JJ, Mushi AT. Performance analysis of renewable energy resources in rural areas: A case study of solar energy. *Tanzania Journal of Engineering and Technology* [Internet]. 2020;39(1):1–12. doi: 10.52339/tjet.v39i1.514
- Floating PV plants [Internet]. Elsevier; 2020. doi: 10.1016/c2018-0-01890-3
- Nisar H, Kashif Janjua A, Hafeez H, Shakir S, Shahzad N, Waqas A. Thermal and electrical performance of solar floating PV system compared to on-ground PV system-an experimental investigation. *Sol Energy* [Internet]. 2022;241:231–47. doi: 10.1016/j.solener.2022.05.062
- Claus R, López M. Key issues in the design of floating photovoltaic structures for the marine environment. *Renew Sustain Energy Rev* [Internet]. 2022;164(112502):112502. doi: 10.1016/j.rser.2022.112502
- Silalahi DF, Blakers A. Global atlas of marine floating solar PV potential. *Solar* [Internet]. 2023;3(3):416–33. doi: 10.3390/solar3030023
- Kim J, Rabelo M, Padi SP, Yousuf H, Cho E-C, Yi J. A review of the degradation of photovoltaic modules for life expectancy. *Energies* [Internet]. 2021;14(14):4278. doi: 10.3390/en14144278
- El Mouatamid A, Ouladsine R, Bakhouya M, Felix V, Elkamoun N, Zine-Dine K, et al. Modeling and performance evaluation of photovoltaic systems. In: 2017 International Renewable and Sustainable Energy Conference (IRSEC). IEEE; 2017.
- Elmouatamid A, Bakhouya M, Ouladsine R, El kamoun N, Zine-Dine K, Khaidar M, et al. Deployment and experimental evaluation of micro-grid systems. In: 2018 6th International Renewable and Sustainable Energy Conference (IRSEC). IEEE; 2018.
- Dhillon J, Unni A, Singh N. Design and simulation of a PV system with battery storage using bidirectional DC-DC converter using matlab Simulink. In: 2022 1st International Conference on Sustainable Technology for Power and Energy Systems (STPES). IEEE; 2022.