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Solar Photovoltaics Engineering

A Power Quality Analysis Using Matlab Simulation
Case Studies



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Dedicated to
MY FAMILY

Preface

This book comprises 10 chapters each of which covers the study on solar energy and its application in solar Photovoltaic grid connected systems. Power quality investigation has been carried highlighting the study of key power quality parameters. Author has made an endeavor to tailor the all chapters for an audience of university faculty members, students, researchers and practitioners in solar energy sector.

Chapter 1 mainly presents the world perspective and growth of electric power through conventional sources and its vis-à-vis comparative growth with various sources of renewable energy. It has been discussed that electric power has been one of the most critical component among others available required for infrastructure and crucial for economic growth and welfare of any nation. The growth of any developing nation mainly depends on various resources critically required in growth of infrastructure. This chapter also highlights the recent advancements recently taken place in renewable energy. The measures being adopted for building and supporting in the further renewable energy growth in developing and developed economies is also presented.

In Chapter 2, an introduction of a solar PV cell with its behavior with the help of its electrical circuits in ideal and practical conditions is presented. This description is carried out using its basic output current and output voltage equations. In addition, the various parameters as defined in a standard manufacturer data-sheet is discussed. The basic difference between a solar PV cell and a normal p-n junction diode is also described. The importance of MPP using $V-I$ and $P-V$ electrical characteristics is highlighted. In order to study any PV model, the dependence of a solar PV cell on variable solar radiation and ambient temperature is derived and discussed.

Chapter 3 has presented a discussion on advantages and limitations of crystalline and thin film technologies with their common features. This chapter has begun from by looking at the development of solar cells from the early stage. Then the commercial silicon wafer based solar cell technology is described. Special attention has been given to each thin film technology as its related material properties, fabrication techniques are discussed. The chapter has covered thin film technologies such as amorphous silicon, CdTe, CIGS, and thin film crystalline silicon solar cell technologies.

Chapter 4 has highlighted the needs of PV installation components other than PV panels. These components are jointly referred to as the Balance of System (BOS) and include the batteries, DC-DC converters, DC-AC converters for AC loads and grid connected systems. Since $P-V$ and $V-I$ curves of a solar panel are non-linear in nature, the need and importance of MPPT technique in extracting variable solar power at maximum points is described in PCS systems.

In chapter 5, the introduction of PQ and its concerns has been presented. The various PQ issues have been introduced and discussed according to IEEE and IEC standards. The effect of each of PQ issue has been described for a distribution system according to IEC standard. It is discussed that in electric power systems, hundreds of power generating stations and load centers are interconnected and operated. There are various PQ problems likewise, voltage sag, voltage swell, transients, voltage interruption, harmonics, noise and notching. Each PQ problem can be solved by the proper coordination among all power system components.

Chapter 6 has presented that Matlab is a software package, which can be used to perform analysis and solve mathematical and engineering problems. Introduction to various Matlab windows have been given and described. Simulink contains a library editor of tools from which we can build input/output devices and continuous and discrete time model simulations. Simulink has a comprehensive block library which can be used to simulate linear, non-linear or discrete systems. C codes can also be generated from Simulink models for embedded applications and rapid prototyping of control systems. This chapter also highlights the procedure for the operation of Simulink software with building blocks.

Chapter 7 has presented the modeling of solar PV single stage grid connected system at unity power factor. No transformer is used in the proposed system as it increases the level of harmonics in the overall system. The nature of real power generated by solar PV array through VSC has been shown and proved that whenever the power from grid is un-available, the real power requirement of the load is achieved by VSC. Data based MPPT is proposed through which behavior of actual DC link voltage is discussed.

In chapter 8, the simulation of the proposed system is performed under two different cases. In first case, the effect of changing power factor on active power, reactive power and THD values is observed. It is observed that the THD of grid current increases with increase in the phase angle of grid current VSC voltage. It affects the active power flow among VSC, load and utility grid. In the second case, the effect of changing frequency on active power, reactive power and THD

values is noticed. It is observed that the THD of VSC current increases whereas, the THD of grid current remains constant.

Chapter 9 has presented the analysis of two-stage solar PV grid connected system which is evaluated at linear RLC load. In DC-DC boost converter, the IC-MPPT technique which is capable to operate even under changing environmental conditions is implemented. Real and reactive power exchange is exchanged among VSC, load and utility grid. Voltage and current waveforms are presented. In order to evaluate the level of power quality, the THD analysis is carried out using FFT. It has been found that although level of harmonics generation from VSC is high, the control system is designed that level of harmonics is reduced for grid injected current.

Chapter 10 has discussed the system performance at P&O based MPPT technique for solar PV two-stage grid connected system. It has been found that harmonic level is reduced for converter current and grid injected current. However, this MPPT is not able to track the reference MPPT voltage accurately. This validates that this MPPT is not able to operate under wide range of changing environmental conditions. The behavior of voltage and current levels of VSC, load connected and utility grid has also been discussed. Active and reactive power exchange among VSC, load connected and utility grid has also been highlighted.

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List of Abbreviations

Air Mass	(AM)
Balance of System	(BOS)
Basic Linear Algebra Subprograms	(BLAS)
Bipolar Junction Transistor	(BJT)
Building Integrated PV	(BIPV)
Clean Power Plan	(CPP)
Copper Indium Gallium Diselenide	(CIGS)
Conference of Parties	(COP)
Electromagnetic Compatibility	(EMC)
Energy Information Administration	(EIA)
European Nation	(EN)
Fast Fourier Transform	(FFT)
Gallium arsenide	(GaAs)
Gigawatts-Thermal	(GW _{th})
Incremental Conductance	(IC)
Individual Harmonic Distortion	(IHD)
Independent Power Producers	(IPP)
Institution of Electrical and Electronic Engineering	(IEEE)
International Energy Outlook	(IEO)
Intended Nationally Determined Contributions	(INDCs)
Integrated Development Environment	(IDE)
International Electro-technical Commission	(IEC)
kilo-watt-hour	(KWH)
Linear Algebra PACKage	(LAPACK)