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Article

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Improving Photovoltaic Systems in Jordan Using TRIZ Principle - Overview and Case Study

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ABSTRACT

Buildings, both residential and commercial, continue to be a major source of energy consumption in the world due to the escalating rate of global energy demand. Energy supplied to buildings through conventional means negatively impacts the environment. Due to its geographic location and climatic conditions, Jordan has high solar energy potential. This encouraged using photovoltaic panels on building envelopes to produce electricity. One of the major problems facing this technology is the performance of the installed systems. In this context, this paper adapted the Theory of Inventive Problem Solving (also known as TRIZ) to improve the performance of photovoltaic systems; with less cost, less time, less installation place, and high output power. TRIZ principle was applied to a case study of an existing photovoltaic system in Jordan in order to study the impact of materials used in PV cells construction on a PV system's performance. The analysis of the results shows the potential of increasing the energy produced by changing the material of the PV cells. Economic analysis was also carried out for the suggested PV systems.

Keywords: TRIZ, Performance, System Prediction and Forecasting, Photovoltaic, Cell Material
JEL Classifications: O16, Q20, Q41, Q42, Q55

1. INTRODUCTION

Jordan is one of the most countries in the world that depends on foreign energy sources to provide 96% of its energy needs (Sandri et al., 2020, Al Asfar et al., 2021). Jordan is a non-fossil fuel-producing country but has abundant supplies of RE sources including solar and wind energy sources (Mohsin et al., 2018, Alfattah et al., 2017). The use of PV systems to produce electricity has increased during the last few years. Developing new efficient photovoltaic systems is important for improving their performance. Trial and error technique was the only method used in the past. As time is passing, several new methods have been developed such as linear extrapolation, morphological method, Delphi and TRIZ methods. Theory of Inventive Problem Solving (TRIZ) in general, is used in two situations: either to solve a specific immediate problem or to forecast how a specific technology will evolve in the future to create next-generation technologies based on possible evolutionary paths (Duran-Novoa et al., 2011). TRIZ is superior to previous methods; since traditional technological forecasts deal with parameters (e.g., speed, power, etc.) rather than with structures, that are capable of realization of these parameters.

On the other hand, TRIZ methodology will lead to a relatively limited number of different solution ideas compared to conventional creative methodology such as brainstorming. TRIZ allows heuristic thinking on a problem as well as systematic way; since it provides knowledge extracted from many high-level inventions (Yan et al., 2022). As a method, TRIZ examines all contradictions and solutions present in a project in order to identify and address them (García-Manilla et al., 2019).

Genrikh Saulovich Altshuller Henry Altshuller (Altshuller, 1999), who created TRIZ principle, studied TRIZ as a problem-solving methodology based on a systematic approach that was developed from reviewing thousands of patents and analysis of technology evolution over a period of several decades. He showed that TRIZ can be used as a powerful intellectual instrument to solve simple and difficult technical problems, more quickly with better results.

TRIZ has many important advantages, which can be discussed. This method is excellent in developing future-oriented technological innovation strategies that lead to creating engineering solutions that suit customer needs (Uyar and Öztürk, 2019) including but limited to reducing the negative environmental effects of the products (Maccioni and Borgianni, 2019). Furthermore, TRIZ helps in developing new urban transportation (Donnici et al., 2019) and business problem structuring (Phillips and Kenley, 2019). In the renewable energy field, TRIZ was used to analyze the priorities of customer expectations for renewable energy investments (Li et al., 2021), inventive principles for the analysis of similarities and differences in inventive thinking in the field of solar cell modules comparing Japanese and European engineers (Moehrle and Paetz, 2014). Analysis of the Constituent Elements in the Design of Solar Photovoltaic Products (Hong, 2019) designing tracking irradiance of surface plane of umbrella orientations (Chao and Peng. 2016). Their work presents the strategy of high-efficiency solar electricity of umbrella using TRIZ analysis. According to the combined statistics of classical and new contradiction matrix, the invention principles may be used for the design of tracking irradiance of surface plane of umbrella orientations including tilted angle (θ) and azimuth angle (Ø). They found that the optimal design of azimuth surfaces of the umbrella was obtained by electricity gain at a fixed tilted angle.

