

**TECHNO-ECONOMICS OF
SOLAR PV BASED HYBRID POWER SYSTEMS FOR
TELECOM TOWERS IN INDIA**

NIRANJAN RAO DEEVELA



**DEPARTMENT OF ENERGY SCIENCE AND ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
MAY 2024**

**TECHNO-ECONOMICS OF
SOLAR PV BASED HYBRID POWER SYSTEMS FOR
TELECOM TOWERS IN INDIA**

by

NIRANJAN RAO DEEVELA

Department of Energy Science and Engineering

Submitted

in fulfilment of the requirements of the degree of

Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI
MAY 2024**

Certificate

This is to certify that the thesis entitled **Techno-economics of Solar PV Based Hybrid Power Systems for Telecom Towers in India** being submitted by **Mr. Niranjana Rao Devela** to Indian Institute of Technology Delhi in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** is a record of Bonafide research work carried out by him under our guidance and supervision at **Department of Energy Science and Engineering, Indian Institute of Technology Delhi**. The results obtained herein have not been submitted in part or in full to any other University or Institute for the award of any degree to the best of our knowledge.

Dr. Tara C. Kandpal

Professor

Department of Energy Science and Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi - 110016

Dr. Bhim Singh

Professor

Department of Electrical Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi - 110016

Acknowledgments

I express my deepest gratitude to the individuals and institutions whose unwavering support and encouragement have been instrumental in my doctoral journey. Foremost, I am profoundly indebted to my research supervisors, **Prof. Bhim Singh** and **Prof. Tara C Kandpal**, for their exceptional guidance, valuable insights, and continuous encouragement throughout my research. Their mentorship has been invaluable, shaping my academic and personal growth in immeasurable ways.

I extend heartfelt thanks to the members of my SRC for their valuable feedback and constructive criticism, which significantly enhanced the quality of my research. I am also extremely grateful to the Head of the Department of Energy Science and Engineering for providing facilities and extending every possible support. My gratitude extends to the dedicated faculty members of the department and my fellow researchers for their collaborative spirit and scholarly discussions that have broadened my horizons.

I would also like to gratefully acknowledge the highly useful inputs provided by the esteemed examiners of my Ph.D. thesis as the same have helped in improving the content and quality of the thesis in its revised version. My heartfelt thanks to them.

I am thankful to my seniors from the group Dr. Anish Malan, Dr. Ashish Sharma, Dr. Chandan Sharma, Mr. Dhanne Singh, Dr. Ram Kumar Pal, Dr. Sunil, Dr. Tarun Kumar Aseri, Dr. Thomar, and as well as current research scholars Mr. Naveen, Mr. Shantanu Kumar, Mr. Shubham, Mr. Sumeet Kumar, Mr Rajeev and other fellow researchers of the Department of Energy Science and Engineering, for their shared experiences and unwavering support during my period of study. Special thanks to my senior, Dr. Farheen, for her unwavering support and encouragement.

I am deeply indebted to my former colleagues Mis Ayumi Fujino, Dr. Rene Van Berkel, Mr. Sanjaya Man Shrestha, and Mr. Suresh Kennit at the United Nations Industrial Development Organization (UNIDO), Mr. Milind Deore at the Bureau of Energy Efficiency (BEE), Dr. Karun Malhotra, Mr. Sairam at Murata Business Engineering India (Murata), and Mr. Rajeev Ralhan from PricewaterhouseCoopers (PwC) India for their support during my doctoral work. Their understanding and encouragement allowed me to balance my professional responsibilities with academic pursuits.

To my steadfast friends Mr. Aditya, Mr. Ameya, Mr. Amit, Mr. Bhaswanth, Mrs. Deepali, Mr. Laxmikanth, Mrs. Prerana, Mr. Sampath, Mr. Samved, Mr. Suresh, Mrs. Swapna, and Mr. Vaibhav who stood by me with unwavering support and encouragement, I am grateful for your kindness and motivation. Your belief in my abilities kept me going during challenging times.

I wish to honor the memory of my grandfather, Shri Ramachandraiah Deeveal, whose influence on my academic journey has been profound and indelible. Even though he has recently passed away, his spirit and the lessons he imparted continue to inspire me daily.

I am immensely grateful to my parents, Shri. Kannamma Deevela and Shri. Ramanarsaiah Deevela, for their boundless love, endless sacrifices, and unwavering belief in my abilities. Their encouragement and support have been my pillar of strength. A special mention is reserved for my wife, Swetha Thalluri, and my precious son, Darahas Deevela. Their endless patience, love, and sacrifices over the past few years have been my driving force. Their unwavering support provided the emotional sustenance I needed to navigate the complexities of this doctoral journey. I owe them more than words can express.

In conclusion, I am thankful to each person mentioned above and countless others who have been part of my academic odyssey. Your contributions, whether big or small, have shaped this thesis and my overall doctoral experience. I am truly blessed to have such an incredible support system.

With heartfelt gratitude,

Niranjan Rao Deevela

Abstract

A techno-economic assessment of solar PV based hybrid systems for powering 4G and 5G telecom towers in India is presented. A preliminary attempt has been made to design and analyze different feasible hybrid power supply configurations including renewable energy-based systems using HOMER at different locations in India. The study internalizes location-specific input parameters, such as duration of grid power outage, solar resource availability, tariff of grid electricity (which may include demand charges, unit purchase price of grid electricity), unit selling price of excess solar PV electricity to the grid, and unit purchase price of diesel while sizing the hybrid system. The economic viability of solar PV based hybrid systems designed to power 4G and 5G telecom towers at 25 locations across the country have also been assessed. Linear multiple regression expressions to estimate cost of electricity (CoE) delivered by solar PV based hybrid systems for powering 4G and 5G telecom towers have also been presented and the same can be used for preliminary estimation of the value of CoE for any location in the country. An attempt to assess and estimate the carbon dioxide emissions has been made along with estimation of CO₂ emissions mitigation potential and unit cost of carbon dioxide mitigation with the adoption of solar PV-based hybrid power systems for telecom towers in India. A preliminary attempt to assess the likely impact of a few incentives on the financial attractiveness of solar PV based hybrid power systems for telecom towers in India has also been made.

