# Chapter 2
# Literature Review

## 2.1 Introduction

A large number of national and international studies have been conducted to study the opportunities of reducing electricity consumption and improving energy efficiency of institutional and governmental buildings during rush hours. These studies show that, it is quite possible to limit the increase in energy use without having negative effects. So, the Government of Egypt has set a strategy to implement a number of polices up to year 2022 to diversify energy resources and rationalize the energy needs of different activities without hindering the development plans. Among these polices are taking executive actions to increase energy efficiency in order to reduce total energy consumption by 8.3 % by the year 2020, and achieving an electricity generation mix composed of 20 % RE, by year 2022 [34].

This chapter provides a literature review about previous work. The survey includes the following aspects:

- Design and sizing of PV systems.
- Power quality improvement of grid-connected PV systems.

## 2.2 Review of Related Work

Many researches on the design and sizing approaches of grid-connected PV systems, and power quality of grid-connected PV systems have been investigated.

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### 2.2.1 Design and Sizing of Photovoltaic Systems

Samimi *et al.* (1997) [35] analyzed the optimal tilt angle and other aspects of PV modules in various climates. However, an economic optimization design tool for optimal PV size based on technology information, current tariffs and policy has not yet been developed.

Hernández *et al.* (1998) [36] developed a methodology for optimal size of PV system for different building types. The adopted design criterion was to optimize the profitability and amortization of PV installation.

Haas *et al.* (1999) [37] investigated the socioeconomic aspects about an Austrian 200 kWp-rooftop program (100 PV systems with an average capacity of 2.28 kWp) to promote small grid-connected PV systems in Austria.

Bansal and Goel (2000) [38] discussed the integration of 25 kWp solar PV system in an existing building of cafeteria on the campus of Indian Institute of Technology, Delhi by creating a solar roof covering an area of about 250 $m^2$. The system was found to be optimum if integrated with an angle of $15^{\circ}$ tilt with relation to north–south axis, in Delhi's climatic conditions, therefore giving it higher efficiency.

Gong, and Kulkarni (2005) [39] suggested an optimization method for a grid-connected PV system based on maximizing the utilization of the array output energy and minimizing the electricity power sold to the grid.

El-Tamaly, and Adel A. Elbaset (2006) [40] proposed a computer program to determine optimal design of PV system. The proposed computer program based on minimization of energy purchased from grid. A comparative study between three different configurations (stand-alone Photovoltaic Power System (PVPS) with Battery Storage (BS), PVPS interconnected with UG without BS and grid-connected PVPS accompanied with BS) has been carried out from economic and reliability points of view with the main goal of selecting suitable one, to be installed at Zâfarana site to feed the load requirement.

Ferna´ndez-Infantes *et al.* (2006) [41] developed a specific computer application for automated calculation of all relevant parameters of the installation, physical, electrical, economical, as well as, ecological for designing a PV system installation that may be either used for internal electric consumption or for sale using the premium subsidy awarded by the Spanish Government. It was found that economic incentives, like subsidies for part of the investment, and the chance to sell all the electricity generated at 6 times its market price, are required to make a PV installation profitable.

Li *et al.* (2009) [42] dealt with the sizing optimization problem of stand-alone PVPS using hybrid energy storage technology. The three hybrid power systems, i.e., PV/Battery system, PV/fuel cell (PV/FC) system, and PV/FC/Battery system, are optimized, analyzed and compared. The proposed PV/FC/Battery hybrid system was found to be the configuration with lower cost, higher efficiency, and less PV modules as compared with single storage system.

Mellit *et al.* (2009) [43] presented an overview of artificial intelligent techniques for sizing PV systems: stand-alone, grid-connected, PV-wind hybrid systems, etc. Their results show that the advantage of using an artificial intelligent-based sizing of PV systems providing good optimization, especially in isolated areas, where the weather data are not always available.

Ren *et al.* (2009) [44] dealt with the problem of optimal size of grid-connected PV system for residential application and developed a simple linear programming model for optimal sizing of grid-connected PV system. The objective of the study is to minimize the annual energy cost of a given customer, including PV investment cost, maintenance cost, utility electricity cost, subtracting the revenue from selling the excess electricity. It would be seen that the adoption of PV system offers significant benefits to household (reduced energy bills) and to the society (reduced $CO_2$ emissions) as a whole.

Kornelakis and Koutroulis (2009) [45] analyzed optimization of grid-connected PV systems using a list of commercially available system devices. The analysis was based on selecting the optimal number and type PV module installation, in such a way that the total net economic benefit achieved during the system's operational lifetime period is maximized.

