CONTROL OF RENEWABLE BASED GRID INTERACTIVE ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

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CERTIFICATE

This is to certify that the thesis entitled, **"Control of Renewable based Grid-Interactive Electric Vehicle Charging Infrastructure "** is being submitted by **Mr. Mohd Khalid** 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. Mohd Khalid 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 have not been submitted to any other University or Institute for the award of any degree.

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ABSTRACT

The increasing prevalence of Electric Vehicle (EV) loads in global load profiles, accompanied by the integration of distributed energy resources (DERs) with advanced power electronics devices, has brought the topic of low-voltage direct current (LVDC) microgrid (MG) systems into focus. The integration of renewable energy sources, energy storage systems, and fuel cells in microgrids offers a promising solution for sustainable and efficient EV charging. This research investigates the synergistic interactions and optimal utilization of these hybrid DERs to facilitate the development of robust and reliable EV charging infrastructure. This thesis delves into the fascinating multidisciplinary research area of LVDC microgrids for EV charging infrastructure. It focuses on several key aspects, including the detailed system configuration encompassing EV loads, storage systems, converters, and more. Additionally, it explores converter control strategies, the integration of renewable energy sources, and power flow management. The operation of storage systems within LVDC systems is thoroughly examined. The detailed aspect of the thesis contribution is discussed as,

1. System modeling, capacity assessment, and other considerations in system configuration are crucial and depend on the specific application. As a result, the initial steps involve studying the different structural blocks to be used in the discussed DCMG system, implementing them, and addressing operational constraints to develop a comprehensive test system.

2. A line compensated power-voltage (P-V) droop-based decentralized power management strategy (DPMS) is devised to ensure the regulation of DC bus voltages by focusing on active power balancing as a crucial indicator. This DPMS aims to maintain power equilibrium within the multiple micro sources to effectively address various system transients, including load fluctuations, intermittent power fluctuations caused by uncertain weather conditions, and accidental islanding, local converter control of the relevant sources are implemented. Moreover, local parameters of each unit, such as common DC link voltage, state of charge (SoC), AC side voltage and frequency, etc., are used to facilitate control decisions during critical scenarios such as load shedding, autonomous mode operation of storage units, and

mode transitions enabled by the grid-connected voltage source converter.

3. Further, the thesis investigates the integration of fuel cells as an additional storage solution along with battery energy storage systems (BESS) in EV charging stations (EVCS). The aim is to extend the longevity of the power support and enhance the overall efficiency and reliability of the charging infrastructure.

4. The vulnerability of DC bus voltage in an LVDC microgrid due to power fluctuations from intermittent renewable energy sources and EV loads is investigated. A novel concept is introduced, utilizing a bidirectional DC-DC converter as a DC machine to replicate inertia characteristics and effectively regulate DC bus voltage fluctuations during power variations in the DCMG, called as virtual DC machine(VDCM) control. This approach enables the bidirectional converter to operate seamlessly in both generating and motoring modes, enhancing system stability and performance.

5. Furthermore, this thesis work is extended for optimizing the placement of solar-powered charging stations in a IEEE standard distribution network. The proposed methodology utilizes stochastic prediction of EV load demand and a Feed-forward neural network for evaluating expected solar power. The impact of EV load on the distribution network is assessed in terms of voltage profile, stability index, voltage deviation, and power loss. An improved chicken swarm optimization algorithm is employed to determine the optimal locations, outperforming other algorithms like Jaya and teaching-learning-based optimization.

संक्षेप(Abstract)

वैश्विक लोड प्रोफ़ाइल में इलेक्ट्रिक वाहन लोड की बढ़ती वर्चस्वता, साथ ही पर वितरित ऊर्जा संसाधनों के साथ उन्नत विद्युत इलेक्ट्रॉनिक्स उपकरणों के संयोजन ने कम वोल्टेज प्रत्यक्ष विद्युत प्रवाह माइक्रोग्रिड प्रणालियों को मुख्य ध्यान में लाया है। नवाचारी ऊर्जा स्रोतों, ऊर्जा भंडारण प्रणालियों, और ईंधन सेल्स को माइक्रोग्रिड में संयोजन एक सतत और कुशल इलेक्ट्रिक वाहन चार्जिंग के लिए एक आशाजनक समाधान प्रदान करता है। यह अनुसंधान इन हाइब्रिड इलेक्ट्रिक वाहन के सिनर्जिस्टिक परस्परक्रियाओं और सर्वश्रेष्ठ उपयोग की जांच करता है, जो मजबूत और विश्वसनीय इलेक्ट्रिक वाहन चार्जिंग बुनाने के लिए विकसित है।