It is observed that the grid power availability in India is still not reliable enough to ensure continuous operation of the telecom towers. Moreover, for most of the locations studied, with larger durations of continuous grid power unavailability, inclusion of DG in the hybrid system is almost inevitable. The solar PV based hybrid power supply configurations may be considered for large scale adoption to meet the electricity demand of telecom towers. As compared to the conventional, commonly adopted hybrid power supply option of grid electricity with diesel generator for telecom towers, the PV based hybrid system is financially more attractive and also contributes towards mitigation of carbon dioxide emissions. Integrating a photovoltaic component into the hybrid system for powering 4G / 5G telecom towers significantly decreases the dependence on DG, lowers grid electricity consumption, and has the potential to generate revenue from surplus electricity fed into the grid. Since the values of the measures of financial performance such as Discounted Payback Period and Internal Rate of Return of the incremental investment on a solar PV based hybrid system for powering telecom tower may not satisfy the investment criteria for the corporate sector, appropriate incentives may be offered to improve their financial attractiveness. Space requirement for practical deployment of solar PV systems may be an important limiting factor particularly in urban areas.

सार

इस शोधग्रंथ में, भारत में 4जी और 5जी दूरसंचार टावरों को बिजली देने के लिए सौर फोटोवोल्टेइक (पीवी) आधारित हाइब्रिड निकायों का तकनीकी-आर्थिक मूल्यांकन प्रस्तुत किया गया है। भारत में विभिन्न स्थानों पर HOMER (तंत्रांश) का उपयोग करके नवीकरणीय ऊर्जा आधारित प्रणालियों सहित विभिन्न संभव हाइब्रिड बिजली आपूर्ति विन्यासों की रचना और विश्लेषण करने का प्रारंभिक प्रयास किया गया है। यह अध्ययन स्थान-विशिष्ट निविष्ट मापदंडों, जैसे कि ग्रिड-ऊर्जा कटौती की अवधि, सौर संसाधन की उपलब्धता, ग्रिड-बिजली का प्रशुल्क (जिसमें मांग शुल्क, ग्रिड-बिजली की प्रति इकाई खरीद मूल्य शामिल हो सकता है), अतिरिक्त सौर पीवी बिजली की प्रति इकाई बिक्री मूल्य और डीजल की इकाई खरीद मूल्य को हाइब्रिड निकायों को डिजाइन करते समय समावेशित करता है। देश भर में 25 स्थानों पर 4जी और 5जी दूरसंचार टावरों को बिजली देने के लिए डिज़ाइन किए गए सौर पीवी आधारित हाइब्रिड निकायों की वित्तीय व्यवहार्यता का आकलन भी किया गया है। 4जी और 5जी टेलीकॉम टावरों को बिजली देने के लिए सौर पीवी आधारित हाइब्रिड निकायों द्वारा प्रदत्त बिजली की लागत का अनुमान लगाने के लिए रैखिक एकाधिक प्रतिगमन अभिव्यक्तियां भी प्रस्तुत की गई हैं और उनका उपयोग देश में किसी भी स्थान के लिए बिजली की लागत के प्रारंभिक अनुमान के लिए किया जा सकता है। भारत में दूरसंचार टावरों के लिए सौर पीवी-आधारित हाइब्रिड निकायों की कार्बन डाइऑक्साइड उत्सर्जन शमन क्षमता और कार्बन डाइऑक्साइड शमन की इकाई लागत के आकलन के साथ-साथ कार्बन डाइऑक्साइड उत्सर्जन के आकलन का प्रयास किया गया है। भारत में दूरसंचार टावरों के लिए सौर पीवी आधारित हाइब्रिड निकायों की वित्तीय व्यवहार्यता पर कुछ प्रोत्साहनों के संभावित प्रभाव का आकलन करने का प्रारंभिक प्रयास भी किया गया है।

इस अध्ययन से यह पता चला है कि भारत में ग्रिड-बिजली की उपलब्धता अभी भी दूरसंचार टावरों के निरंतर संचालन को सुनिश्चित करने के लिए पर्याप्त नहीं है। इसके अतिरिक्त, चयन किए गए अधिकांश स्थानों के लिए, बड़ी अवधि तक निरंतर ग्रिड-बिजली अनुपलब्धता के साथ, हाइब्रिड निकायों में डीज़ल जनित्र (डीजी) को शामिल करना लगभग अपरिहार्य है। दूरसंचार टावरों की बिजली की मांग को पूरा करने के लिए सौर पीवी आधारित हाइब्रिड निकायों को बड़े पैमाने पर अपनाने पर विचार किया जा सकता है। दूरसंचार टावरों के लिए डीजी के साथ ग्रिड-बिजली के पारंपरिक, हाइब्रिड बिजली आपूर्ति विकल्प की तुलना में, सौर पीवी आधारित हाइब्रिड निकाय वित्तीय रूप से अधिक आकर्षक है और कार्बन डाइऑक्साइड उत्सर्जन को कम करने में भी योगदान देता है। 4जी/5जी टेलीकॉम टावरों को

बिजली देने के लिए हाइब्रिड निकाय में पीवी को एकीकृत करने से डीजी पर निर्भरता काफी कम हो जाती है और ग्रिड-बिजली की खपत कम हो जाती है। इसके अतिरिक्त, अनेक स्थानों पर, ग्रिड में आपूर्ति की गई अधिशेष बिजली से राजस्व उत्पन्न करने की क्षमता भी होती है। चूंकि सौर पीवी आधारित हाइब्रिड निकायों के लिये वित्तीय गुणवत्ता के मापदंड जैसे कि डिस्काउन्टेड पेबैक पीरियड, नेट प्रेज़ेन्ट वैल्यू, इन्टरनल रेट ऑफ रिटर्न आदि का मान कॉर्पोरेट निवेशकों के लिये अनेक स्थानों पर आकर्षक नहीं है, समुचित प्रोत्साहन के उपायों की आवश्यकता होगी। कुछ स्थानों पर पीवी मॉड्यूल्स को लगाने के लिये आवश्यक जगह की कमी भी एक चुनौती हो सकती है।