In 2006, Siemens has some experience with TRIZ as its corporate technology department. However, companies like Samsung and Intel showed a different approach to TRIZ methodology which gave them a huge advantage over their competition. In addition, the Innovation Tool Academy built up on the experience of the level of the methods used in Siemens on three levels of knowledge: Use of basic, advanced and professional methods (Zhang et al., 2006). Samsung implemented TRIZ principles for better competitiveness since TRIZ tools may be applied to a wide variety of problems and challenges. Moreover, TRIZ greatly accelerates natural innovation by focusing issues and expanding solution concepts to the company and its research and development department (Sung-Wook et al., 1998).

Based on above, TRIZ principle was never used as a comprehensive methodology that considers all parameters affecting the performance of photovoltaic systems in Jordan. In this work, TRIZ will be applied to an existing photovoltaic system in Jordan to improve its performance by taking all needed parameters into account. On the other hand, the improvement stage on the material and tracking photovoltaic systems from the year 2005 to the present will be studied and compared with the results obtained if TRIZ principle was adopted.

The first part of this study includes "forecasting using TRIZ," where the general steps of TRIZ forecasting will be overviewed and explained to develop a new generation of photovoltaic material. While the second part of this work presents a discussion and analysis of an existing case study to show how TRIZ will improve its performance.

2. METHODOLOGY

The first step, in solving any problem by TRIZ, is to analyze the given problem accurately. Then, the innovative situation questionnaire can be used to gain a clear understanding of the problem. In addition to the problem description, the Ideal Final Result is formulated. Then, TRIZ contradiction matrix is applied to determine the conflicts. Next, contradictions which contain two parameters: the first parameter is improved (improving feature rows), but the second parameter is reduced (worsening feature columns). Next, the number of principles that needs to be changed is found in a contradiction table. Finally, these principles are explained to increase the ideality of a system by increasing the useful function for this system and reducing the harmful function and cost. A contradiction table is an important tool in TRIZ methodology, it consists of 39 lines and 39 columns of engineering parameters. This table helps in solving the problem by giving different inventive principles which help in solving the technical contradiction.

The operating parameters of a PV system that will be discussed are: Open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), maximum power voltage (V_{mp}), maximum power current (I_{mp}), maximum power (P_{mp}), PV Efficiency (η), fill factor (FF) and performance ratio (PR).

A basic principle of TRIZ is that systems evolve towards increased ideality, where ideality is defined as:

$$\text{Ideality} = \sum \text{Benefits}/(\sum \text{Costs} + \sum \text{Harm})$$

Which is a simple tool used to show how the ideal final (IFR) result concept can guide the problem definition thinking. This tool is based on a simple questionnaire originally configured by Altshuller in 1964 as a way of structural thinking.

In PV systems, one can develop an idea or component to enhance the performance of the system. Most of all ideality centered problem definition thinking will lead to either knowledge or effects problem or a contradiction. The basic idea starts IFR problem definition as in Figure 1. There are already several examples of this strategy in operation (Mann, 1999, Mann, 2000).

"9-Windows" is one of the techniques used for logic segmentation for the system, a simple tool that helps users think in terms of time and space. The basic principle of operation is divided into nine segments. It is often a good idea to label these things on a 9-Windows picture. Not only does this allow brains to see segments of a given problem, but it also allows to define the situation for others who may be able to help. For example, nine windows applied to PV tracking system is discussed in Figure 2.

Intellectual property for the system can be used to identify where a system is on its current S-curve. Research has identified several

