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SOLAR FARMS

THE EARTHSCAN EXPERT GUIDE TO
DESIGN AND CONSTRUCTION OF
UTILITY-SCALE PHOTOVOLTAIC SYSTEMS

Susan Neill, Geoff Stapleton
and Christopher Martell



Solar Farms

The Earthscan Expert Guide to Design
and Construction of Utility-scale
Photovoltaic Systems

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and Christopher Martell*

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Solar Farms

The market and policy impetus to install increasingly utility-scale solar systems, or solar farms (sometimes known as solar parks or ranches), has seen products and applications develop ahead of the collective industry knowledge and experience. Recently however, the market has matured and investment opportunities for utility-scale solar farms or parks as part of renewable energy policies have made the sector more attractive. This book brings together the latest technical, practical and financial information available to provide an essential guide to solar farms, from design and planning to installation and maintenance.

The book builds on the challenges and lessons learned from existing solar farms, that have been developed across the world, including in Europe, the USA, Australia, China and India. Topics covered include system design, system layout, international installation standards, operation and maintenance, grid penetration, planning applications, and skills required for installation, operation and maintenance. Highly illustrated in full colour, the book provides an essential practical guide for all industry professionals involved in or contemplating utility-scale, grid-connected solar systems.

Susan Neill is Director of Training and Engineering at Global Sustainable Energy Solutions (GSES), Australia.

Geoff Stapleton is Managing Director of GSES and a part-time lecturer at the School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Australia.

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Solar:

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Acronyms and abbreviations

AC	alternating current
alt_{EQ}	solar altitude during the equinox
alt_s	solar altitude during the solstice
ANSI	American National Standards Institute
ARENA	Australian Renewable Energy Agency
AS	Australian standard
a-Si	Amorphous silicon
AVR	Automatic voltage regulation
AWG	American wire gauge
BLM	Bureau of Land Management
BMS	Building management system
BoS	balance of system
BS	British Standards
CAD	computer-aided design
CB	circuit breaker
CCC	current-carrying capacity
CCTV	closed-circuit television
CdTe	cadmium telluride
CEC	Commission of the European Communities
CEFC	clean energy finance corporation
CfD	contract for difference
CIGS	copper–indium–gallium–diselenide
CSA	cross-sectional area
DC	direct current
DIN	German standards
DNI	direct normal irradiance
DNO	distribution network operator
DRED	demand response-enabled devices
ECT	equivalent cell temperature
EFI	earth fault interrupter
EIA	environmental impact analysis/assessment
ELV	extra low voltage
EMI	electromagnetic interference
EMS	energy management system
EN	European standards
EPBC	environmental protection and biodiversity conservation
EPC	engineering, procurement and construction
FCAS	frequency control ancillary services
FiT	feed-in tariff
GFDI	ground fault detection interrupter
GHGs	greenhouse gases

GHI	global horizontal irradiation
GIS	geographic information system
GSC	solar constant
GSES	global sustainable energy solutions
GUI	graphical user interface
GW	gigawatt
HMI	human-machine interface
HS	health and safety
HV	high voltage
I_{trip}	rated trip current
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronics Engineers
Imp	current at maximum power point
IP	ingress protection
IREC	Interstate Renewable Energy Council
IRR	internal rate of return
I_{sc}	short-circuit current
ISO	International Organization for Standardization
IT	information technology
JIS	Japanese Standards
LCF	local control facility
LCOE	levelised cost of electricity
LV	low voltage
MC	multi-contact
MCB	miniature circuit breaker
MET	meteorological
MJ	Mega-joule
MPP	maximum power point
MPPT	maximum power point tracker
MTBF	mean time between failures
MV	medium voltage
MVA	megavolt ampere
MW	megawatt
MW _p	megawatt peak
NA	not applicable
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NOCT	nominal operating cell temperature
NPV	net present value
NREL	National Renewable Energy Laboratory
NSW	New South Wales
NZS	New Zealand standard
O&M	operations and maintenance
OLE	object linking and embedding
OPC	open platform communications
OSHA	occupational safety and health administration
PF	power factor