Contents

Certificate	i
Acknowledgments	ii
Abstract	iv
Contents	vii
List of Figures	xii
List of Tables	xviii
Nomenclature	xxi
Chapter – 1	1
1. Introduction	1
1.1. Background	1
1.2. Mobile Telephone Communication Network.....	3
1.3. Current and Future Mobile Communication Technology and Subscriber Growth.....	4
1.4. Global Status of Telecommunication Market	7
1.4.1. Status of Indian Telecommunication Market	11
1.5. Telecom Towers	14
1.5.1. Types of Telecom Towers	15
1.5.2. Configurations of Base Transceiver Stations (BTS)	17
1.6. Conventional Options to Meet Electricity Requirement of Telecom Towers.....	17
1.6.1. Electricity Requirement of Telecom Towers.....	19
1.6.2. Electrical Loads in Telecom Towers	19
1.6.3. Energy Carrier Mix and Options for Meeting Electricity Demand	23
1.7. Renewable Energy based Options for Powering Telecom Towers.....	28
1.7.1. Solar Photovoltaics (PV) Systems:	30
1.7.2. Wind Energy based Systems:	31
1.7.3. Systems based on Biofuels	31
1.7.4. Pico-hydro Systems	32
1.7.5. Fuel-cell based Systems Powered with Renewable Source of Energy.....	32
1.7.6. Battery Energy Storage.....	33
Chapter – 2	36
2. Literature Review	36
2.1. Overview	36

2.2.	Configurations of Renewable Energy based Hybrid Systems	36
2.2.1.	PV, DG and Battery based System	36
2.2.2.	PV, Wind and Battery based System	38
2.2.3.	PV, Wind, DG and Battery based System	40
2.2.4.	Wind, DG and Battery based System	41
2.2.5.	PV, Wind, Fuel Cell and Battery based System	42
2.3.	Techno-economic Feasibility of Hybrid Systems for Electricity Supply to Telecom Towers.....	44
2.4.	Policy Environment for Adoption of Renewable Energy Based Hybrid Systems for Telecom Towers.....	46
2.5.	Motivation and Objectives of the Study.....	48
Chapter – 3		52
3.	Preliminary Analysis of Potential Designs of Renewable Energy based Hybrid Systems for Telecom Towers in India	52
3.1.	Introduction.....	52
3.2.	Potential Configurations of Hybrid Systems for Powering Telecom Towers.....	52
3.3.	Methodology	56
3.3.1.	Selecting Hybrid Power Supply Configurations.....	57
3.3.2.	Electrical Load of Telecom Tower	57
3.3.3.	Assessing Grid Power Unavailability	57
3.3.4.	Locations Selected for Preliminary Study	62
3.3.5.	HOMER and its Application to Design Hybrid Power Supply Systems for Telecom Towers.....	63
3.3.6.	Details of Input Parameters for HOMER based Design of Hybrid Power Supply Systems for Telecom Towers	65
3.4.	Results and Discussion.....	69
3.5.	Summary	77
Chapter – 4		78
4.	Techno-Economics of Solar PV based Hybrid Power Systems for 4G Telecom Towers in India	78
4.1.	Introduction	78
4.2.	Annual Hours of Grid Power Unavailability, Solar Resource and Other Relevant Data for 132 Locations in India	80
4.2.1.	Load Profile of Telecom Tower (BTS)	80
4.2.2.	Teledensity.....	80
4.2.3.	Unavailability of Power Supply from Grid	82

4.2.4. Grid Electricity Tariffs	88
4.2.5. Unit Purchase Price of Diesel	88
4.2.6. Solar Resource Availability	88
4.2.7. Costs of Different Components of Hybrid System.....	90
4.3. Hybrid System Configuration, Modeling, and Techno-economic Analysis	90
4.3.1. Methodology for Selection of 25 Locations for Detailed Analysis	90
4.3.2. Hybrid System Configuration.....	90
4.3.3. Components of a Hybrid System.....	94
4.3.4. Modeling and Optimization of Hybrid Systems	95
4.3.5. HOMER based Financial Appraisal Metrics	98
4.3.6. Setting of HOMER Optimization Algorithm	98
4.4. Results and Discussion.....	100
4.4.1. Annual Electricity Output of Hybrid Systems.....	100
4.4.2. Techno-economic Analysis of Hybrid Systems	102
4.4.3. Techno-economic Comparison of Hybrid Systems	
(Grid+PV+DG) With Conventional Hybrid Systems (Grid+DG).....	105
4.4.4. Effect of Independent Causal Factors on the Optimal Design of	
Solar PV based Hybrid Systems	107
4.5. Summary	113
Chapter – 5	116
5. Techno-Economics of Solar PV based Hybrid Power Systems	
for 5G Telecom Towers in India	116
5.1. Introduction	116
5.2. Hybrid System Configuration and Techno-economic Analysis.....	116
5.2.1. Load of 5G Telecom Tower	116
5.2.2. Identification of Locations for analyzing Renewable Energy based Hybrid	
Systems for 5G Telecom Towers	117
5.2.3. Solar PV based Hybrid System Design using HOMER	119
5.2.4. Financial Appraisal of PV based Hybrid Systems.....	119
5.3. Results and Discussion.....	122
5.3.1. Annual Electricity Output of Solar PV based and Conventional	
Hybrid Systems.....	122
5.3.2. Financial Performance of Hybrid Systems	125
5.3.3. Comparison of Financial Performance of Solar PV based Hybrid	
Systems for Powering 5G and 4G Telecom Towers	130