Figure 1: Ideal final result problem definition strategy

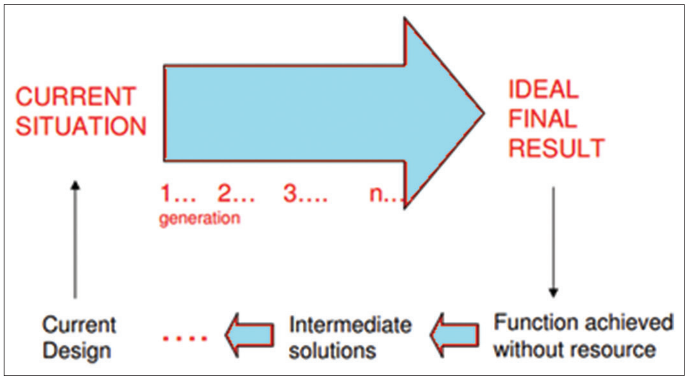
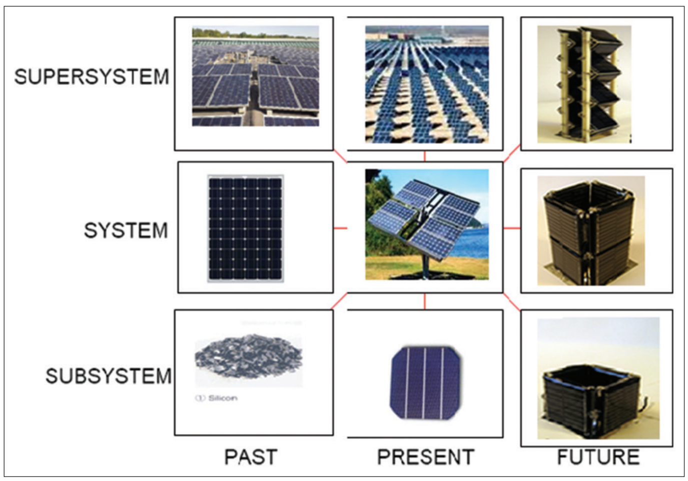


Figure 2: The nine-windows of the tracking PV system



generic steps in the types of patents being granted for a given system over the course of its evolutionary life as in Figure 3. The global cumulative PV capacity is presented in Figure 4.

After analyzing the collected information about the system, the analyst identifies contradictions in the system and identifies appreciative TRIZ tools that could be used later. There are two stages in problem formulation:

- Preliminary formulation: which covers main technological processes
- Final Formulation: that includes clarification of general processes, working out of detailed formulators on different processes and selection and analysis of obtained problem statements.

TRIZ technology is applied to visualize future trends in photovoltaic systems. Different materials are proposed. These materials are studied to predict better performance in the future. Furthermore, the used tracking system and its effect are investigated and evaluated. TRIZ methodology expects to increase the number of possible inventions during the time until the system reaches the ideal final result, and work without any harmful losses.

3. RESULTS AND DISCUSSION

This methodology was applied to the AL-Qwasme mosque PV system located in Amman, Jordan (+31.87 Latitude and +35.22 longitude) as a case study to examine the type of material used in the AL-Qwasme mosque PV system. The PV system type is an on-grid system as shown in Figure 5. Table 1 gives a technical description of the photovoltaic system at Al-Qwasme mosque (masjid) and the cost of electricity purchased from the utility company. Furthermore, forecast the future of the photovoltaic system by TRIZ nine windows was applied to show how some trends are used to develop the material of the PV system to improve its performance.

TRIZ states that PV systems can achieve increased ideality by increasing their ability to absorb as much light as possible. Some problems faced the system under investigation is the light absorption because of the type of PV cells used. The monocrystalline cell, which was used in this case study, is considered the first generation of PV cells. The first-generation PV technology is known to be based on thick crystalline films (mainly Si) which does not only leads to low efficiency, but also to high cost. The first-generation solar cells have the following problems: the thickness of crystalline silicon wafer which causes the high cost of raw material for silicones, less flexibility, complexity in manufacturing and temperature coefficient for module. The ideality in this case will happen if the system operates as close to its optimal peak power point (MPP) as possible by providing a higher power output.

Figure 3: Correlations between S-curve position and invention focus (Nieto et al., 1998)

