# The Technical, Operational and Energy Policy Issues for Developing Photovoltaic Systems: A Review

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***Abstract*— In recent years, photovoltaic (PV) units are getting popular in different countries, including Australia, as they contribute to reducing emissions of CO and enhancing energy efficiency. However, several technical and economic challenges need to be addressed to ensure maximum benefit from this renewable generation. Moreover, the development of energy policies and regulations also affects the development of such systems. Therefore, this paper aims to review several technical, operational and energy policy issues for developing reliable and efficient PV systems. In addition, this paper summarizes the existing modeling and sizing methods, the maximum power point tracking (MPPT) techniques, and the interface power-electronic devices in this field. Moreover, recommendations for future researchers and investors for developing such systems are provided in this research paper.**

***Keywords*— PV systems, energy policy, MPPT, PV technical issues, PV operational issues.**

## I. Introduction

Recently, the use of renewable energy sources has been rapidly growing worldwide. At the same time, the fossil fuel is running out and the global warming problem is sharply increasing. Based on that, future energy generation will greatly depend on using of the renewable energy sources for reducing the global warming problem [1]. Also, the renewable energy sources have some precarious problems in their production because of their intermittent nature [2]. A photovoltaic (PV) energy source is one of the most promising renewable energy sources for generating electricity [3]. The development of this technology is still emerging in terms of increasing its efficiency and decreasing its cost. The levelized cost of electricity (LCoE), which is generated by PV systems, is cost-effective in world markets across residential and commercial segments. Several energy policies and regulations around the world have encouraged investors to invest in such systems. In 2010, the capacity of PV projects has been larger than that in the previous four decades. In 2013, around 100 MW capacity was installed per day to meet the growing load demand. Moreover, 85 GW PV capacity was in place worldwide in 2017. Based on the IEA road-map 2014 edition, the capacity of installed PV systems is estimated to be 16% of the generation of global electricity by 2050. To meet this target, the technical, operational and energy policy issues have to be taken into consideration for developing PV systems to increase their usage in the global market [4].

PV systems can be categorized in the form of feeding the load demand as standalone PV systems and grid-connected PV systems [5]. They are used for supplying several loads, for example water pumping systems, residential and commercial appliances, street lighting, telecommunications, electrical vehicles, military, and agricultural applications. In general, PV systems may be centralized or decentralized. Around 60% of PV systems are installed as decentralized, while 40% of PV systems are centralized systems. PV systems now contribute only 1% of the global market [2]. Existing review papers focused only technical aspect in developing PV systems [6] and [7]. However, several other important aspects are missing, which help the designer, the investor and the end user to understand the requirements to get reliable, and cost-effective PV system. These aspects are energy policies and regulations, optimal modeling and sizing techniques of PV systems, the proper interfacing power-electronic devices, and the important operational issues.

This paper aims to summarize the technical, operational and energy policy issues for developing PV systems and increasing their usage worldwide. The structure of this review paper is as follows: Section II classifies the types of PV systems. Section III highlights the energy policy issues for increasing investment on PV systems. Section IV reviews different modeling and sizing techniques of PV systems. Section V briefly highlights the maximum-power-point tracking techniques and interfacing power-electronic devices for increasing the efficiency of PV systems. Section VI describes some of the important operational issues. Section VII summarizes some recommendations based on the reviewed research works. Finally, Section VIII concludes the paper.

## II. Types of PV Systems

In general, PV systems can be categorized in terms of their use to three types; standalone PV systems, hybrid PV systems, and grid-connected PV systems [8]. This classification relies upon the PV systems operational and component configurations. The PV systems are designed to provide AC and/or DC power, and connected with or without storage energy systems. Moreover, PV system have the capability to connect with other renewable energy sources [9].

Standalone PV systems aim to provide the electrical energy in both DC and/or AC form to the required loads. Mostly, such a system is used to operate in remote areas where it is independent of the electric utility grid. This system can be operated solely by a PV array, or by a PV/battery combination. The typical standalone PV system consists of a PV array, storage energy system, DC/DC converter, charge controller and inverter. Usually, a maximum-power-point tracker (MPPT) is used to operate the system at its maximum efficiency [10].

Grid-connected PV systems convert solar radiation into electrical power and then inject it directly to the grid. Mostly, this system is used without a back-up energy storage system. In this case, the system needs less maintenance and has lower cost. The inverter is the main component in this type of system, which converts the DC power generated by the PV array into an AC power consistent according to the voltage level and the power quality requirements of the electrical power system. The back-up energy storage system is mostly utilized in grid-connected PV systems for providing power during fluctuations, supplying electricity during peak hours, improving power quality and operating reserves [11].