5.3.4. Likely Impact(s) of Future Developments.....	131
5.4. Summary	133
Chapter – 6	135
6. Assessment of Carbon Dioxide Emissions from Telecom Towers and Mitigation Potential of Solar PV based Hybrid System for Powering Telecom Towers in India	135
6.1. Introduction	135
6.2. Methodology	135
6.2.1. Electricity Load of Telecom Tower for Estimating Carbon Dioxide Emissions.....	136
6.2.2. Power Supply Options	136
6.2.3. Estimation of CO ₂ Emissions and Corresponding Mitigation Potential	
as well as unit cost of Emissions Mitigation	137
6.3. Results and Discussion.....	142
6.3.1. CO ₂ Emissions from 4G Telecom Towers	142
6.3.2. CO ₂ Emissions from 5G Telecom Towers	144
6.3.3. Likely Impact of Increased Level of Adoption of 5G Telecom Towers on CO ₂ Emissions	145
6.3.4. Consideration of Embodied CO ₂ Emissions in the Solar PV System	147
6.3.5. CO ₂ Emissions Mitigation Potential of Solar PV based Hybrid Power Supply Systems for 4G Telecom Towers	149
6.3.6. CO ₂ Emissions Mitigation Potential of Solar PV based Hybrid Power Supply Systems Powering 5G Telecom Towers.....	150
6.3.7. Unit Cost of Carbon Dioxide Emissions Mitigation for Solar PV based Hybrid Systems for Telecom Towers	151
6.4. Summary	152
Chapter – 7	156
7. Analysis of Feasible Options to Incentivize Adoption of Solar PV based Hybrid Power Systems for Telecom Towers in India	156
7.1. Introduction	156
7.2. Barriers to Adoption of Solar PV based Hybrid Systems for Powering Telecom Towers in India.....	157
7.3. Methodology	160
7.4. Results and Discussion.....	167
7.5. Summary	203
Chapter – 8	204
8. Conclusions and Recommendations for Further Work	204

8.1.	Conclusions	204
8.2.	Recommendations for Further Work.....	207
	Appendices	209
A.	Appendix A	209
B.	Appendix B	226
C.	Appendix C	232
D.	Appendix D	240
	References	246
	List of Publications	279
	About the Author	280

List of Figures

Figure 1.1	A schematic of the components and connectivity of typical mobile telecom network	5
Figure 1.2	Steps involved in making a call from a Mobile Phone A to another Mobile Phone B (The numbers shown correspond to mobile telecom network in India in March 2021)	6
Figure 1.3	Number of mobile telephone connections in 2021 and projections for 2025 in different regions of the world (GSMA, 2022a, 2020b, 2018)	8
Figure 1.4	Region-wise penetration rates of mobile telephone connections as a percentage of the total population (GSMA, 2022a, 2020b, 2018)	8
Figure 1.5	Existing and projected global numbers on mobile subscribers and smartphone ownership (GSMA, 2023)	9
Figure 1.6	Regional distribution of commercial deployments of 5G services across the world (GSMA, 2022a)	10
Figure 1.7	Share of 2G,3G,4G and 5G technologies in total subscribers (GSMA, 2022a)	10
Figure 1.8	Subscribers of 5G telecom services in 2022 and estimated numbers for 2030 (GSMA, 2022a)	11
Figure 1.9	Time variation of Tele-density in India (DoT 2018, 2022)	12
Figure 1.10	Details of technology specific share of BTS (%) in some states/service areas of India in 2022 (TRAI, 2022c)	14
Figure 1.11	Distribution of telecom tower ownership by different tower companies in India (DOT, 2022)	15
Figure 1.12	Wireless network coverage of (a) Vodafone Idea Limited, (b) Airtel India Limited, (c) Reliance Jio Infocomm Limited, (d) Bharat Sanchar Nigam Limited in India ((nperf, 2023) maps accessed on 07-04-2024)	16
Figure 1.13	Schematic diagrams of (a) Ground Based Tower (b) Ground Based Pole used as Telecom Tower (DoI 2021)	17
Figure 1.14	Share of electricity consumption by active and passive equipment in a telecom tower (Carmine Lubritto 2008; Roy 2008)	19
Figure 1.15	Typical interconnectivity of electrical equipment in a telecom tower (Cordiner et al., 2017; Karthigeyan et al., 2017; Ramamurthi and Jhunjunwala, 2012)	20
Figure 1.16	Typical break-up of the load due to AC and DC equipment in (a) indoor telecom tower and (b) outdoor telecom tower with BTS configuration of (4+4+4) (Prasad 2008)	22
Figure 1.17	Hourly load profile of different BTS configurations (Ramamurthi and Jhunjunwala 2012)	23
Figure 1.18	Specific fuel consumption of (a)15kW fixed speed DG and (b)12kW variable speed DG at different loads (Jhunjunwala et al. 2012)	27
Figure 2.1	A schematic of a power supply configuration based on PV, DG and battery storage system	37
Figure 2.2	A schematic of a power supply configuration based on PV, wind and battery storage systems	39
Figure 2.3	A schematic of a power supply configuration based on DG, wind, PV and battery storage systems	41

Figure 2.4	A schematic of a power supply configuration based on Wind, DG and battery storage systems	42
Figure 2.5	A schematic of a power supply configuration based on PV array, fuel cell and batter storage systems	43
Figure 3.1	A schematic of a hybrid system for power supply	54
Figure 3.2	Geographical distribution of hybrid systems installed across the world	55
Figure 3.3	Distributed energy sources and energy storage options being employed in various hybrid systems	56
Figure 3.4	A schematic representation of methodology adopted for preliminary analysis of potential designs of renewable energy-based hybrid systems for telecom towers in India	58
Figure 3.5	Schematics of power supply configurations based on (a) grid with battery, (b) grid, DG and battery, (c) grid, PV and battery, and (d) grid, WT and battery	59
Figure 3.6	Schematics of power supply configurations based on (e) grid, PV, DG and battery (f) grid, PV, WT and battery, (g) grid, WT, DG and battery, and (h) grid, PV, WT, DG and battery	60
Figure 3.7	Hourly load profile of an outdoor BTS with (4+4+4) configuration	61
Figure 3.8	A schematic describing various steps involved in use of HOMER (HOMER Pro, 2022)	64
Figure 3.9	Monthly average daily values of global solar radiation availability for Vadodara (HOMER Pro, 2022)	66
Figure 3.10	Monthly average wind speed (m/s) data for Vadodara (HOMER Pro, 2022)	66
Figure 3.11	Schematic depicting different total durations of power unavailability considered in the study (a) one continuous outage; (b) several short duration outages	67
Figure 3.12	Values of CoE for eight power supply configurations under different cases of continuous power unavailability modes at Varanasi	76
Figure 3.13	Values of CoE for eight power supply configurations under different cases of intermittent power unavailability modes	76
Figure 4.1	Hourly load profile of an outdoor BTS with (4+4+4) configuration	81
Figure 4.2	The overall tele-density (%) of different states of India (as on 30th November 2022)	81
Figure 4.3	Annual hours of grid power unavailability at 132 locations	83
Figure 4.4	State specific grid electricity tariffs for commercial consumers	89
Figure 4.5	Unit purchase price of diesel in various states in India (as on 30th November 2022)	89
Figure 4.6	Annual average global solar radiation in India (Jamil et al., 2016)	91
Figure 4.7	Methodology adopted for selecting 25 locations for detailed investigation	93
Figure 4.8	Locations (25) selected for detailed techno-economic analysis	94
Figure 4.9	A schematic of grid-connected PV and DG-based hybrid system	95
Figure 4.10	Annual status of hourly grid power unavailability modelled in HOMER (HOMER Pro, 2022)	98
Figure 4.11	Operation status of different constituents of the hybrid system under LF strategy (obtained from HOMER based analysis for Ameerpeth location)	99
Figure 4.12	Effect of annual hours of grid power unavailability on NPC and CoE	103
Figure 4.13	A component wise breakup of NPC as well as DG operating hours for the hybrid system at 25 locations	103

