CONTROL OF RELIABLE CHARGING INFRASTRUCTURE FOR EVS WITH RENEWABLE ENERGY GRID INTERFACE

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DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

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CERTIFICATE

This is to certify that the thesis entitled, **"Control of Reliable Charging Infrastructure for EVs with Renewable Energy Grid Interface"** being submitted by **Mr. Anjeet Kumar Verma** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him in the Department of Electrical Engineering of Indian Institute of Technology Delhi.

Mr. Anjeet Kumar Verma has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results obtained here in have not been submitted to any other University or Institute for the award of any degree.

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Place: New Delhi

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ABSTRACT

In view of the proliferation of EVs, the development of the multi-functional EV charging infrastructure is of paramount importance. In addition, integrating renewable energy into the core of the EV charging system is crucially significant. Therefore, this thesis deals with the design, control and implementation of various configurations of PV array, wind energy conversion system (WECS), storage battery, grid/DG set based EV charging station, beneficial for EVs, domestic loads, and utility. For EVs and the household loads, the charging stations are designed to operate in multimodes such in an islanded mode, the grid connected mode and the DG set connected mode with automatic and seamless mode transition among them, to provide the uninterruptible power. Moreover, it takes care of the harmonics distortion created by the EVs and the household loads by mitigating them locally, thus avoiding the penalty from the utility. For utility, the charging station provides the facility to exchange active and reactive powers with the grid in vehicle-to grid (V2G), grid-to-vehicle (G2V), storage-to-grid (S2G), grid-to-storage (G2S) etc., without compromising the power quality at grid side. Besides, the charging station supports other multi-functional operations such as vehicle-to-home (V2H), storage-to-home (S2H), storage-to-vehicle (S2V), vehicle-to-storage (V2S) and vehicle-to-vehicle (V2V), which improves the operational efficiency of the charging station. In the designed charging station configurations, a single voltage source converter is used to performs various tasks, such as energy management among different energy sources, extraction of maximum power from the PV array, the regulation of voltage and frequency of the DG set etc. The charging station also ensures the maximum power point operation of the renewable energy sources for maximum utilization of them. All the designed charging station configurations are modelled and simulated in the MATLAB/Sumulink environment using the Simpower technol-

ogy blocks and the same has been verified through the laboratory prototype. The performance of the charging stations are discussed in various steady state conditions and the dynamic conditions.

ABSTRACT

ईवी के प्रसार को देखते हुए, मल्टी फंक्शनल ईवी चार्जिंग इंफ्रास्ट्रक्चर का विकास सबसे महत्वपूर्ण है। इसके अलावा, ईवी चार्ज प्रणाली के मूल में अक्षय ऊर्जा का एकीकरण करना महत्वपूर्ण है। इसलिए, इस शोध-प्रबन्ध में पीवी सरणी, पवन ऊर्जा रूपांतरण प्रणाली, स्टोरेज बैटरी, ग्रिड / डीजी सेट आधारित ईवी चार्जिंग स्टेशन के डिजाइन और उस के नियंत्रण पर कार्य किया हैं। ईवी और घरेलू भार को अबाधित पॉवर प्रदान करने लिए चार्जिंग स्टेशनों को बहु-मोड, जैसे कि स्टैंडअलोन मोड, ग्रिड कनेक्टेड मोड, डीजी सेट कनेक्टेड मोड तथा उनके बीच स्वचालित और सीमलेस मोड परिवर्तन के साथ संचालित किया गया है। इसके अलावा, यह इवीस् और घरेलू भार द्वारा निर्मित हार्मोनिक्स विकृति का ख्याल रखता है तथा उन्हें स्थानीय स्तर पर कम करता है। ग्रिड के लिए, चार्जिंग स्टेशन एक्टिव तथा रिएक्टिव पॉवर एक्सचेंज करने की सुविधा, ग्रिड की पॉवर क्वालिटी से समझौता किए बिना, व्हीकल - टू -ग्रिड, ग्रिड-टू-व्हीकल, स्टोरेज-टू-ग्रिड, ग्रिड-टू-स्टोरेज मोदस् में प्रदान करता है। इसके अलावा, चार्जिंग स्टेशन अन्य बहुआयामी कार्यों जैसे व्हीकल -टू-होम (V2H), स्टोरेज-टू-होम (S2H), स्टोरेज-टू-व्हीकल (S2V), व्हीकल-टू-स्टोरेज (V2S) का समर्थन करता है, जो कि चार्जिंग स्टेशन की परिचालन दक्षता को बढाता है। डिज़ाइन किए गए चार्जिंग स्टेशन कॉन्फ़िगरेशनस् में केवल एक वोल्टेज स्रोत कनवर्टर का उपयोग विभिन्न कार्यों, जैसे विभिन्न ऊर्जा स्रोतों के बीच ऊर्जा प्रबंधन, पीवी सरणी से अधिकतम शक्ति का निष्कर्षण, वोल्टेज का विनियमन और डीजी सेट की आवृत्ति आदि, को करने के लिए किया जाता है। चार्जिंग स्टेशन नवीकरणीय ऊर्जा स्रोतों के अधिकतम शक्ति बिंदु संचालन को भी उनके अधिकतम उपयोग के लिए सुनिश्चित करता है। डिज़ाइन किए गए सभी चार्जिंग स्टेशन कॉन्फ़िगरेशनस का MATLAB/Simulink वातावरण में सिमपावर प्रौद्योगिकी ब्लॉकों का उपयोग करके मॉडल और सिमुलेट किया गया है और उसी को प्रयोगशाला प्रोटोटाइप के माध्यम से सत्यापित किया गया है। चार्जिंग स्टेशनों के प्रदर्शन की चर्चा विभिन्न स्थिर स्थितियों और गतिशील स्थितियों में किया गया है।

