DESIGN AND IMPLEMENTATION OF SOLAR PV GRID INTERFACED SYSTEMS AND APPLICATIONS TO EV CHARGING

VANDANA JAIN

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA
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by

VANDANA JAIN

Department of Electrical Engineering

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Dedicated to

My family and all the teachers whom I came across at different stages during my life.

CERTIFICATE

It is certified that the thesis entitled "**DESIGN AND IMPLEMENTATION OF SOLAR PV GRID INTERFACED SYSTEMS AND APPLICATIONS TO EV CHARGING**," being submitted by **Ms. Vandana Jain** for award of the degree of **Doctor of Philosophy** in the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of the student work carried out by her under my supervision and guidance. The matter embodied in this thesis, has not been submitted for the award of any other degree or diploma.

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(Dr. Bhim Singh)
Professor
Electrical Engineering Department
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016, India

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ABSTRACT

This thesis presents the solar photovoltaic based electrical vehicle charging station interfaced to the three phase grid. The EV battery is charged using the power generated by the PV array and the surplus power is supplied to the grid. During the grid failure, the PV array is used to feed the power to the local loads connected at the charging station. However, in case of insufficient PV array generation, the EV battery discharges to provide the power to the local load. The design of the charging station is further extended by connecting an auxiliary battery energy storage, which acts as buffer to provide uninterrupted power to the charging stations during emergency situations. The configurations of the EV charging station are identified on the basis of the connection/disconnection with the grid as grid connected mode/standalone mode, number of stages of power conversion as single stage or double stage, battery energy storage connection i.e., directly connected at the DC-link or via DC-DC (bidirectional) converter. In a double stage system, a boost converter performs the MPPT (Maximum Power Point Tracking) operation for the extraction of the maximum power from the PV array and the second stage is VSC (Voltage Source Converter), which is used for the conversion of DC power generated by the PV array to the AC power to be interfaced with the grid. However, in a single stage topology, boost converter stage is eliminated and VSC is used to perform both the MPPT and DC-AC conversion. There are several issues with the grid like harmonics in the grid currents, deterioration in the power factor, distortion and unbalance in the grid voltages. The VSC switching pulses are generated by implementation of the proper control algorithm, mitigates all the above mentioned issues. An improved generalized integrator-based control is presented for the three phase double-stage grid interfaced PV system. It is used for harmonics mitigation, reactive power compensation, unity power factor operation, and grid currents balancing. The perturb and observe based MPPT algorithm is implemented for the extraction of the peak power from the PV array used in the system. Moreover, an adaptive synchronization controller is used to feed the local load in the absence of the grid. The new adaptive control is demonstrated for the three-phase single stage grid connected PV array based EV charging system. The system is tested under different condition such as with and without local loads, grid connected mode, standalone mode of operation, etc. The positive sequence component of the grid voltage is used for the estimation of the unit templates to generate the balanced and sinusoidal grid currents even under abnormal operating scenarios. The synchronization technique is used to switch between the grid connected control and the standalone mode of operation. The generalized integrator-based control is used to achieve optimal operation of

three-phase double stage and single stage grid interfaced electric vehicle charging stations while feeding the power to the local loads. The bi-directional buck-boost converter-based electric vehicle load is used under various operating scenarios. Detailed performance is studied under abnormalities in the grid such as voltage sag, voltage swell, grid outage, recovery of the grid, etc. The controller is developed for an optimal operation of the three-phase grid interfaced solar photovoltaic array system-based electric vehicle charging station with and without a buck-boost converter controlled battery energy storage. The dynamic performance of the system has been demonstrated for several practical scenarios such as grid outage, grid recovery, charging and discharging of electric vehicles, etc. Moreover, a synchronization controller is used to facilitate the smooth transition between grid-connected mode to islanded mode and vice-versa. All the identified configurations are modeled and simulated in the MATLAB/Simulink and the simulated results are validated by test results on the prototype developed in the laboratory.