PLC	programmable logic controller
Pmp	maximum power point
POI	point of interface
PPA	power purchase agreement
PPP	public-private partnership
PR	performance ratio
PSH	peak sun hours
PV	photovoltaic
RAPID	regulatory and permitting information desktop
RCD	residual current device
RECs	renewable energy certificates
REIPP	renewable energy independent power producer procurement
RFP	request for proposals
ROW	right of way
RPS	renewable portfolio standard
RTU	remote telemetry unit
SCADA	supervisory control and data acquisition
SRECs	solar renewable energy credits
SRMC	short-run marginal cost
STC	standard test conditions
SWMS	safe work methods statements
TNO	transmission network operator
UK	United Kingdom
UL	Underwriters' Laboratory
UPS	uninterruptible power supply
USA	United States of America
UV	ultra-violet
VAR	volt-ampere reactive
Vmp	voltage at maximum power point
Voc	open-circuit voltage
WA	Western Australia
Wh	watt hour
Wp	watt-peak

Notes on the authors

Susan Neill has been involved in the Australian and international renewable energy industry for 30 years. Susan has extensive experience arising from her experience with the rapid market development in grid-connected solar since 2005. Susan had worked with international product manufacturers and distributors as well as providing EPC services before joining GSES, where she has held the position of training and engineering director since 2009.

Geoff Stapleton has been part of the renewable energy industry for over 30 years and has been instrumental in the development of industry training and capacity building in Australia and many other countries: Ghana, Sri Lanka, Malaysia, China and the Pacific region. Geoff's vast engineering experience has been instrumental in the development of Australian standards and guidelines for the renewable energy industry. Geoff has been a part-time lecturer at the University of New South Wales, Australia for the past 15 years.

Christopher Martell has held the position of Principal Engineer for GSES since 2014. Christopher has extensive experience through his multidiscipline engineering qualifications, including the design and implementation of large-scale grid-connected solar systems. Christopher has contributed to the vast information base required to write this publication and to ensure currency for the equipment and practices included.

Preface and acknowledgements

The world of renewable energy has expanded from the time when it was considered only as a potential source of energy for niche applications: renewable energy is now touted as one of the foundations for mitigating global climate change. Solar photovoltaics are able to be deployed to meet the insatiable power demands ranging from a solar lantern through to powering populations in cities.

The impetus of solving the world's global warming problem and the need to find suitable alternative energy sources has contributed to and highlighted the enormous growth in the photovoltaic industry since 2009. Since that time, the prices for solar modules have reduced by a factor of five and the price for solar systems has reduced by a factor of three. The 2014 IEA Roadmap states that the cumulative installed capacity of solar PV has grown at an average rate of 49% per year in the years up to 2014.

A stark indication of this industry's stellar growth can be seen when comparing the total installed capacity of solar PV at the end of 2009 at 23 GW compared to the figure of 227 GW installed capacity at the end of 2015.

The solar farm, or utility-scale solar installation, is now an established part of international power supply landscape as well as being the catalyst for the introduction and adaptation of financial instruments and funding models so that the services for solar farms are part of mainstream banking, finance and the law.

This publication describes the solar technology used in solar farms; the technology's performance characteristics; all enabling equipment used in a solar farm; the extensive system design required; the supporting technical, social and environmental aspects; how to estimate a solar farm's performance and financial metrics.

Susan Neill, Geoffrey Stapleton and Christopher Martell from Global Sustainable Energy Solutions Pty Ltd (GSES) have extensive knowledge and experience in grid-connected solar systems and these systems' engineering, design, compliance and performance. As the authors of this publication, they have welcomed the opportunity to produce this *Solar Farms* publication, as this industry continues its international growth.

Given the rapid growth in the international market for solar farms, extensive time and resources were necessary to research and document the status of this constantly evolving market. Kayla Inglis in GSES's Sydney office has worked extensively on this publication: collecting the technology and market information, researching, writing content and developing the chapters to meet the broad, international context of this topic. GSES thanks those industry participants who have supported the development of this publication and provided information and images and we trust these are correctly acknowledged.

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