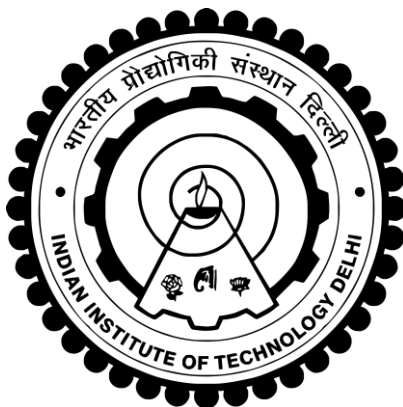


SINGLE-STAGE ISOLATED CURRENT-FED BI-DIRECTIONAL CONVERTER FOR ON-BOARD EV CHARGING

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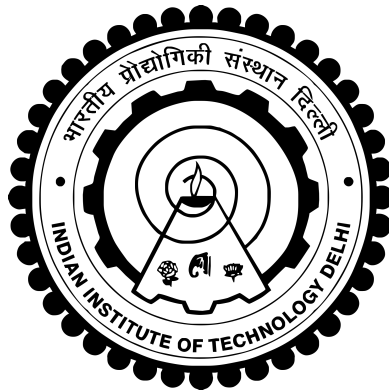
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Submitted

in fulfilment of the requirements for the degree of

Doctor of Philosophy



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Certificate

This is to certify that the thesis titled **Single-Stage Isolated Current-Fed Bi-directional Converter for On-board EV Charging**, submitted by **Mr. Manish Kumar**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work done by him under our supervision and guidance. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Manish Kumar

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Abstract

The transition to sustainable transportation from conventional internal combustion engine-based vehicles to electric vehicles has gained significant momentum in recent years. This shift is driven by the need to reduce greenhouse gas emissions, mitigate climate change, and promote sustainable transportation alternatives. However, one critical aspect that remains a challenge for widespread electric vehicle adoption is the long charging time and availability of efficient and convenient charging infrastructure. This necessitates the need for convenient charging processes and robust charging infrastructure.

Consequently, onboard chargers integrated into electric vehicles offer an AC-charging solution with bidirectional power flow capabilities, enabling electric vehicle batteries to power external devices and homes or contribute to the electric grid. However, the adoption of bidirectional onboard chargers presents new challenges in power converter design, requiring high-efficiency, compact, and cost-competitive solutions.

Therefore, **Chapter 1** begins with a brief motivation for the topic of electric mobility. The landscape of electric vehicle charging infrastructure, charging methods and state-of-the-art onboard electric vehicle charging concepts are summarized.

In **Chapter 2**, an overview of the state-of-the-art converter topologies for onboard EV charging applications is presented. Among these, single-stage structure-based converter topologies provide better electrical and volumetric efficiency than the two-stage counterpart. Building on this observation, the L-L type isolated current-fed dual-active bridge converter with bidirectional capability is selected for the onboard EV charging applications.

Following this, the grid-to-vehicle operational mode of the L-L type isolated current-fed dual-active bridge converter is discussed in **Chapter 3**. The state-of-the-art secondary side modulation techniques for active current commutation are evaluated. An improved discontinuous current phase shift modulation is proposed to reduce the circulating current flowing through the high-frequency transformer windings throughout the grid cycle and light load conditions. Additionally, a universal input charger concept with both AC and DC input power source compatibility is also demonstrated.

The objective and concept of vehicle-to-home operational mode in an onboard electric vehicle charger is discussed in **Chapter 4**. The bidirectional capability of the single-stage L-L type isolated current-fed dual-active bridge converter is explored for vehicle-to-home application. A new sinusoidal phase shift modulation is proposed to generate a well-

regulated AC voltage across residential loads in the event of a grid outage. The overall control structure in terms of power flow during grid-to-vehicle, vehicle-to-home operational modes, grid-outage detection, and mode transition are discussed.

The concept of single and three-phase grid adaptable onboard electric vehicle chargers is investigated in **Chapter 5**. Building on this concept, a modular single and three-phase grid adaptable based on the L-L type isolated current-fed dual-active bridge converter is proposed. This proves to be a commercially viable solution as a single converter provides users with the convenience of using both single-phase domestic utility outlets and commercial three-phase charging ports.

Finally, **Chapter 6** summarizes and concludes the main contribution of the thesis and presents an outlook on possible future research work.

सार

हाल के वर्षों में पारंपरिक आंतरिक दहन इंजन आधारित वाहनों से इलेक्ट्रिक वाहनों की ओर संधारणीय परिवहन में बदलाव ने महत्वपूर्ण गति प्राप्त की है। यह बदलाव ग्रीनहाउस गैस उत्सर्जन को कम करने, जलवायु परिवर्तन को कम करने और संधारणीय परिवहन विकल्पों को बढ़ावा देने की आवश्यकता से प्रेरित है। हालाँकि, एक महत्वपूर्ण पहलू जो व्यापक रूप से इलेक्ट्रिक वाहन अपनाने के लिए एक चुनौती बना हुआ है, वह है लंबा चार्जिंग समय और कुशल और सुविधाजनक चार्जिंग बुनियादी ढांचे की उपलब्धता। इसके लिए सुविधाजनक चार्जिंग प्रक्रियाओं और मजबूत चार्जिंग बुनियादी ढांचे की आवश्यकता है।