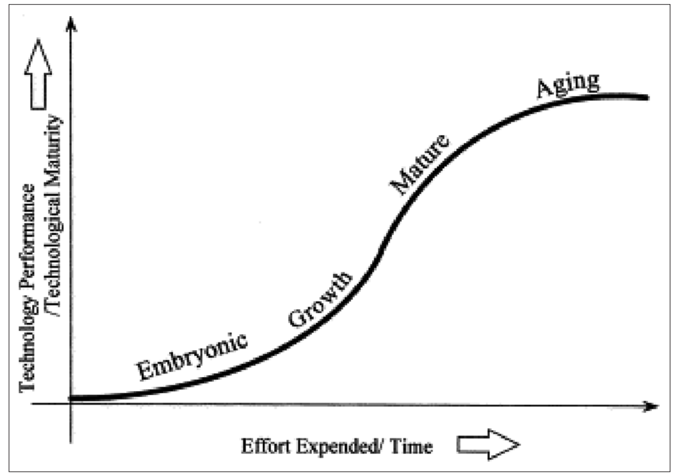
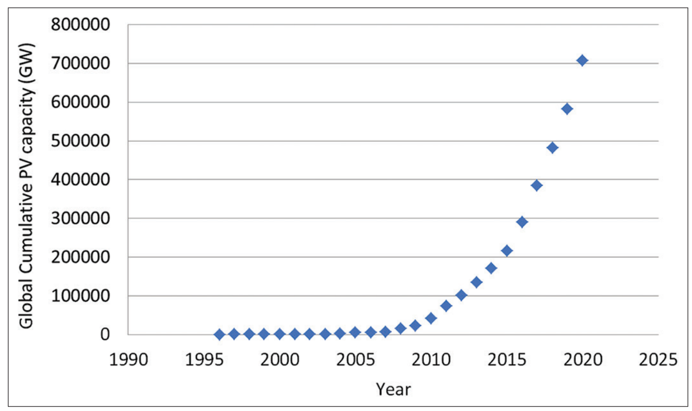


Figure 4: Global cumulative PV capacity (Source: BP statistical review of world energy)



The physical contradictions in TRIZ are used to determine certain parameter to invent a new material that may be less in cost and more efficient. A summary of the TRIZ principles and trends numbers that are pertinent to improving the first generation of solar cells is shown in Table 2.

For example, the parameter number 30 is" Flexible shells and thin films," which implies that scientists may invent a new technology in photovoltaic systems, like using flexible shells and thin films panel in the second-generation solar cell. The second generation combines the low cost and flexibility of polymer thin films. A major advantage of flexible solar cells is that they are light due to the lack of heavy glass sheets and metal frames. This will reduce the transportation and deployment costs. Other principles have been applied to the PV system such as principle number 35 "Parameter Changes" as illustrated in Table 3.

The thin-film technology solar cells are considered the second-generation solar cells. This technology involves depositing a thin layer of photo-active material (Non-crystalline silicon) onto inexpensive substrates material using plasma enhanced chemical vapor deposition process. Amorphous semiconductor material (Si) is commonly used. An amorphous material differs from crystalline material in that there is no long-range order in the structural arrangement of the atoms. Although the thin film PV cells are less subject to breakage and not vulnerable to most of the other manufacturing problems, its efficiency is significantly lower, which is the main problem in this type. There are also some concerns about the toxic legacy of the materials both in manufacturing and lifecycle. The amorphous solar cells are much flexible to install, less support is needed when placing panels on rooftops and it also has the advantage of fitting panels on light materials like backpack, textiles etc. The efficiency of thin film technologies solar cell is approaching about 25% (Green et al., 2021).

Then, the third-generation solar cells involves different Semiconductor Technologies that are fundamentally different from the previous semiconductor devices. It has been estimated that third-generation solar technologies will achieve higher efficiencies and lower costs than first- or second-generation technologies. Some of these technologies are nanocrystal Solar Cells, Photo-electrochemical cells, Dye-sensitized hybrid solar cells and polymer solar cells. Additional advantages of these cells are; low-energy and high-throughput processing technologies, low material cost, and will perform even at low incident light conditions.

The fourth-generation solar cells combined the third-generation technologies, it is predicted to be of lower cost of material, which will make solar deployment more affordable. The confirmed efficiency for different module types is shown in Figure 6. The use of the fourth generation of solar cell like "Perovskite" helps to improve the harvesting of solar energy, energy conversion into electricity. This technology offers better efficiency than the third-generation solar cells. The Production of perovskite cell is simpler, has lower cost, lower embedded energy and greatly reduced environmental impact. Perovskite uses abundant, inexpensive materials, with a simple cell structure, low wastage and low manufacturing cost. It is printed as a second layer on top of standard PV cells to increase absorption and efficiency. Solar devices using these materials have increased from 3.8% in 2009 to 22.1% in early 2016, making this the fastest-advancing solar technology to date. With the potential of achieving even higher efficiencies and very low production costs, perovskite solar cells have become commercially attractive (Chen et al., 2021).