Kornelakis and Marinakis (2010) [46] proposed an approach to select the optimal PV installation using Particle Swarm Optimization.

Kornelakis (2010) [47] presented a multi-objective optimization algorithm based on PSO applied to the optimal design of grid-connected PV systems. The proposed methodology intends to suggest the optimal number of system devices and the optimal PV module installation details, such that the economic and environmental benefits achieved during the system's operational lifetime period are both maximized.

Al-Salaymeh *et al.* (2010) [6] proposed a design of PV system to produce energy for basic domestic needs. The proposed design studied the feasibility of utilizing PV systems in a standard residential apartment in Amman city in Jordan to conduct energy and economic calculations. It was found that the calculated payback period high in a stand-alone system, to decrease payback period a grid-connected PV system was suggested. The output results of this study show that installation of PV system in a residential flat in Jordan may not be economically rewarding owing to the high cost of PV system compared to the cost of grid electricity.

Suryoatmojo *et al.* (2010) [48] presented a method to determine optimal capacities of PV system, battery bank and diesel generator unit according to minimum cost objective functions of system reliability and $CO_2$ emissions. The optimization method included studying on three different PV technologies: ASE-300 (mc-Si based EFG), Kyocera KC-120 (mc-Si based wafer) and AstroPower AP-120 (thin film Si). The optimization results indicates that the AP-120 module is recommended to be installed in the rural area case; East Nusa Tenggara, Indonesia.

Muneer *et al.* (2011) [49] proposed an optimization model to facilitate an optimal plan for investment in large-scale solar PV generation projects in Ontario, Canada. The optimal set of decisions includes the location, sizing, and time of investment that yields the highest profit. They considered various relevant issues associated with PV projects such as location-specific solar radiation levels, detailed investment costs representation, and an approximate representation of the transmission system.

Li *et al.* (2012) [50] studied a grid-connected PV system installed in an institutional building in Hong Kong. The analysis was based on two years measured data made in Hong Kong from 2008 to 2009. Technical data including available solar radiation and output energy generated were systematically recorded and analyzed. It was found that with Feed-in-tariff schemes, high electricity selling price can shorten the payback period for grid-connected PV system to a reasonable time period that should be less than the lifetime (e.g. less than 20 years).

Oko *et al.* (2012) [51] presented a design analysis of PV system to supply a Laboratory at the Department of Mechanical Engineering, University of Port Harcourt, Nigeria. An automated MS Excel spreadsheet was developed for the design and economic analyses of PV system. Their results show that, unit cost of electricity for the designed PV system is high compared to the current unit cost of the municipally supplied electricity, but will be competitive with lowering cost of PV system components and favorable government policies on Renewable Energy (RE).

Mehleri *et al.* (2013) [52] presented an optimization based approach for evaluation of RES on a Greek residential sector taking into account site energy loads, local climate data, utility tariff structure, characteristics of RE technologies (technical and financial) as well as geographical circumstances.

### 2.2.2 Power Quality Improvement of Grid-Connected Photovoltaic Systems

Prodanovic′ and Green (2003) [53] designed a filter and a complementary controller for a three-phase inverter that rejects grid disturbance, maintains good waveform quality and achieves real and reactive power control. A full discrete-time controller design has been presented and validated with experimental results using DSP implementation. Both voltage-mode and current-mode control have been examined in order to choose the appropriate control strategy for power quality. Both methods provide a solution for active and reactive power control but the current-mode control has been chosen for its advantages in respect of rejection by the current control loop of harmonic distortion present in the grid. The power quality has been demonstrated with time and frequency domain results showing the high quality of the currents injected into the voltage grid.

Oliva and Balda (2003) [54] presented a power quality study performed on a PV generator in order to estimate the effects that inverter-interfaced PV dispersed generation might have upon the quality of electric power. Different interpretations of the harmonic distortion limits set in the IEEE 519-1992 standard are performed together with a comparison with the BC Hydro’s harmonic current limits. This paper also includes a statistical analysis of all measurements recorded with the help of two PQ monitors, an evaluation of the results from a connection/disconnection test, and harmonic simulation results.

Sannino *et al.* (2003) [55] highlighted the concept of "custom power" for medium power applications. Advantages and disadvantages of several custom power devices have been pointed out. Both devices for mitigation of interruptions and voltage dips and devices for compensation of unbalance, flicker and harmonics were treated. It was concluded that custom power devices provide in many cases higher performance compared with traditional mitigation methods. However, the choice of the most suitable solution depends on the characteristics of the supply at the PCC, the requirements of the load and economics.