परिणामस्वरूप, इलेक्ट्रिक वाहनों में एकीकृत ऑनबोर्ड चार्जर द्विदिशीय विद्युत प्रवाह क्षमताओं के साथ एक एसी-चार्जिंग समाधान प्रदान करते हैं, जिससे इलेक्ट्रिक वाहन बैटरी बाहरी उपकरणों और घरों को बिजली देने या इलेक्ट्रिक ग्रिड में योगदान करने में सक्षम होती हैं। हालाँकि, द्विदिशीय ऑनबोर्ड चार्जर को अपनाने से पावर कनवर्टर डिज़ाइन में नई चुनौतियाँ आती हैं, जिसके लिए उच्च दक्षता, कॉम्पैक्ट और लागत-प्रतिस्पर्धी समाधानों की आवश्यकता होती है।

इसलिए, **अध्याय 1** इलेक्ट्रिक मोबिलिटी के विषय के लिए एक संक्षिप्त प्रेरणा के साथ शुरू होता है। इलेक्ट्रिक वाहन चार्जिंग इंफ्रास्ट्रक्चर, चार्जिंग विधियों और अत्याधुनिक ऑनबोर्ड इलेक्ट्रिक वाहन चार्जिंग अवधारणाओं के परिदृश्य को संक्षेप में प्रस्तुत किया गया है।

अध्याय 2 में ऑनबोर्ड ईवी चार्जिंग अनुप्रयोगों के लिए अत्याधुनिक कनवर्टर टोपोलॉजी का अवलोकन प्रस्तुत किया गया है। इनमें से, एकल-चरण संरचना-आधारित कनवर्टर टोपोलॉजी दो-चरण समकक्ष की तुलना में बेहतर विद्युत और वॉल्यूमेट्रिक दक्षता प्रदान करती है। इस अवलोकन के आधार पर, ऑनबोर्ड ईवी चार्जिंग अनुप्रयोगों के लिए द्विदिश क्षमता वाले एल-एल प्रकार के पृथक करंट-फेड दोहरे-सक्रिय ब्रिज कनवर्टर का चयन किया गया है।

इसके बाद, **अध्याय 3** में एल-एल प्रकार के पृथक धारा-आधारित दोहरे सक्रिय ब्रिज कनवर्टर के ग्रिड-टू-व्हीकल परिचालन मोड पर चर्चा की गई है। सक्रिय धारा परिवर्तन के लिए अत्याधुनिक सेकेंडरी साइड मॉड्यूलेशन तकनीकों का मूल्यांकन किया गया है। ग्रिड चक्र और

हल्के भार की स्थितियों में उच्च आवृत्ति वाले ट्रांसफॉर्मर वाइंडिंग के माध्यम से प्रवाहित होने वाली परिसंचारी धारा को कम करने के लिए एक बेहतर असंतत धारा चरण शिफ्ट मॉड्यूलेशन का प्रस्ताव किया गया है। इसके अतिरिक्त, एसी और डीसी इनपुट पावर स्रोत संगतता दोनों के साथ एक सार्वभौमिक इनपुट चार्जर अवधारणा का भी प्रदर्शन किया गया है।

ऑनबोर्ड इलेक्ट्रिक वाहन चार्जर में वाहन-से-घर परिचालन मोड के उद्देश्य और अवधारणा पर **अध्याय 4** में चर्चा की गई है। वाहन-से-घर अनुप्रयोग के लिए एकल-चरण एल-एल प्रकार के पृथक करंट-फेड दोहरे-सक्रिय ब्रिज कनवर्टर की द्विदिश क्षमता का पता लगाया गया है। ग्रिड आउटेज की स्थिति में आवासीय भार में एक अच्छी तरह से विनियमित एसी वोल्टेज उत्पन्न करने के लिए एक नया साइनसॉइडल चरण शिफ्ट मॉड्यूलेशन प्रस्तावित किया गया है। ग्रिड-टू-वाहन, वाहन-से-घर परिचालन मोड, ग्रिड-आउटेज डिटेक्शन और मोड ट्रांज़िशन के दौरान बिजली प्रवाह के संदर्भ में समग्र नियंत्रण संरचना पर चर्चा की गई है।

अध्याय 5 में सिंगल और थ्री-फेज ग्रिड एडैप्टेबल ऑनबोर्ड इलेक्ट्रिक व्हीकल चार्जर की अवधारणा की जांच की गई है। इस अवधारणा के आधार पर, एल-एल प्रकार के आइसोलेटेड करंट-फेड डुअल-एक्टिव ब्रिज कनवर्टर पर आधारित मॉड्यूलर सिंगल और थ्री-फेज ग्रिड एडैप्टेबल प्रस्तावित किया गया है। यह व्यावसायिक रूप से व्यवहार्य समाधान साबित होता है क्योंकि सिंगल कनवर्टर उपयोगकर्ताओं को सिंगल-फेज घरेलू उपयोगिता आउटलेट और वाणिज्यिक थ्री-फेज चार्जिंग पोर्ट दोनों का उपयोग करने की सुविधा प्रदान करता है।

अंत में, **अध्याय 6** थीसिस के मुख्य योगदान का सारांश और निष्कर्ष प्रस्तुत करता है और संभावित भविष्य के शोध कार्य पर एक दृष्टिकोण प्रस्तुत करता है।

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Glossary

Abbreviations

CCS	Combined Charging System
DCPSM	Discontinuous Current Phase Shift Modulation
EV	Electric Vehicle
G2V	Grid-to-Vehicle
HFT	High Frequency Transformer
HV	High Voltage
IC	Internal Combustion
ICF	Isolated Current Fed
ICFDAB	Isolated Current Fed Dual Active Bridge
IDCPSM	Improved Discontinuous Current Phase Shift Modulation
IEC	International Electrotechnical Commission
IPT	Inductive Power Transfer
LV	Low Voltage
OBC	Onboard Charger
PFC	Power Factor Correction
SAE	Society of Automobile Engineers
SOC	State of Charge
SSM	Secondary Side Modulation
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
ZCS	Zero Current Switching
ZVS	Zero Voltage Switching