Due to the improvements in solar modules efficiency and the increase in global production of solar modules, the cost of photovoltaics was reduced with time. Photovoltaic prices have fallen from \$76.67/W in 1977 to \$0.23/W in 2020 (Lafond et al.,

Figure 5: PV system in Al qwasme masjid

Table 1: Description of AL-Qwasme PV system

Monthly PV performance data	
Requested location	AL-Qwasme mosque Amman Jordan
Latitude (deg N)	31.87
Longitude (deg E)	35.22
Module type	Standard (monocrystalline)
Array type	Fixed (roof mount)
Inverter Efficiency:	96
Average cost of electricity purchased from utility($/kWh)	0.25
Capacity factor (%)	18.9

Table 2: Contradiction Matrix

Parameter That improves / worsens	2: Weight of stationery	6: Area of Stationary	8:Volume of stationery	36: Device complexity
21-Power	19, 26, 17, 27	17, 32, 13, 38	30, 6, 25	20, 19, 30, 342
39-Productivity	28, 27, 15, 3	10, 35, 17, 7	35, 37, 10, 2	12, 17, 28, 24
37-Reliability	3, 10, 8, 28	32, 35, 40, 4	2, 35, 24	1, 13, 35
32-Ease of manufacturing	1, 27, 36, 13	16, 40	35	1, 27, 26

2017). Figure 7 shows the global solar module production and the module price history since 2010.

Using the methodology outlined in the previous section, Table 4 compares the monocrystalline solar module used in Al-Qwasme mosque and two other types of solar modules. The specifications of the three modules are listed in Table 4.

Figure 8 shows the PV System Output (kWh) per Month for monocrystalline modules and for other array types. Monocrystalline modules produce the least amount of energy, as shown in the Figure.

The economic value in $ as a comparison between monocrystalline array and other arrays is presented in Figure 9.

Economically, the thin film technology is the best option. The excess energy produced can be sold to the in exchange for credits on monthly electricity bills. Table 4 shows the capacity factor comparison between monocrystalline and thin film.

This previous analysis shows the development stages for the solar cell material from the first to fourth generation. The photovoltaic engineers took more than 50 years to predict the expected future model of solar cell. If photovoltaic engineers used TRIZ to develop the material and to solve problems they were facing, then they would have saved several years of time.

Figure 6: Confirmed module efficiencies (Data source; [Green et al., 2021])

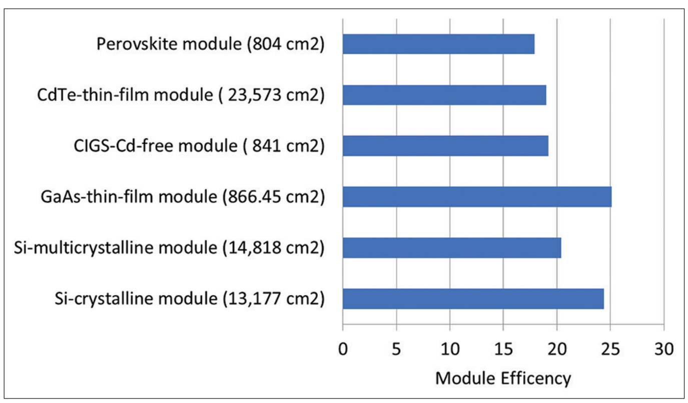


Table 3: TRIZ principles applied on PV

Principle 30. Flexible shells and thin films	Principle 35. Parameter changes
Use flexible shells and thin films instead of three-dimensional Structures	Change an object's physical state (e.g. to a gas, liquid, or solid)
	Change the concentration or consistency
Isolate the object from the external environment using flexible shells and thin films	Change the degree of flexibility
	Change the temperature
	Change the pressure
	Change other parameters

Figure 7: Global electricity from solar (Source: BP statistical review of world energy and ember) and solar PV module cost (Sources: Lafond et al., 2017)