सार

यह थीसिस तीन चरण ग्रिड से जुड़े सौर फोटोवोल्टिक आधारित विद्युत वाहन चार्जिंग स्टेशन प्रस्तुत करता है। EV बैटरी को PV सरणी द्वारा उत्पन्न शक्ति का उपयोग करके चार्ज किया जाता है और अतिरिक्त बिजली की आपूर्ति ग्रिड को की जाती है। ग्रिड की विफलता के दौरान, चार्जिंग स्टेशन से जुड़े स्थानीय भार को बिजली खिलाने के लिए पीवी सरणी का उपयोग किया जाता है। हालांकि, अपर्याप्त पीवी सरणी पीढ़ी के मामले में, स्थानीय लोड को शक्ति प्रदान करने के लिए ईवी बैटरी डिस्चार्ज हो जाती है। चार्जिंग स्टेशन के डिजाइन को एक सहायक बैटरी ऊर्जा भंडारण को जोड़कर आगे बढ़ाया जाता है, जो आपातकालीन स्थितियों के दौरान चार्जिंग स्टेशनों को निर्बाध बिजली प्रदान करने के लिए बफर के रूप में कार्य करता है। ईवी चार्जिंग स्टेशन के विन्यास की पहचान ग्रिड से कनेक्शन/डिस्कनेक्शन के आधार पर ग्रिड कनेक्टेड मोड/स्टैंडअलोन मोड, सिंगल स्टेज या डबल स्टेज के रूप में बिजली रूपांतरण के चरणों की संख्या, बैटरी ऊर्जा भंडारण कनेक्शन यानी सीधे कनेक्टेड के आधार पर की जाती है। डीसी-लिंक या डीसी-डीसी (द्विदिशात्मक) कनवर्टर के माध्यम से। एक डबल स्टेज सिस्टम में, एक बूस्ट कन्वर्टर PV सरणी से अधिकतम शक्ति के निष्कर्षण के लिए MPPT (अधिकतम पावर प्वाइंट ट्रैकिंग) ऑपरेशन करता है और दूसरा चरण VSC (वोल्टेज सोर्स कन्वर्टर) है, जिसका उपयोग DC के रूपांतरण के लिए किया जाता है। ग्रिड के साथ इंटरफेस करने के लिए एसी पावर के लिए पीवी सरणी द्वारा उत्पन्न बिजली। हालांकि, सिंगल स्टेज टोपोलॉजी में, बूस्ट कन्वर्टर स्टेज को खत्म कर दिया जाता है और वीएससी का इस्तेमाल एमपीपीटी और डीसी-एसी रूपांतरण दोनों को करने के लिए किया जाता है। ग्रिड के साथ कई मुद्दे हैं जैसे ग्रिड धाराओं में हार्मोनिक्स, पावर फैक्टर में गिरावट, ग्रिड वोल्टेज में विकृति और असंतुलन। वीएससी स्विचिंग पल्स उचित नियंत्रण एल्गोरिदम के कार्यान्वयन से उत्पन्न होते हैं, उपरोक्त सभी मुद्दों को कम करते हैं। थ्री फेज डबल-स्टेज ग्रिड इंटरफेस पीवी सिस्टम के लिए एक बेहतर सामान्यीकृत इंटीग्रेटर-आधारित नियंत्रण प्रस्तुत किया गया है। इसका उपयोग हार्मोनिक्स शमन, प्रतिक्रियाशील शक्ति क्षतिपूर्ति, एकता शक्ति कारक संचालन और ग्रिड धाराओं के संतुलन के लिए किया जाता है। गड़बड़ी और निरीक्षण आधारित एमपीपीटी एल्गोरिथम को सिस्टम में प्रयुक्त पीवी सरणी से पीक पावर के निष्कर्षण के लिए लागू किया गया है। इसके अलावा, ग्रिड की अनुपस्थिति में स्थानीय भार को खिलाने के लिए एक अनुकूली तुल्यकालन नियंत्रक का उपयोग किया जाता है। नया अनुकूली नियंत्रण थ्री-फेज सिंगल स्टेज ग्रिड कनेक्टेड पीवी एरे आधारित ईवी चार्जिंग सिस्टम के लिए प्रदर्शित किया गया है। सिस्टम का परीक्षण विभिन्न परिस्थितियों में किया जाता है जैसे कि स्थानीय भार के साथ और बिना, ग्रिड कनेक्टेड मोड, ऑपरेशन का स्टैंडअलोन मोड, आदि। ग्रिड वोल्टेज के सकारात्मक अनुक्रम घटक का उपयोग संतुलित और साइनसॉइडल ग्रिड उत्पन्न करने के लिए यूनिट टेम्पलेट्स के आकलन के लिए किया जाता है। असामान्य परिचालन परिदृश्यों के तहत भी धाराएं। सिंक्रोनाइज़ेशन तकनीक का उपयोग ग्रिड से जुड़े नियंत्रण और ऑपरेशन के स्टैंडअलोन मोड के बीच स्विच करने के लिए किया जाता है। सामान्यीकृत इंटीग्रेटर-आधारित नियंत्रण का उपयोग स्थानीय भार को बिजली की आपूर्ति करते हुए तीन-चरण डबल चरण और एकल चरण ग्रिड इंटरफेस वाले