यह थीसिस कम वोल्टेज प्रत्यक्ष विद्युत प्रवाह माइक्रोग्रिड्स के लिए इलेक्ट्रिक वाहन चार्जिंग संरचना को विस्तार से जांचती है। इसका मुख्य ध्यान है, जिसमें इलेक्ट्रिक वाहन लोड, भंडारण प्रणालियाँ, कनवर्टर्स, और अन्य कई महत्वपूर्ण पहलुओं पर विस्तृत प्रणाली को शामिल किया गया है। इसके अलावा, यह कनवर्टर नियंत्रण रणनीतियों, नवाचारी ऊर्जा स्रोतों के संयोजन, और विद्युत प्रवाह प्रबंधन की जांच करता है। कम वोल्टेज प्रत्यक्ष विद्युत प्रवाह प्रणालियों के भीतर भंडारण प्रणालियों का संचयन होता है।

थीसिस के यथार्थ संदर्भ के रूप में, इसमें निम्नलिखित प्रमुख दिशाओं पर ध्यान केंद्रित किया गया है:

1. सिस्टम मॉडलिंग, क्षमता मूल्यांकन, और प्रणाली कॉन्फ़िगरेशन में विचार करना महत्वपूर्ण है, और इसका निर्भर करता है कि विशिष्ट अनुप्रयोग पर जांच किए जाने वाले विभिन्न संरचनात्मक खंडों का अध्ययन किया जाए, उन्हें लागू किया जाए, और संचालनिक प्रतिबंधों का समाधान करने के लिए विकसित किए जाएं।
2. एक लाइन संशोधित विद्युत-वोल्टेज ड्रूप-आधारित डिसेंट्रलाइज़्ड पावर प्रबंधन रणनीति को तैयार किया गया है ताकि डीसी बस वोल्टेज का नियमन किया जा सके, जो महत्वपूर्ण संकेतक के रूप में सक्रिय पावर संतुलन पर महत्वपूर्ण प्राधिकृत हो। यह डिसेंट्रलाइज़्ड पावर प्रबंधन रणनीति विभिन्न प्रणालियों के बीच शक्ति संतुलन को बनाए रखने का उद्देश्य रखता है ताकि लोड के फ्लक्चुएशन, अनिश्चित मौसम स्थितियों के कारण होने वाली अंतर्राष्ट्रीय बिजली की फ्लक्चुएशन, और आकस्मिक आइलैंडिंग सहित विभिन्न सिस्टम के अस्थायी परिस्थितियों का सहयोग कर सके, स्थानीय कनवर्टर कंट्रोल का आमल किया जाता है। इसके अलावा, प्रत्येक इकाई के स्थानीय पैरामीटर, जैसे कि सामान्य प्रत्यक्ष धारा लिंक वोल्टेज, स्थिति चार्ज, प्रत्यावर्ती धारा साइड वोल्टेज और फ्रीक्वेंसी, आदि, लोड शेडिंग, भंडारण इकाइयों के स्वतंत्र मोड संचालन, और ग्रिड कनेक्टेड वोल्टेज स्रोत के द्वारा संचालन के दौरान नियंत्रण निर्णयों को सुविधा पूर्वक बनाने के लिए उपयोग किए जाते हैं।
3. इसके बाद, थीसिस इलेक्ट्रिक वाहन चार्जिंग स्टेशन्स में बैटरी ऊर्जा संग्रहण प्रणालियों के साथ ईंधन सेल्स के संयोजन की जांच करती है। लक्ष्य है कि शक्ति समर्थन की जीवनकाल को बढ़ावा देना और चार्जिंग संरचना की समग्र क्षमता और विश्वसनीयता को बढ़ावा दिया जाए।
4. कम वोल्टेज प्रत्यक्ष विद्युत प्रवाह माइक्रोग्रिड में डीसी बस वोल्टेज के पावर फ्लक्चुएशन को शक्ति स्रोतों के अंतर्राष्ट्रीय ऊर्जा स्रोतों और इलेक्ट्रिक वाहन लोड्स के अस्थायी बिजली के परिवर्तनों के कारण होने वाले पावर परिवर्तनों की निगरानी की जाती है। यहां एक नवाचारी अवधारणा पेश की गई है, जो एक डीसी-डीसी कनवर्टर का उपयोग डीसी मशीन के आविर्भाव गुणधर्मों को नकल करने और सिस्टम स्थिरता और प्रदर्शन को सुचारित रूप से विनियमित करने के लिए करती है। इसे वर्चुअल प्रत्यक्ष धारा मशीन नियंत्रण कहा जाता है। यह दृष्टिकोण बिन्दु-संतुलन और प्रदर्शन को बढ़ावा देने में सहायक होता है।
5. इसके अलावा, यह थीसिस एईईई मानक वितरण नेटवर्क में सौर प्रयोजित चार्जिंग स्टेशन्स की स्थाननिर्धारण को अधिकतम करने के लिए बढ़ाई जाती है। प्रस्तावित मैथमैटिक विश्लेषण ईवी लोड मांग की स्टोकेस्टिक पूर्वानुमान और अपेक्षित सौर ऊर्जा का मूल्यांकन करने के लिए फीड-फॉरवर्ड न्यूरल नेटवर्क का उपयोग करता है। वितरण नेटवर्क पर इलेक्ट्रिक वाहन लोड का प्रभाव वोल्टेज प्रोफ़ाइल, स्थिरता सूचकांक, वोल्टेज विचलन, और विद्युत हानि के रूप में मूल्यांकन किया जाता है। एक बेहतर चिकन स्वार्म अपशिक्षण एल्गोरिथम का उपयोग करके शीर्षक स्थानों का निर्धारण करने के लिए किया जाता है, जो अन्य एल्गोरिथम्स जैसे जाया और शिक्षा-सीखने आधारित अनुकूलन को प्रदर्शन में पिछड़ने में आगे है।

