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

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by

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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. Niranjan Rao Deevela** 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.

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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 CO_2 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 मॉडयूल्स को लगाने के लिये आवश्यक जगह की कमी भी एक चुनौती हो सकती है।

Contents

List of Figures

List of Tables

Nomenclature

Symbols

AD_s	Annual amount of diesel saved
$AEE_{fedback}$	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 1st 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
$Cem_{fedback}$	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
$MB_{fedback}$	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_{cm}	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_{recs}	Unit selling price of RECs
$USPE_{fedback}$	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	Transpoding 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