Li *et al.* (2005) [56] presented a three-phase four-wire grid-interfacing power quality compensator for compensating voltage unbalance and voltage sag, in a microgrid. During UG voltage unbalance, the proposed compensator, using a shunt and a series four phase-leg inverter, can enhance both the quality of power within the microgrid and the quality of currents flowing between the microgrid and UG. Functionally, the shunt four-leg inverter is controlled to ensure balanced voltages within the microgrid and to regulate power sharing among the parallel-connected DG systems. The series inverter is controlled complementarily to inject negative- and zero-sequence voltages in series to balance the line currents, while generating zero real and reactive power. During utility voltage sags, the series inverter can also be controlled to limit the flow of large fault currents using a proposed flux–charge control algorithm. The performance of the proposed compensator has been verified in simulations and experimentally using a laboratory prototype.

Teichmann and Bernet (2005) [57] evaluate three-level topologies as alternatives to two-level topologies for low-voltage applications. Topologies, semiconductor losses, filter aspects, part count, initial cost, and life-cycle cost were compared for a grid interface conventional drive application, and a high-speed drive application. It was found that a three-level topology is superior in terms of total semiconductor losses at switching frequencies as low as and beyond 2–3 kHz in practical applications. At switching frequencies above 5 kHz, the three-level converter always features lower losses.

Alepuz *et al.* (2006) [24] presented a novel approach for the connection of PV system to the UG by means of a three-level neutral-point clamped VSI (3L-NPCVSI). The controller of the system is based on the multivariable LQR control technique. The good performance of the system in both steady state and transient operation has been verified through simulation and experimentation using a 1-kW prototype, where a PC-embedded digital signal processor board is used for the controller implementation. With the model and regulator presented, a specific switching strategy to control the DC-link neutral-point voltage is not required.

Busquets-Monge *et al.* (2008) [58] proposed a control and modulation scheme for the connection of a set of PV arrays to a multilevel diode-clamped three-phase inverter. The scheme allows one to independently set each PV array voltage to its MPP without diminishing the quality of the output voltages. Comparing to a conventional system using a two-level inverter, this feature allows one to increase the power extracted, particularly under partial shades covering the PV facility or in case of mismatched PV arrays. Simulation and experimental tests have been conducted with three PV arrays connected to a four-level three-phase diode-clamped converter to verify the good performance of the proposed system configuration and control strategy.

Gajanayake *et al.* (2009) [59] presented a controller design for a Z-source inverter based flexible DG system to improve power quality of the UG. The controllers were designed to operate in two modes. The inverter injects high-quality current into the grid when the DG system operates in full capacity. When the system operates below its ratings, the designed controllers improve the voltage quality of the grid. The proposed control method was tested with simulation results obtained using MATLAB/Simulink/PLECS toolboxes and subsequently it was experimentally validated using a laboratory prototype. Simulation results show good reference tracking and harmonics performance.

Geibel *et al.* (2009) [60] demonstrated possibilities of inverter-coupled systems in terms of power quality and reliability improvement. Measurements for active power filters (series and shunt) as well as measurements of the behavior of inverter-coupled systems with UPS functionality during grid faults were shown and discussed. Implementation of these functionalities in real series products will strongly depend on the additional economic benefit. Reduced subsidies on renewable energy sources raise the possibilities for a high deployment of such systems.

Hosseini *et al.* (2009) [61] presented a control system that combines grid-connected PV system and power quality enhancement with two system configurations. In the first configuration, the PV panel is connected directly to active filter and the output voltage of PV panel is equal to the DC bus voltage in MPP. In the second configuration, due to low voltage of PV panel, it is connected to active filter through a DC–DC boost converter. The system can not only realize PV generation, but also suppress current harmonics and compensate reactive Power. Simulation results with PSCAD/EMTDC software show that the PV system can be used to provide the function of power quality managements and also to transfer its power to the ac local loads.

Luo *et al.* (2011) [62] developed a building integrated photovoltaic (BIPV) central inverter control strategy combined with reactive power compensation, harmonic suppression and grid-connected power generation. Recursive integral PI had been adopted to obtain precise current of a BIPV inverter. The improved ip-iq algorithm could detect the harmonics and reactive power rapidly. The introduction of network voltage forward feed control can effectively restrain system disturbance. Also, it enables BIPV inverter not only to provide active energy, but also to suppress the harmonics and reactive power current brought in by load. Prototype development based on simulation results and photovoltaic experimental platform had been set up and united control research had been done.