Hybrid PV systems may be operated as a grid-connected system or a standalone system. In this system, two types or more of renewable energy sources cooperate to cover the load demand such as PV/wind, PV/diesel generator, PV/wind /diesel generator etc. [12].

## III. Energy Policy Issues

Currently, the most challenging issue is to deal with negative impacts of fossil fuel sources. Therefore, the current energy policies aim to reduce these negative impacts on the environment by supporting renewable energy initiatives for meeting the daily energy demand. In 2012, most initiatives for using and developing the PV systems applications have been in Europe. Recently, these initiatives are dramatically increasing in Asia, especially in China. The major concern in the existing PV technology is its low energy efficiency and high capital costs. As a result, new energy policies are required for renewing proposals, system integration and regulatory issues in order to increase the use of PV systems in both residential and commercial use.

In [13], the authors mentioned the existing energy policies for PV systems in several countries such as USA, China, Germany, Australia, Japan, Canada and France, and highlighted the required regulations for integrating renewable energy sources into the electrical grid. Moreover, it is mentioned that the retail financing terms must be flexible to grow PV technology in the market and for the end user. Several policies in different forms of economic incentives are reviewed which need to be improved to increase the use of such PV systems. These economic policies include feed-in-tariffs (FIT), production incentives, renewable portfolio standard (RPS), investment tax credits, quota requirements, pricing laws, trading systems etc. The main motivation of improving these policies is to reduce the negative impacts of the energy sector on the environment, reduce reliance on fossil fuels and encourage development in this field for both industrial and residential sectors. Based on that, Table I summarizes some of the energy policy issues in developing PV systems. In addition, Table II shows the forecast capacity of PV projects (GWp) and the cost of the energy generated (US cents/kWh) for United States of America (USA), Europe, China and Japan.

TABLE I
Energy Policy Issues in PV Systems

| **Objectives of the energy policy** | **The methodology of the energy policy** | **Ref.** |
|---|---|---|
| Study the impacts of PV - based distribution generation (DG) system on economic and environmental issues | The use of PV-based DG systems aims to decrease the volatility in wholesale prices and decrease the cost of the centralized PV plant on a long-term investment | [14] |
| Study the initiatives for decentralized PV systems | Enhancing the energy efficiency in distribution systems to encourage the use of renewable sources | [15] |
| Study the cost benefit of the PV system deployment | An hourly PV energy output of net feed-in-tariff (FIT) values | [16] |
| Design a FIT program | A guaranteed internal rate of return (IRR) value that encourages investments based on several FIT values | [17] |
| Detailed methodology for energy allocation based on a multi-objective model | A tool model for assisting designers and investors in matters related to energy policy | [18] |

From Table I, it is noticed that the investment and finance issues are essential to improve the energy policies. Therefore, credible and clear decisions from the policy makers aim at decreasing the level of risks, and inspiring confidence. This will encourage investors and consumers for increasing installation of PV projects.

TABLE II
The Forecast Capacity of PV Projects (GWp) and the Cost of the Energy Generated (US cents/kWh) [19]

| **Year** | **2010** | | **2020** | | **2030** | |
|---|---|---|---|---|---|---|
| | *Capacity* | *Cost* | *Capacity* | *Cost* | *Capacity* | *Cost* |
| USA | 2.1 | 13.4 | 36 | 10 | 246 | 7 |
| Europe | 3.0 | 19.8 | 41 | 11 | 200 | 6.6 |
| China | 0.37 | 25.9 | 63.5 | 9.4 | 634 | 5 |
| Japan | 4.8 | 20.6 | 30 | 12.5 | 205 | 8.6 |
| World | 14.0 | | 200 | | 1805 | |

Based on Table II, it is clear that the installation of PV systems has risen worldwide with an average rate of 49% per annum. Based on recent trends, it is expected that the share of the PV systems will rise in China from 18% of global generation in 2015 to 40% in 2030, while the price of insulation of PV systems will decrease by

81% in 2030. In Asian countries, it is expected that the share of PV systems will increase to be 25% in 2030. In Japan, the expected share of PV systems will increase by 97% from 2010 to 2030, while the price of installation of PV systems will decrease by 58% by 2030. In USA, the expected share of PV systems may settle at around 15% from 2020 to 2030, while the price of the installation of PV systems will decrease by 48% by 2030. In Europe, the expected share of PV systems will decline linearly from 44% in 2015 to 4% in 2030, while the price of the installation of PV systems will decrease by 67% by 2030. As a result, in 2030, the highest share of PV systems will be in China, with the lowest price.