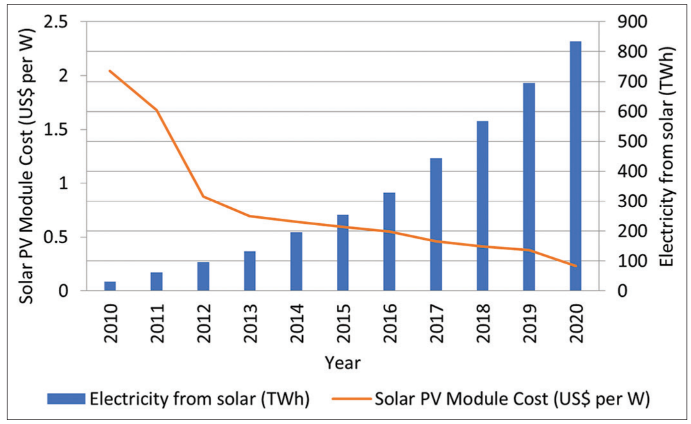


Figure 8: PV system output (kWh) per month

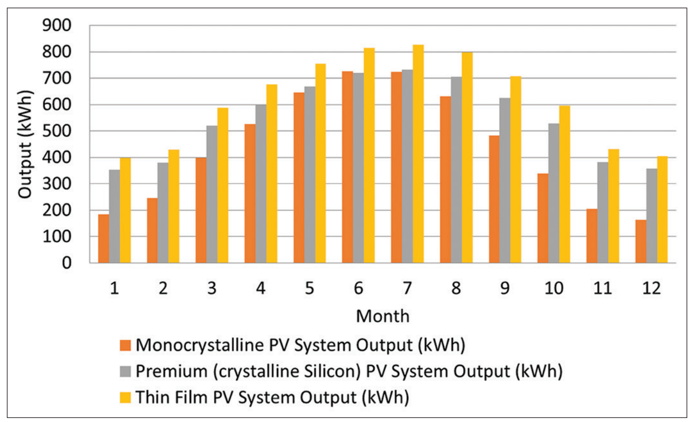


Figure 9: The economic value ($) per month

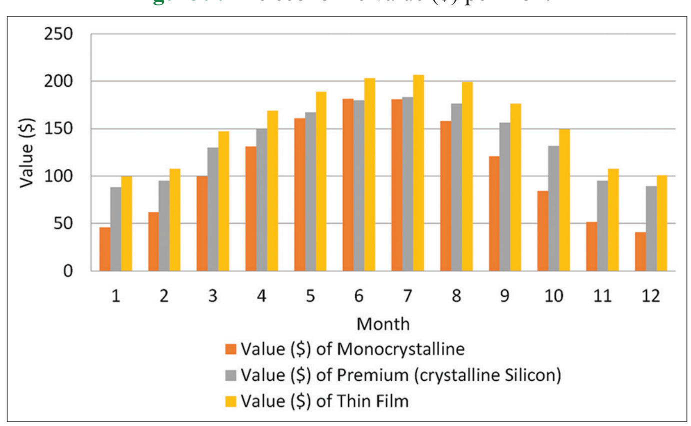


Table 4: Module Type Options

Type	Approximate Efficiency	Module Cover	Temperature Coefficient of Power	Capacity factor
monocrystalline Silicon	15%	Glass	-0.47%/°C	15%
Premium (crystalline Silicon)	19%	Anti-reflective	-0.35%/°C	18.7%
Thin film	10%	Glass	-0.20%/°C	21.2%

4. CONCLUSION

Solar power generation greatly improves building sustainability through the improvement of energy efficiency the generation of renewable energy. The work discussed and provided details about applying TRIZ methodology ontoV systems to develop and improve their performance. The development inofV material was illustrated and discussed through a case study. The case study analysis clarified the material of PV systems and illustrated the development of PV system efficiency from first to fourth generation solar cells. This research proved that, through the application of TRIZ methodology, engineers can minimize their efforts and reduce the time they spend on research. The contradiction matrix in TRIZ methodology provides ideas to engineers to help facilitate inventions in the field of phphotovoltaics

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