इलेक्ट्रिक वाहन चार्जिंग स्टेशनों के इष्टतम संचालन को प्राप्त करने के लिए किया जाता है। द्वि-दिशात्मक हिरन-बूस्ट कनवर्टर-आधारित इलेक्ट्रिक वाहन लोड का उपयोग विभिन्न ऑपरेटिंग परिदृश्यों के तहत किया जाता है। ग्रिड में असामान्यताओं के तहत विस्तृत प्रदर्शन का अध्ययन किया जाता है जैसे कि वोल्टेज शिथिलता, वोल्टेज प्रफुल्लित, ग्रिड आउटेज, ग्रिड की वसूली, आदि। नियंत्रक को तीन-चरण ग्रिड इंटरफेस्ड सौर फोटोवोल्टिक सरणी प्रणाली-आधारित इलेक्ट्रिक वाहन के इष्टतम संचालन के लिए विकसित किया गया है। एक हिरन-बूस्ट कनवर्टर के साथ और बिना चार्जिंग स्टेशन नियंत्रित बैटरी ऊर्जा भंडारण। ग्रिड आउटेज, ग्रिड रिकवरी, इलेक्ट्रिक वाहनों की चार्जिंग और डिस्चार्जिंग आदि जैसे कई व्यावहारिक परिदृश्यों के लिए सिस्टम के गतिशील प्रदर्शन का प्रदर्शन किया गया है। इसके अलावा, एक सिंक्रोनाइज़ेशन कंट्रोलर का उपयोग ग्रिड-कनेक्टेड मोड से आइलैंडेड मोड के बीच सुचारू संक्रमण की सुविधा के लिए किया जाता है। और इसके विपरीत। सभी पहचाने गए कॉन्फ़िगरेशन को MATLAB/Simulink में मॉडलिंग और सिम्युलेटेड किया जाता है और नकली परिणाम प्रयोगशाला में विकसित प्रोटोटाइप पर परीक्षण परिणामों द्वारा मान्य होते हैं।

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LIST OF ABBREVIATIONS

PV	Photovoltaic
PQ	Power Quality
EV	Electric Vehicle
SOC	State of Charge
MPPT	Maximum Power Point Tracking
PID	Proportional Integral Derivative
BES	Battery Energy Storage
VSC	Voltage Source Converter
CSC	Current Source Converter
DSTATCOM	Distribution Static Compensator
PCC	Point of Common Coupling
INC	Incremental Conductance
P&O	Perturb and Observe
AFLL	Advanced Frequency Locked Loop
IANF-FLL	Improved Adaptive Notch Filter Frequency Locked Loop
ENF	Enhanced Notch Filter
MINF-QSG	Multiple-Improved-Notch-Filter Quadrature Signal Generator
MVF-FLL	Multi-Variable Filter Frequency Locked Loop
ILST	Improved Linear Sinusoidal Tracer
LMF	Least Mean Fourth

SOGI-FLL	Second Order Generalized Integrator With Frequency Locked
SRF	Synchronous Reference Frame
SOGI	Second Order Generalized Integrator
IGBT	Insulated Gate Bi-Polar Transistor
ZCD	Zero Crossing Detector
PLL	Phase Locked Loop
DSP	Digital Signal Processor
UT	Unit Templates
MNF	Modified Notch Filter

LIST OF SYMBOLS

V_{dc}	DC bus voltage of voltage source converter
C_{dc}	DC bus capacitance of voltage source converter
a	Over loading factor
P_{pv}	Solar power generation
f_{sw}	Switching frequency
v_{sabc}	Line voltage of the grid
i_{sabc}	Three phase grid currents
i_{Labc}	Three phase line currents
i_{vsc}	Three phase currents of the voltage source converter
D	Duty ratio
w_{pa}	Magnitude of fundamental load component
w_{cp}	Loss component
w_{pv}	Solar photovoltaic feed-forward component
w_{lpa}	Load component
w_{sp}	Total amplitude of reference grid currents
i_{ref}	Three phase reference grid currents
L	Interfacing inductor of voltage source converter
V_{pv}	Solar PV array voltage
V_{pv}^*	Reference PV array voltage
I_{pv}	Solar PV array current

V_{mpp}	MPP voltage
I_{mpp}	MPP current
P_{mpp}	MPP power
V_{oc}	Open circuit PV array voltage
I_{sc}	Short circuit PV array current
V_t	Terminal voltage of common coupling point
u_{pabc}	In-phase unit templates
u_{qabc}	Quadrature unit templates
Γ	Gain of frequency locked loop
k_{dc}	Gain if DC control loop of generalized integrator
ω	System frequency
v_{pabc}	Positive sequence of phase voltages
P_s	Active power in the grid
Q_s	Reactive power in the grid
V_{bes}, I_{bes}	BES voltage and BES current
L_f	Interfacing inductor
R, C	Ripple filter