Figure 4.14	(a) Contributions of different components of hybrid system to its NPC,..... (b) Shares of capital costs of PV and DG in NPC, (c) Shares of replacement cost, and (d) Share of operation and maintenance (O&M) cost respectively in NPC of the hybrid systems at the three locations 105	105
Figure 4.15	Values of Net Present Cost of proposed hybrid and conventional hybrid systems for powering BTS of a 4G telecom tower at 25 locations 106	106
Figure 4.16	Values of Cost of Electricity of proposed hybrid and conventional hybrid systems for powering BTS of a 4G telecom tower at 25 locations 107	107
Figure 5.1	The hourly variation in telecom traffic and electricity load profile of a 5G base station..... 117	117
Figure 5.2.	A component wise breakup of different constituents of NPC and CoE 127	127
Figure 6.1	Methodology to estimate CO ₂ emissions from a telecom tower in India using conventional hybrid power supply system (grid and DG)..... 138	138
Figure 6.2	Methodology to estimate CO ₂ emissions mitigation due to adoption of Solar PV based hybrid power supply options for telecom towers 139	139
Figure 6.3	Number of telecom towers in different telecom circles and technology specific average number of BTSs per telecom tower in India (TRAI, 2022c, 2022a)..... 140	140
Figure 6.4	Annual CO ₂ emissions from 4G telecom tower at 25 locations 143	143
Figure 6.5	Annual CO ₂ emissions from a 5G telecom tower at 25 locations 144	144
Figure 6.6	Total annual CO ₂ emissions using conventional hybrid as well as solar PV based hybrid systems for powering telecom towers at 25% penetration of 5G services 147	147
Figure 6.7	Total annual CO ₂ emissions using conventional hybrid as well as solar PV based hybrid systems for powering telecom towers at 50% penetration of 5G services 147	147
Figure 6.8	Total annual CO ₂ emissions using conventional hybrid as well as solar PV based hybrid systems for powering telecom towers at 75% penetration of 5G services 148	148
Figure 6.9	Total annual CO ₂ emissions using conventional hybrid as well as solar PV based hybrid systems for powering telecom towers at 100% penetration of 5G services 148	148
Figure 6.10	Total annual CO ₂ emissions using conventional hybrid and solar PV based hybrid systems for powering telecom towers at different degrees of penetration of 5G services..... 148	148
Figure 6.11	Effect of embodied emission on total annual CO ₂ emissions while using solar PV based hybrid system for powering telecom towers 149	149
Figure 6.12	Annual CO ₂ emissions mitigation potential of solar PV based hybrid systems for powering 4G telecom tower..... 149	149
Figure 6.13	Annual CO ₂ emissions mitigation potential of solar PV-based hybrid systems..... for powering 5G telecom towers 150	150
Figure 6.14	Estimates of total annual CO ₂ emission mitigation potential for different..... levels of penetration of 5G services in existing telecom towers in India 151	151
Figure 6.15	GHG abatement cost along with estimated values of the unit cost of CO ₂ mitigation for solar PV based hybrid systems for telecom towers (Lee et al.,2020; McKinsey & Company, 2022; Pauline et al., 2021; Per-Anders et al., 2010)..... 153	153
Figure 6.16	Unit cost of CO ₂ emissions mitigation by adopting solar PV-based hybrid system for powering 4G telecom towers..... 154	154

Figure 6.17	Unit cost of CO ₂ emissions mitigation by adopting solar PV-based hybrid system for powering 5G telecom towers.....	154
Figure 7.1	Effect of RECs on Net Present Value (NPV) of hybrid systems for powering 4G telecom towers at 25 locations in India	173
Figure 7.2	Effect of RECs on Discounted Payback Period (DPP) of hybrid systems for powering 4G telecom towers at 25 locations in India	173
Figure 7.3	Effect of RECs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	174
Figure 7.4	Effect of RECs on Internal Rate of Return (IRR) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	174
Figure 7.5	Effect of RECs on Net Present Value (NPV) of hybrid systems for powering 5G telecom towers at 25 locations in India	175
Figure 7.6	Effect of RECs on Discounted Payback Period (DPP) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	175
Figure 7.7	Effect of RECs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 5G telecom towers at 25 locations in India	176
Figure 7.8	Effect of RECs on Internal Rate of Return (IRR) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	176
Figure 7.9	Effect of CERUs on Net Present Value (NPV) of hybrid systems for powering 4G telecom towers at 25 locations in India	178
Figure 7.10	Effect of CERUs on Discounted Payback Period (DPP) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	178
Figure 7.11	Effect of CERUs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	179
Figure 7.12	Effect of CERUs on Internal Rate of Return (IRR) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	179
Figure 7.13	Effect of CERUs on Net Present Value (NPV) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	180
Figure 7.14	Effect of CERUs on Discounted Payback Period (DPP) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	180
Figure 7.15	Effect of CERUs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	181
Figure 7.16	Effect of CERUs on Internal Rate of Return (IRR) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	181
Figure 7.17	Combined effect of RECs and CERUs on Net Present Value (NPV) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	182
Figure 7.18	Combined effect of RECs and CERUs on Discounted Payback Period (DPP) of hybrid systems for powering 4G telecom towers at 25 locations in India ...	182
Figure 7.19	Combined effect of RECs and CERUs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 4G telecom towers at 25 locations in India ...	183
Figure 7.20	Combined effect of RECs and CERUs on Internal Rate of Return (IRR) of hybrid systems for powering 4G telecom towers at 25 locations in India ...	183
Figure 7.21	Combined effect of RECs and CERUs on Net Present Value (NPV) of hybrid systems for powering 5G telecom towers at 25 locations in India ...	184
Figure 7.22	Combined effect of RECs and CERUs on Discounted Payback Period (DPP) of hybrid systems for powering 5G telecom towers at 25 locations in India ...	184
Figure 7.23	Combined effect of RECs and CERUs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 5G telecom towers at 25 locations in India ...	185