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
CS	Charging Station
EVCS	Electric Vehicle Charging Station
PV	photovoltaic
WECS	Wind Energy Conversion System
SEIG	Self Excited Induction Generator
PMBLDCG	Permanent Magnet Brushless DC Generator
AC	Alternating Current
DC	Direct Current
V2G	vehicle-to-grid
G2V	Grid-to-Vehicle
S2G	Storage-to-Grid
G2S	Grid-to-Storage
V2H	Vehicle-to-Home
S2H	Storage-to-Home
S2V	Storage-to-Vehicle
V2S	Vehicle-to-Storage
PV2H	PV-to-Home
PV2V	PV-to-Vehicle
PV2G	PV-to-Grid
W2G	Wind-to-Grid
W2H	Wind-to-Home
W2V	Wind-to-Vehicle
DG	Diesel generator
IM	Islanded Mode
GCM	Grid Connected Mode
DGCM	DG Set Connected Mode
MPP	Maximum Power Point

MPPT	Maximum Power Point Tracking
V2V	vehicle-to-vehicle
IEEE	Institute of Electrical and Electronics Engineers
INC	Incremental Conductance
PCC	Point of Common Coupling
SS	Static Switch
PI	Proportional Integral
SOGI	Second Order Generalized Integrator
DSOGI	Dual Second Order Generalized Integrator
PLL	Phase Locked Loop
FLL	Frequency Locked Loop
S/H	Sample and Hold
THD	Total Harmonic Distortion
VSC	Voltage Source Converter
ZCD	Zero Crossing Detection
UPF	Unity Power Factor
IGBT	Insulated Gate Bipolar Transistor
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
PWM	Pulse Width Modulator
RC	Resistor-Capacitor
CC/CV	Constant Current/Constant Voltage
DSO	Digital Storage Oscilloscope
SMC	Sliding Mode Controller
SOGI-FLL-DRC	Second-Order Generalized Integrator-Frequency Locked Loop with DC Rejection Capability
SOC	State of Charge
APSA	Affine Projection Sign Algorithm
ILST	Improved Linear sinusoidal Tracer

CAPSA	Convex Combined Affine Projection Sign Algorithm
DPF	Displacement Power Factor
SS-LMSE	Variable Step Size Least Mean Switching Error
ANC	Adaptive Notch Cancellation
VLLMS	Variable Leaky Least Mean Square
AFF-SOGI-DRC	Adaptive Frequency Fixed Second Order Generalized Integrator with DC Offset Rejection Capability

LIST OF SYMBOLS

C_{dc}	DC-link capacitor (F)
V_{dc}	DC-link voltage (V)
v_s	Single phase instantaneous grid voltage (V)
v_c	Single phase instantaneous PCC voltage (V)
v_g	Single phase instantaneous DG set voltage (V)
v_a	Single phase instantaneous DG set auxiliary winding voltage (V)
i_s	Single phase instantaneous grid current (A)
i_c	Single phase instantaneous PCC current (A)
i_g	Single phase instantaneous DG set current (A)
i_a	Single phase instantaneous DG set auxiliary winding current (A)
R_f	Ripple filter resistance (Ω)
C_f	Ripple filter capacitor (F)
i_e	Single phase instantaneous EV current (A)
i_h	Single phase instantaneous household load current (A)
E	Synchronizing signal
C_b	Storage battery capacitor (F)
C_e	EV battery capacitor (F)
I_b	Storage battery current (A)
I_ev	EV battery current (A)
V_{PV}	PV array voltage (V)
V_W	WECS rectified voltage (V)
I_{PV}	PV array current (V)
I_W	WECS rectified current (V)
P_s	Grid active power (kW)
Q_s	Grid reactive power (kVAR)
S	Grid apparent power (kVA)
ω	Angular frequency of grid (rad/s)
k	is safety factor
P_g	DG set active power (kW)
P_b	Storage battery active power (kW)
P_e	EV active power (kW)
P_{ev}	EV battery power (kW)
P_h	Household load active power (kW)
P_{PV}	PV array power (kW)

P_W	WECS power (kW)
L_c	Interfacing inductor (H)
L_b	Interfacing inductor (H)
V_m	Amplitude pf PCC voltage
v_{ca}, v_{cb}, v_{cc}	Three phase instantaneous PCC voltage (V)
v_{sa}, v_{sb}, v_{sc}	Three phase instantaneous grid voltage (V)
v_{ga}, v_{gb}, v_{gc}	Three phase instantaneous DG set voltage (V)
i_{ca}, i_{cb} and i_{cc}	Three phase instantaneous PCC current (A)
i_{sa}, i_{sb} and i_{sc}	Three phase instantaneous grid current (A)
i_{ga}, i_{gb} and i_{gc}	Three phase instantaneous DG set current (A)