Wang *et al.* (2011) [63] proposed a grid-interfacing system topologies with enhanced voltage quality for microgrid applications. Two three-phase four-leg inverters, together with DC microsources and nonlinear loads, are employed to construct a general series–parallel grid-interfacing system. With the reconfigurable functionalities, the proposed systems have been compared with conventional series–parallel systems and shunt-connected systems, showing flexible applicability. The system also shows the possibility to achieve auxiliary functions such as voltage unbalance correction and harmonic current compensation. The proposed methods have been verified by experimental tests on a laboratory setup.

Bojoi *et al.* (2011) [64] proposed a control scheme for a single-phase H-bridge inverter with power quality features used in DG systems. The proposed scheme employed a current reference generator based on Sinusoidal Signal Integrator (SSI) and Instantaneous Reactive Power (IRP) theory together with a dedicated repetitive current controller. The idea is to integrate the DG unit functions with shunt active power filter capabilities. With this approach, the inverter controls the active power flow from the renewable energy source to the grid and also performs the nonlinear load current harmonic compensation by keeping the grid current almost sinusoidal. Experimental results have been obtained on a 4 kVA inverter prototype tested for different operating conditions. The experimental results have shown good transient and steady state performance in terms of grid current THD and transient response.

Kamatchi Kannan and Rengarajan (2012) [65] dealt with a model of PV array or battery operated DC–DC boost converter fed three-leg VSI with star/delta transformer for power quality improvement. A synchronous reference frame was proposed for three-phase four-wire Distribution Static Compensator (DSTATCOM) for reactive power compensation, source harmonic reduction, and neutral current compensation at the PCC. The PV array or battery operated boost converter was used to step up the voltage to match the DC-link requirement of the three-leg VSC. To derive the reference current in order to generate the firing pulse to the VSC, the overall system is designed, developed and validated by using MATLAB/Simulink environment.

### 2.2.3 Small-Signal Model of DC–DC Converter

Until now a numerous software applications of small-signal model for DC–DC converter applications have been developed to be utilized in controller design and increase converters' performance. These applications vary in various aspects such as PSCAD/EMTDC software, PSpice simulator, Internet-based platform PowerEsim and MATLAB/Simulink software package.

Mahdavi *et al.* (1997) [66] presented a generalized state-space averaging method to the basic DC–DC single-ended topologies. Simulation results were compared to the exact topological state-space model and to the well-known state-space averaging method.

Reatti and Kazimierczuk (2003) [67] presented a small-signal circuit model for pulse width modulated (PWM) DC–DC converters operated in discontinuous conduction mode. The proposed model is suitable for small-signal, frequency-domain representation of the converters.

Mohamed Assaf *et al.* (2005) [68] analyzed the nonlinear, switched, state-space models for buck, boost, buck–boost, and Cuk converters. MATLAB/Simulink was used as a tool for simulation in the study and for close loop system design.

Ghadimi *et al.* (2006) [69] presented a detailed small-signal and transient analysis of a full bridge PWM converter designed for high voltage, high power applications using an average model. The derived model was implemented in PSCAD/EMT tool and used to produce the small-signal and transient characteristics of the converter.

Mayo-Maldonado *et al.* (2011) [70] proposed an average large signal as well as small-signal dynamic model for the buck–boost converter to investigate the dynamic modeling, stability analysis and control of the continuous input current buck–boost DC–DC converter. Also, experimental results of a current-mode control based on Linux and an open-source real-time platform were presented.

Galia Marinova (2012) [71] dealt with the possibility to apply the PSpice simulator as a verification tool for switched mode power supply design with the Internet-based platform PowerEsim utilizing real component models in PSpice, which give better accuracy.

Ali Emadi (2013) [72] presented a modular approach for the modeling and simulation of multi-converter DC power electronic systems based on the generalized state-space averaging method. A modular modeling approach based on the generalized state-space averaging technique had been utilized to build large-signal models.

Modabbernia *et al.* (2013) [73] presented a complete state-space average model for the buck–boost switching regulators. The presented model included the most of the regulator's parameters and uncertainties.

Mashinchi Mahery and Babaei (2013) [74] proposed a new method for mathematical modeling of buck–boost DC–DC converter in CCM. The proposed method is based on Laplace and Z-transforms. The simulation results in PSCAD/EMTDC software as well as the experimental results were used to reconfirm the validity of the hypothetical investigation.

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