Figure 7.24	Combined effect of RECs and CERUs on Internal Rate of Return (IRR) of hybrid systems for powering 5G telecom towers at 25 locations in India ...	185
Figure 7.25	Effect of AD on Net Present Value (NPV) of hybrid systems for powering 4G telecom towers at 25 locations in India	188
Figure 7.26	Effect of AD on Discounted Payback Period (DPP) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	188
Figure 7.27	Effect of AD on Benefit to Cost Ratio (B/C) of hybrid systems for powering 4G telecom towers at 25 locations in India	189
Figure 7.28	Effect of AD on Internal Rate of Return (IRR) of hybrid systems for powering 4G telecom towers at 25 locations in India	189
Figure 7.29	Effect of AD on Net Present Value (NPV) of hybrid systems for powering 5G telecom towers at 25 locations in India	190
Figure 7.30	Effect of AD on Discounted Payback Period (DPP) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	190
Figure 7.31	Effect of AD on Benefit to Cost Ratio (B/C) of hybrid systems for powering 5G telecom towers at 25 locations in India	191
Figure 7.32	Effect of AD on Internal Rate of Return (IRR) of hybrid systems for..... powering 5G telecom towers at 25 locations in India	191
Figure 7.33	Effect of PTCs on Net Present Value (NPV) of hybrid systems for powering 4G telecom towers at 25 locations in India	192
Figure 7.34	Effect of PTCs on Discounted Payback Period (DPP) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	193
Figure 7.35	Effect of PTCs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 4G telecom towers at 25 locations in India	193
Figure 7.36	Effect of PTCs on Internal Rate of Return (IRR) of hybrid systems for powering 4G telecom towers at 25 locations in India.....	194
Figure 7.37	Effect of PTCs on Net Present Value (NPV) of hybrid systems for powering 5G telecom towers at 25 locations in India	194
Figure 7.38	Effect of PTCs on Discounted Payback Period (DPP) of hybrid systems for powering 5G telecom tower s at 25 locations in India.....	195
Figure 7.39	Effect of PTCs on Benefit to Cost Ratio (B/C) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	195
Figure 7.40	Effect of PTCs on Internal Rate of Return (IRR) of hybrid systems for powering 5G telecom towers at 25 locations in India.....	196
Figure C.1	Annual profile of 5G telecom tower load served, grid electricity purchases and sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Kotanka	232
Figure C.2	Annual profile of 5G telecom tower load served, grid electricity purchases & sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Carambolim.....	233
Figure C.3	Annual profile of 5G telecom tower load served, grid electricity purchases & sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Baijnathpur.....	234
Figure C.4	Annual profile of 5G telecom tower load served, grid electricity purchases and sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Allipur	235
Figure C.5	Annual profile of 5G telecom tower load served, grid electricity purchases & sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Marol.....	236

Figure C.6	Annual profile of 5G telecom tower load served, grid electricity purchases and sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Kamrup Metro.....	237
Figure C.7	Annual profile of 5G telecom tower load served, grid electricity purchases and sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Bahadurpur.....	238
Figure C.8	Annual profile of 5G telecom tower load served, grid electricity purchases and sales, electricity produced by DG and Solar PV power output of Solar PV based hybrid system at Sector 37 – Chandigarh.....	239

List of Tables

Table 1.1	Technology-wise Numbers of Base Transceiver Stations (BTSs) in some states/service areas of India in 2022	13
Table 1.2	Configurations of BTSs used in a telecom tower (BIL, 2010)	18
Table 1.3	Various possible BTS configurations with minimum required power rating of passive equipment (Prasad 2008).....	21
Table 1.4	Cooling load details for different BTS configurations (as presented by a telecom tower company) (Xiaoqin et al. 2014)	24
Table 1.5	Summary of annual hours of grid power unavailability in 132 locations in India (Prayas Energy Group, 2019).....	25
Table 1.6	Comparison among different types of battery technologies (Karthigeyan et al. 2017).....	34
Table 3.1	Configurations of installed hybrid systems based on distributed energy sources	53
Table 3.2	Summary of continuous duration of power unavailability in a year considered for analysis in this chapter at 36 locations across the country	61
Table 3.3	Summary of day wise total duration of power unavailability in a year considered for analysis in this chapter at 36 locations across the country	67
Table 3.4	Values of input parameters used in analysis with HOMER	69
Table 3.5	Summary of CoE and NPC of conventional hybrid power supply configurations under different hours of grid power unavailability conditions as depicted in Figure 3.11.....	70
Table 3.6	Summary of CoE of renewable energy based hybrid power supply configurations at 10 different locations under different hours of Continuous (C) and Intermittent (I) grid power unavailability scenarios as depicted in Figure 3.11	72
Table 3.7	Summary of NPC of renewable energy based hybrid power supply configurations at 10 different locations under different hours of Continuous (C) and Intermittent (I) grid power unavailability scenarios as depicted in Figure 3.11	74
Table 3.8	Annual amount of electricity (kWh) contributed by different components of lowest CoE configurations (Grid,PV and Battery and Grid,PV, DG and Batter) for all the scenarios of grid power unavailability at Varanasi	77
Table 4.1	Summary of daily hours of grid power unavailability (min, avg and max) in 132 locations in India (Prayas Energy Group, 2019)	84
Table 4.2	Input parameters used for optimization of hybrid Systems	92
Table 4.3	Location-specific input parameters used in the techno-economic analysis for the selected 25 locations (SC; State Capital; DH: District Head Quarter; VG: Village) - values are compiled during November 2022	97
Table 4.4	Sizes of different components of hybrid system and corresponding contribution to electricity production	101
Table 4.5	Combinations of causal factors and their effect on share of different components of solar PV based hybrid system	111
Table 4.6	Comparison of the values of cost of electricity of solar PV based hybrid system for powering 4G telecom tower as estimated from linear multiple	