On the other hand, developing countries are currently increasing the implementation of PV systems in order to sustain their economic growth parallel with reaching their environmental goals. In fact, the installation of PV systems in these countries increased by 38% (291 GW) of global PV capacity in 2016 compared to 5% (6 GW) in 2006 [20]. According to the medium-term renewable-energy market report, published by the International Energy Agency (IEA) in 2016, developing countries will lead the future installation of PV systems by 540 GW in 2021 [21]. This capacity represents nearly the half of the global installations. Developing countries create some policies for encouraging stakeholders to invest in PV systems with competitive and sustainable prices. Currently, the low cost of investing in PV systems installation creates new opportunities for investors to shift their investments to the power sector, since solar energy is widely available. In 2015 to 2016, prices of LCoE in small-scale PV projects were less than 0.10 \$/kWh in South Africa, India, Brazil etc. and less than 0.04 \$/kWh in Chile, Mexico, and the UAE [22]. Recently, large-scale PV projects have been rapidly installed to meet the increased load demand of growing economies in developing countries. The large-scale PV projects are very important for developing countries for three main reasons. First, the distribution of solar radiation is very good in most developing countries [23]. Second, the manufacturing costs of PV technologies are decreased by nearly 74% in 2016 [24]. Third, the installation period for PV plants is relatively short compared with other power generation plants such as hydropower plants [25]. TABLE III highlights some information about the installation of PV projects in developing countries such as the name of the plan, its implementation period, its capacity, its capital cost and its LCoE.

TABLE III
A SUMMARY OF THE INSTALLATION OF PV PROJECTS IN DEVELOPING COUNTRIES [26]

| Country | plan | Execute time | Capacity (MW) | Capital cost ($mn) | LCoE ($/kWh) |
|---|---|---|---|---|---|
| India | Karnataka (Phase II) | 2013-2015 | 6 | 7.5 | 0.11 |
| | Andhra Pradesh | 2014-2016 | 40 | 36 | 0.086 |
| | Telangana | 2014-2016 | 10 | 10 | 0.108 |
| | JNNSM (Phase II - Batch I) | 2014-2015 | 20 | 18 | 0.088 |
| | Punjab | 2015-2016 | 28 | 25.2 | 0.116 |
| UAE | Dubai (Phase II) | 2014-2017 | 200 | 250 | 0.059 |
| | Dubai (Phase III) | 2016-2018 | 800 | 600 | 0.03 |
| Jordan | Phase II, P1 | 2015-2018 | 50 | 56.5 | 0.061 |
| | Phase II, P2 | 2015-2018 | 50 | 56.5 | 0.065 |
| | Phase II, P3 | 2015-2018 | 50 | 59 | 0.069 |
| | Phase II, P4 | 2015-2018 | 50 | 60 | 0.077 |
| South Africa | REIPP (R3-P1) | 2013-2016 | 75 | 183.75 | 0.085 |
| | REIPP (R3-P2) | 2013-2016 | 75 | 202.5 | 0.097 |
| | REIPP (R3-P3) | 2013-2016 | 75 | 202.5 | 0.109 |
| | REIPP (R4-P1) | 2015-2018 | 75 | 93.75 | 0.064 |
| | REIPP (R4-P2) | 2015-2017 | 75 | 93.75 | 0.066 |
| | REIPP (R4-P3) | 2015-2018 | 75 | 93.75 | 0.069 |
| Zambia | 100 MW Solar-P1 | 2016-2017 | 45 | 49.5 | 6 |
| | 100 MW Solar-P2 | 2016-2017 | 28 | 40.04 | 0.078 |
| Uganda | Get FiT | 2014-2016 | 10 | 19 | 0.164 |
| Jamaica | 37 MW RE | 2016-2018 | 33 | 48.51 | 0.085 |
| Brazil | Pernambuco | 2013-2015 | 11 | 18.04 | 0.103 |
| | Plan VI | 2014-2017 | 260 | 319.8 | 0.087 |
| | Plan VII | 2015-2017 | 75 | 92.25 | 0.085 |
| Chile | 2015/01 Plan | 2016-2021 | 100 | 59 | 0.20 |
| | 2015/02 Plan | 2015-2017 | 141 | 197.4 | 0.068 |
| El Salvador | 100 MW RE Plan | 2014-2016 | 100 | 150 | 0.102 |

Based on TABLE III, several plans for installing PV systems starting in 2016 and to the present in developing countries such as India, the UAE, Jordan, South Africa, Zambia, Uganda, Jamaica, Brazil, Chile and El Salvador. The prices for LCoE vary in the range of 0.024 to 0.184 \$/kWh. From TABLE I, it can be concluded as follows: First, 27 PV projects are expected to be executed, from 6 MW in India to 800 MW in Dubai. Second, the capital costs of such projects are within the range of 7.5 \$ mn to 600 \$ mn, while the average capital cost is 97.48 \$ mn which indicates the availability of low capital cost for investment in large-scale PV plants in developing countries. Third, the LCoE varies between 0.03 \$/kWh in the UAE to 0.116 \$/kWh in India. It is clear that investments in PV systems increased during these years in developing countries, which will let these countries lead this field in the near future.