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
AVDI	Average voltage deviation index
BDDC	Bidirectional DC to DC Converter
BESS	Battery Energy Storage System
CC/CV	Constant Current/Constant Voltage
CS	Charging Station
CSO	Chicken swarm optimization
DC	Direct Current
DCMG	DC Microgrid
DAC	Digital to Analog Converter
DoD	Depth of Discharge
DPMS	Decentralized Power Management System
EMS	Energy Management System
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
FC	Fuel Cell
FEBC	Front-end Bidirectional Converter
FENN	Feed-forward Neural Network
GFL	Grid Following Mode
GFM	Grid Forming Mode
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
LCDC	Line Compensated Droop Control
LFC	Life Cycle
MCSO	Modified chicken swarm optimization
MG	Microgrid
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
Of	Objective function
PEMFC	Proton Exchange membrane FC
P & O	Perturn and Observe
PCC	Point of Common Coupling
PI	Proportional Integral

PLL	Phase Locked Loop
PMS	Power Management System
PWM	Pulse Width Modulator
PV	photovoltaic
PV2G	PV-to-Grid
RES	Renewable energy source
SOC	State of Charge
TF	Transfer function
THD	Total Harmonic Distortion
TLBO	Teaching learning based optimization
UPF	Unity Power Factor
V2G	vehicle-to-grid
V2H	Vehicle-to-Home
V2V	Vehicle to Vehicle
VDCM	Virtual DC machine
VID	Virtual inertia and damping
VSI	Voltage sensitivity index
VSM	Virtual synchronous machine
VSC	Voltage Source Converter
VSI	Voltage Source Converter
VD	Voltage deviation
Of	Objective function
VSI	Voltage Source Converter
VSM	Virtual synchronous machine
V2H	Vehicle-to-Home
V2V	Vehicle to Vehicle
VID	Virtual inertia and damping
VSM	Virtual synchronous machine
VDCM	Virtual DC machine
VSC	Voltage Source Converter
VSI	Voltage Source Converter
V2H	Vehicle-to-Home
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VSM	Virtual synchronous machine
VSC	Voltage Source Converter
V2H	Vehicle-to-Home
V2V	Vehicle to Vehicle
VID	Virtual inertia and damping
VSM	Virtual synchronous machine
FENN	Feed-forward Neural Network
AVDI	Average voltage deviation index
VSI	Voltage sensitivity index
Of	Objective function
VD	Voltage deviation
TLBO	Teaching learning based optimization
CSO	Chicken swarm optimization
MCSO	Modified chicken swarm optimization

LIST OF SYMBOLS

C_{bs}, G_{bs}	Capacitance and parasitic conductance of BESS's capacitor
I_{BESS}	BESS current
I_{FC}	FC current
I_{maxj}	Maximum permissible current from j^{th} unit
K, Q	Polarization constant, maximum battery Capacity
K_D, K_I	Inertia and damping coefficients DC machine
K_m, K_c	Energy stored in a machine and capacitor
K_f, Z	Field constant, machine constant depends on construction and rating
P_{B1}, P_{B2}	Output power of $BESS_1$ and $BESS_2$
P_{EV}	EV load demand
P_G, Q_G	Active and reactive power from the grid
P_{PV}	Output power of PV source
P_{vm}, P_{ve}	Mechanical and electrical power of VDCM
R_{dj}, K_j	Droop gain and feedforward compensation of j^{th} unit
R_{int}	Equivalent internal resistance of the battery
R_{lj}	Line resistance of j^{th} unit
SoC_j	SoC of j^{th} battery storage unit
V_{B,E_B,I_B}	Terminal voltage, open circuit voltage, and discharging/charging current of the battery
V_{DCbus}	DC bus voltage
V_{oj}, V_j	No load terminal voltage and output voltage
V_r	Rated EMF voltage of DC machine
ΔV	Maximum allowed DC bus fluctuation in steady state
ω, ω_r	Actual and rated speed of VDCM
τ_m, τ_e	Mechanical and electrical torque of DC machine
d_{b1}, d_{b2}	Duty ratio of bottom and top switch of BESS
i_o, i_{DCbus}	Input and Output current of DC link capacitor of BESS
i_a, l_a, ϕ_a, r_a	Armature current, inductance, flux, and resistance of VDCM
i_f, l_f, ϕ_f, r_f	Field current, inductance, flux, and resistance of VDCM
$i_{bs}, r_{bs}, L_{bs}, v_{bs}$	Current, series resistance, inductance, and voltage of battery
r_{bs}, L_{bs}	Series resistance and inductance of BDDC