	regression expression with the values obtained from detailed HOMER based analysis	112
Table 4.7	Comparison of the cost of electricity of solar PV based hybrid system for powering 4G telecom tower as estimated using linear multiple regression expressionl as against values obtained by HOMER based analysis for four new locations in the country.....	113
Table 5.1.	Input parameters used for modeling and techno-economic analysis of solar PV based hybrid systems for powering 5G telecom towers	118
Table 5.2.	Location Specific NPC and CoE values of proposed solar PV based hybrid system as well as conventional hybrid system	120
Table 5.3.	Capacity of each component of conventional hybrid and solar PV based hybrid systems at 25 locations and corresponding electricity production.....	123
Table 5.4	Comparison of the predicted values of cost of electricity of solar PV based hybrid system for powering 5G telecom tower linear multiple regression expression with values as obtained HOMER (for 25 locations considered in the study).....	126
Table 5.5	Comparison of predicted values of cost of electricity for solar PV based hybrid system for powering 5G telecom tower as estimated using linear multiple regression expression as against values obtained by HOMER (four new locations in the country)	127
Table 5.6.	Measures of financial viability of solar PB based hybrid system (PV+DG+Grid) for powering 5G telecom tower	129
Table 5.7.	Financial performance parameters of solar PV based hybrid systems for powering 5G and 4G telecom towers.....	130
Table 5.8.	Capacity and electricity share of each component of conventional hybrid and solar PV based hybrid systems at three locations for powering 6G telecom tower.....	133
Table 6.1	Total annual CO2 emissions from telecom towers at selected locations in India using conventional hybrid (grid electricity and DG) and solar PV based hybrid power supply system with the adoption of solar PV based hybrid systems.....	146
Table 7.1	Financial performance of solar PV based hybrid systems for powering 4G telecom tower at 25 locations (without considering any incentives).....	169
Table 7.2	Financial performance of solar PV based hybrid systems for powering 5G telecom tower at 25 locations (without considering any incentives).....	171
Table 7.3	Effect of the provision of RECs on financial attractiveness of solar PV based hybrid systems for powering 4G and 5G telecom towers	177
Table 7.4	Effect of CERU prices on financial attractiveness of solar PV based hybrid systems for powering 4G and 5G telecom towers.....	186
Table 7.5	Combined effect of REC's and CERU's on financial attractiveness of solar PV based hybrid systems for powering 4G and 5G telecom towers.....	187
Table 7.6	Effect of PTC on financial attractiveness of solar PV based hybrid systems for powering 4G and 5G telecom towers.....	192
Table 7.7	Comparison of discounted payback period (DPP) under different higher tariffs for excess PV electricity fed into the grid for 4G telecom tower (font colour indicates less than 4 years DPP, font colour indicates less than 6 years DPP, and font colour indicates less than 8 years DPP).....	197

Table 7.8	Comparison of internal rate of return (IRR) under different higher tariffs for excess PV electricity fed into the grid for 4G telecom tower (font colour..... indicates above 15% IRR, font colour indicates above 20% IRR, and font colour indicates above 25% IRR).....	198
Table 7.9	Comparison of discounted payback period under different higher tariffs for excess PV electricity fed into the grid for 5G telecom tower (font colour indicates less than 4 years DPP, font colour indicates less than 6 years DPP, and font colour indicates less than 8 years DPP).....	199
Table 7.10	Comparison of internal rate of return (IRR) under different higher tariffs for excess PV electricity fed into the grid for 5G telecom tower (font colour indicates above 15% IRR, font colour indicates above 20% IRR, and font colour indicates above 25% IRR).....	200
Table 7.11	Effect of RECs (total PV electricity produced) on financial performance parameters of a solar PV based hybrid system for powering 4G and 5G telecom towers at 25 locations in India	201
Table 7.12	Effect of CERUs (total PV electricity produced) on financial performance parameters of a solar PV based hybrid system for powering 4G and 5G telecom towers at 25 locations in India	202
Table A.1	Summary of field installations of renewable energy based hybrid systems for powering telecom towers in urban and rural areas.....	209
Table A.2	Potential technology options for meeting electricity requirement of telecom..... towers and their operation modalities in different grid power and resource availability scenarios	217
Table A.3	Validation of HOMER results based on the results of studies undertaken by other authors	220
Table A.4	Comparison of Unit Cost of Electricity Produced by solar PV component in the hybrid system as obtained by HOMER with the values obtained by using standard formulae of engineering economics	222
Table A.5	Calculation of Unit Cost of Electricity Produced by DG by using standard formulae of engineering economics	224
Table B.1	Sizes of different components of Grid+PV +Battery+DG based hybrid system, corresponding contribution to electricity production and economic performance parameters.....	226
Table B.2	Sizes of different components of Grid+PV+Wind+Battery+DG based hybrid system, corresponding contribution to electricity production and economic performance parameters	228
Table B.3	Sizes of different components of PV+ Battery+DG based hybrid system, corresponding contribution to electricity production and economic performance parameters.....	230
Table D.1	Effect of including a 300 Ah battery in Grid+DG+PV configuration on the cost of electricity delivered at three locations	240
Table D.2	A brief summary of literature review dealing with impact of climate change on the solar/wind resource availability.....	241