## IV. MODELING AND SIZING TECHNIQUES FOR PV SYSTEMS

Optimum modeling of the components in PV systems may lead to improvements in the performance and operation of PV systems at minimum cost. This includes accurate modeling of the PV module, storage technology, power-electronic devices and loads as well. Table IV summarizes the modeling methods of different topologies of PV systems.

TABLE IV
MODELING METHODS FOR PV SYSTEMS

| Type of PV system | Objectives | Results of the study | Ref. |
|---|---|---|---|
| Standalone PV system | Study the performance of a standalone PV system by modeling the PV modules and storage battery using MATLAB | Optimal design and operation of a standalone PV system at a minimum cost | [27] |
| | Sizing a standalone PV system by modeling the solar radiation, load demand and system efficiency based on a developed regression model | The accuracy of the predicted results match with the actual dataset with a confidence level of 92% | [28] |
| Grid-connected PV system | Modeling the grid-connected PV system components, PV modules, MPPT, and inverter and its synchronization with the grid) using MATLAB | Developing a proper method for modeling and controlling a grid-connected PV system | [29] |
| | Sizing a grid-connected PV system for a particular application using Homer software | Optimal size of the components of grid-connected PV system at a minimum net present cost | [30] |
| Hybrid PV system | Sizing and energy dispatch control of a PV/battery/diesel system using RETScreen software | Evaluation of the energy performance of the system with its economic analysis | [31] |
| | Sizing the components of a PV/wind system using Homer software | Sizing the components of the system for a higher level of availability at a minimum cost | [32] |

Based on Table IV, it is noted that to obtain optimum results of the sizing for PV systems, the following issues must be taken into account:

- small step historical meteorological and load demand time-series data (hourly or smaller);
- accurate techniques for modeling the components of the PV systems;
- a well-formulated objective function; and
- a fast and accurate simulation algorithm.

## V. MAXIMUM-POWER-POINT TRACKING TECHNIQUES AND INTERFACE POWER-ELECTRONIC DEVICES

The output power of a PV module fluctuates because of the variations in the solar radiation and the ambient temperature. Here, the power delivered to the load side fluctuates, and may affect the performance of the load. Moreover, the load demand varies from time to time and will move the operating point on the current-voltage PV curve. To solve this issue, a maximum-power-point tracker (MPPT) is used for ensuring the maximum system efficiency. Several MPPT techniques are used to extract the required amount of current to operate the system at its maximum-power point. Table V summarizes different studies of MPPT techniques for PV systems.

TABLE V
MPPT TECHNIQUES FOR PV SYSTEMS

| MPPT techniques | Results of the study | Ref. |
|---|---|---|
| Perturb and observe (PO) and incremental conductance (IC) methods | Improving the efficiency of a grid-connected PV system based on a variable-step algorithm with a buck-boost converter | [33] |
| Fuzzy logic control (FLC) method | Developed an adaptive FL controller for controlling the MOSFET on/off time in a boost converter and developed an MPPT under different conditions | [34] |
| Offline and online methods | Analyzed the performance and tracker efficiency of a PV system in both steady-state and dynamic behavior | [35] |
| Converterless matching technique | Explored the advantages of using the MPPT in PV systems based on linear and resistive loads with real test conditions | [36] |
| Voltage-controlled MPPT and level-shifted PWM modulation | Developed an MPPT algorithm for charging and discharging a battery by tracking the PV output voltage. This study aims to improve the efficiency and reliability of the battery with an optimal life-cycle | [37] |

Based on Table V, several MPPT techniques have been utilized for maximizing the efficiency of PV systems. The choice of proper technique will be done based on the type of application, system requirements, implementation of the hardware, cost, simplicity, and effectiveness.

In several applications, the voltage level generated by the PV modules must be in a specific range to operate the inverter. Buck and boost converters are used to adjust the output voltage to be in that range. The buck converter aims to step down the voltage level, while the boost converter aims to step up that level. The relationship between the input and the output voltage level in such devices and their design formulas are mentioned in [38]. Table VI summarizes the impact of using power-electronic interface devices in PV systems.

According to Table VI, the selection of the proper converter for a particular PV system application is a critical role, which affects the efficiency of the such system. Several power-electronic interface devices are implemented, which aims to reduce the mismatch losses, and to increase the efficiency and reliability of the PV system as well.

## VI. PV PLANT'S OPERATIONAL ISSUES

To validate the modeling and sizing techniques as well as get recommendations from the existing systems for developing future projects, the performance and reliability of the installed PV systems must be analyzed. In addition, an economic evaluation for the capital, maintenance and operation costs is supposed to be performed to determine the cost of the energy generated by the system. Therefore, several operational issues in PV plants are summarized in Table VII.

TABLE VI

THE POWER-ELECTRONIC INTERFACE DEVICES IN PV SYSTEMS

| Interface power-electronic techniques | Results of the study | Ref. |
|---|---|---|
| Explore the principle of work for the converter and the control devices in grid-connected PV systems | The response speed is good with lower oscillations | [11] |
| Describe the use of MPPT with one-cycle control, and the use of the power-factor correction unit in a grid-connected PV system | An efficient operation for the one-cycle control in terms of power extracted from PV array | [39] |
| Study the performance of a single-stage inverter | Increased the quality of the AC output power and the operation of the MPPT | [40] |
| Study the energy losses by the mismatch and propose reduction techniques | Decreased the effect of mismatch losses in both partial and homogeneous conditions | [41] |
| Compare the performance of using string and micro inverters in PV systems | Summarized advantages and disadvantages of utilizing string and micro inverters in PV system based on different technical and economic indicators | [42] |
| Modeling and operating a PV micro-inverter to study its performance | A developed inverter architecture with two switches for controlling the inverter | [43] |

## VII. RECOMMENDATIONS

From the previous research works, some recommendations are concluded. These recommendations can be summarized as follows:

- The updated proposals from the leading PV systems countries in the field of technology, system integration, legislative and regulatory issues will help to overcome the economic and non-economic barriers.
- Policymakers should facilitate the investments in PV projects more and more in developing countries to meet the load demand within the technical aspects.
- Well-planned PV projects, supportive energy policies and proper regulations are key roles to achieve low prices and increase the investments for installing PV plants in developing countries.
- Artificial intelligence (AI) methods have several advantages over conventional methods to optimally size PV systems.
- The accuracy of the modeling techniques for modeling the components of the PV systems, considering all factors, is an essential requirement for an accurate PV sizing.
- Suitable power-electronic device and MPPT technique are required to manage and control the power flow based on the variation of the load demand in order to improve the operation of the PV system.
- A feasible design of a PV system needs an accurate monitoring system which can be used for recording the important data about the status of the PV system for better protection and control as well as improving the performance and cost of future designs of PV plants.

TABLE VII

PV PLANT'S OPERATIONAL ISSUES

| Objectives | Results of the study | Ref. |
|---|---|---|
| Study the performance of 4.9 & 5 MW DC PV plants | Obtained the parameters for performance and costs over 5 years operation period | [44] |
| Estimate the cost of preventive scheduling maintenance | Developed an optimization method for a systems cost | [45] |
| Examine a PV-powered reverse plant | Th using of a 3-phase induction motor reflects more efficient results than the using of a DC motor in a PV-powered reverse plant, which reduces the consumption of the electrical energy | [46] |
| Study the impact of using new methodologies and tools on a PV grid-connected system | Reduced the limitations for using the PVDG and improved the power quality of the electrical grid | [47] |
| Study the stability of the PV system frequently | Measured the abnormal conditions and the matching with the grid code | [48] |
| Study the PV system operation and its maintenance cost | Measured the system downtime and the possibilities for reducing the cost | [49] |

## VIII. CONCLUSIONS

This paper presents reviews of the technical, operational and energy policy issues that affect the development of PV systems worldwide. A historical study of the technologies of producing the PV cells is presented, mentioning the characteristics of each technology. As the energy policies and regulations affect investors decisions for investing in PV systems, some of the studies are summarized to explore these policies, and the future capacities and prices for PV systems worldwide. Additionally, the paper includes a summarized study of existing modeling and sizing studies for different types of PV systems. Moreover, several studies for developing the power-electronic devices in the PV system are investigated to increase its efficiency. Finally, PV plants operational issues are mentioned for monitoring their performance, which can be used to develop higher efficiency and lower cost PV plants. The main objective is to summarize the existing technical challenges and present recommendations for future research work in developing PV systems.

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