Nomenclature

Symbols

AD_s	Annual amount of diesel saved
AEE_{feedback}	Annual amount of excess solar PV electricity fed into the grid
AGE_{red}	Annual amount of reduction in the grid electricity consumed by the telecom tower with the adoption of the solar PV based hybrid system
B_{AD100}	Present value of income tax benefit due to provision of 100% accelerated depreciation (AD) in the 1 st year
B_{AD40}	Cumulative present value of income tax benefit due to provision of 40% AD in the first two years and 20% in the third year
B_{AD50}	Cumulative present value of income tax benefit due to provision of 50% AD in the first two years
B_{ADSL}	Income tax benefit for the project with an assumption of straight line depreciation
B_{hyd}	Monetary benefits of solar PV based hybrid system
B_{inc}	Incremental annual revenue generation
CEF_{diesel}	Carbon fraction in the diesel
CEF_{grid}	Carbon dioxide emission factor for grid electricity
Cem_{diesel}	CO ₂ emissions mitigation due to diesel saving
Cem_{feedback}	CO ₂ emissions mitigation due to excess electricity fed back to grid
Cem_{grid}	CO ₂ emissions mitigation due to decrease in grid electricity consumption
Cem_{total}	Annual amount of CO ₂ emissions mitigated
CO ₂	Carbon Dioxide
CO _{2eq}	Carbon Dioxide Emissions equivalent
$C_{o,i}$	Incremental capital cost
C_{om}	Annual cost of operation and maintenance (O&M) specific to solar PV module, controller, and converter
CPV_{ptc}	Cumulative present value of all PTC benefits
d	the discount rate (in fraction)
MB_{diesel}	Monetary value of diesel saved
MB_{feedback}	Additional revenue generated by selling excess electricity back to grid
MB_{grid}	Monetary value of avoided electricity purchased from grid
MB_{total}	Annual monetary benefits
N	Useful life of solar PV based hybrid system
N_{ceru}	Total number of CERUs earned
N_{ptc}	Total annual number of RECs
N_{recs}	Total annual number of RECs
R_{itax}	rate of income tax
R_{CCAD100}	Effective reduction in the capital cost due to the provision of 100% AD in the first year
R_{CCAD50}	Effective reduction in the capital cost due to provision of 50% AD in each of the first two years
R_{CCAD40}	Effective reduction in the capital cost due to provision of 40% AD in each of the first two years and 20% in the third year

T_{ptc}	Period of benefit of PTCs
UC_{em}	Unit cost of carbon dioxide mitigation
UP_{ceru}	Unit selling price of CERUs
UPP_{diesel}	Unit purchase price of diesel
$UPP_{grid\ electricity}$	Unit purchase price of grid electricity
UP_{ptc}	Value of PTC for each unit of excess solar PV electricity fed into the grid
UP_{reccs}	Unit selling price of RECs
$USPE_{feedback}$	Unit selling price of excess solar PV electricity to the grid

Acronyms

\$	Dollar
1G	1st Generation
2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
A	Ampere
AAU	Active Antenna Units
AC	Alternating Current
AD	Accelerated Depreciation
Ah	Ampere Hour
ATC	American Tower Company
ATS	Automatic Transfer Switch
B/C	Benefit to Cost Ratio
BBU	Base Band Units
BSC	Base Station Controller
BSNL	Bharat Sanchar Nigam Limited
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CAGR	Compounded Annual Growth Rate
CC	Carbon Capture
CCS	Carbon Capture and Storage
CERU	Certified Emissions Reduction Units
CHP	Combined Heat and Power
CoE	Cost of Electricity
COP21	21 st Conference of Parties
CPCB	Central Pollution Control Board (India)
CPU	Central Processing Unit
CSP	Concentrated Solar Power
CSR	Corporate Social Responsibility
DC	Direct Current
DG	Diesel Generator
DH	District Headquarters

DoT	Department of Telecommunication
DPP	Discounted Payback Period
DR	Demand Response
DWDM	Dense Wavelength-Division Multiplexing
EIR	Equipment Identity Register
ETS	Emission Trading Scheme
EU	European Union
FC	Fuel Cell
FCC	Federal Communication Commission
FDI	Foreign Direct Investment
GBT	Ground Based Towers
GHGs	Greenhouse Gas
GHI	Global Horizontal Irradiance
GHz	Giga Hertz
GMSC	Gateway Mobile Service Switching Centers
GPS	Global Positioning System
GSMA	Global System for Mobile Communications Association
GT	Gas Turbine
GW	Gigawatt
HLR	Home Location Register
HOMER	Hybrid Optimization of Multiple Energy Resources
ICT	Information and Communication Technology
IDU	Indoor Unit
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IRR	Internal Rate of Return
ISDN	Integrated Services Digital Network
kg	Kilogram
kVA	kilovolt Ampere
kW	kilowatt
kWh	Kilowatt Hour
kW _p	kilowatt (peak)
LCOE	Levelized Cost of Electricity
LF	Load Following
LFP	Lithium iron phosphate
LPG	Liquefied Petroleum Gas
MAX	Maximum
MA	Municipal Area
MCB	Miniature Circuit Breaker
MIDC	Maharashtra Industrial Development Corporation
MIMO	Multi-Input and Multi-Output
MIN	Mobile Identification Number

MNRE	Ministry of New and Renewable Energy
MNOs	Mobile Network Operators
MoC&I	Ministry of Commerce and Industry
MPPT	Maximum Power Point Tracking
MSC	Mobile Service Switching Centers
MTNL	Mahanagar Telephone Nigam Limited
MUX	Multiplexer
MW	MegaWatt
MWH	MegaWatthour
NPC	Net Present Cost
NPV	Net Present Value
NREL	National Renewable Energy Laboratory, (USA)
NSS	The network Switching Subsystem
NTP	National Telecom Policy
O&M	Operation and Maintenance
ODU	Outdoor Unit
OEMs	Original Equipment Manufacturers
OTN	Optical Transport Network
PCC	Point of Common Coupling
PEM	Proton-Exchange Membrane
PHP	Pico Hydro Plant
PLMN	Public Land Mobile Network
PTC	Production Tax Credit
PV	Photovoltaics
PWD	Public Works Department
RECs	Renewable Energy Certificates
RETs	Renewable Energy Technologies
RF	Radio Frequency
RRU	Remote Radio Unit
Rs.	Indian Rupee
RTT	Rooftop Towers
SC	State Capital
SFC	Specific Fuel Consumption
SIM	Subscriber Identity Module
SMPS	Switched Mode Power Supply
SOC	State of Charge
ToD	Time of the Day
TR	Ton of Refrigeration
TRAI	Telecom Regulatory Authority of India
TRAU	Transponding Rate and Adaption Unit
TRX	Transceiver
TT	Telecom Tower
US	United States

V	Voltage
VG	Village
VLR	Visitor Location Register
VRLA	Valve Regulated Lead Acid
W	Watts
WCDMA	Wideband Code Division Multiple Access
WT	Wind Turbine