

**DESIGN & IMPLEMENTATION OF
DIFFERENT CONTROL SCHEMES FOR VSC IN
VARIOUS GRID CONDITIONS**

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**DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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DESIGN & IMPLEMENTATION OF DIFFERENT CONTROL SCHEMES FOR VSC IN VARIOUS GRID CONDITIONS

by

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DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

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Dedicated to

My parents & brother

“There is not a discovery in science, however revolutionary, however sparkling with insight that does not arise out of what went before.”

..... Isaac Asimov

Certificate

This is to certify that the dissertation entitled “**Design & Implementation of Different Control Schemes for VSC in Various Grid Conditions**” being submitted by **Surya Prakash** to the Department of Electrical Engineering, Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is the record of the bonafide research work carried out by him under my supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Abstract

Due to increased penetration of renewable energy sources (RES), the distribution network is constantly changing and moving away from the conventional form. Various distributed generators (DGs) require voltage source converters to share power between the renewable source and the grid. The conventional control approach for these VSCs generally do not take the grid condition into consideration. In a low voltage distribution network, the grid strength may be very weak due to low SCR combined with low X/R ratio. It is also necessary for the controller to take account of this variation in grid intensity in order to provide a satisfactory operation. In addition, small-scale power systems commonly known as microgrids are required for electrification for remote areas where the grid is not available. Microgrid systems with hybrid distributed generations (DGs) (mainly RES) are therefore gaining popularity due to environmental emission concerns and increased fuel costs. Power-sharing between various DGs needs to be maintained by a stable and reliable active distribution network. Another grid scenario is called the Open Phase scenario, where one phase out of three phases is disconnected from the primary side of the Distribution Transformer (DT). This results in a sharp decline in the secondary side of the DT, where low-end users are connected. If the operation continues during the open phase fault, there may be a permanent power outage due to the operation of the system beyond the overcurrent limit of the distribution lines. The goal of this study is to establish control schemes that can resolve different issues related to grid connectivity related to a low voltage active distribution network.

First, a weak grid operating condition for VSCs is taken into account in this thesis. A PLL less controller has been proposed that gives satisfactory control in weak grid scenarios over the varying grid condition such as swag, swell & frequency variation.

The controllers proposed in this thesis emphasize not only the dynamic performance in terms of settling time, overshoots and undershoots, but also on the ease of implementation in real time, the reduction of control efforts and the reduction of the number of parameters to be tuned. The proposed PLL less control algorithm uses instantaneous samples of voltage sensor readings.

The second state where the complete absence of a grid is taken into account which is known as an autonomous or islanded condition. In the case of low-voltage islanded grid conditions, the main objective is to maintain stable voltage and frequency throughout its network for the smooth operation of distributed loads. The other objective is to maintain a proportionate distribution of power between multiple sources connected by voltage source converters (VSCs). A decentralized fast terminal sliding mode control strategy for active power sharing between parallel VSCs has been proposed in this case. A detailed mathematical model based on Lyapunov's stability theory-based study is designed to establish the operating stability of the proposed controller. However, the chattering issue with this controller remains an issue. To overcome the problem of chattering, this thesis further presents a decentralized adaptive droop-based control for active power sharing between parallel inverters in autonomous microgrids. A dynamic droop coefficient is designed to achieve improved transient performance during dynamic loading.

In the third and final scenario, the impact of the open phase fault on the power supply of end consumers connected to the low voltage side of DT is presented. The open phase condition at a voltage level (11 kV) will result in a continuous voltage sag at low voltage (LV) voltage (400 V) which may be detrimental to various types of loads, especially constant power loads. The grid-connected photovoltaic (PV) with battery energy storage (BESS) system has been used for a number of demand-related issues. This study explores the use of grid-connected PV with BESS in the event of an open phase fault in the distribution system. The usefulness of the proposed configuration is demonstrated with the voltage restoration in all phases at the LV level during an open phase fault at the MV level, with MATLAB simulation as well as real-time experimental results obtained for selected possible loading conditions have been presented.

सार

नवीकरणीय ऊर्जा स्रोतों (आरईएस) की बढ़ती पहुंच के कारण, वितरण नेटवर्क लगातार बदल रहा है और पारंपरिक रूप से दूर जा रहा है। विभिन्न वितरित जनरेटर (डीजी) को अक्षय स्रोत और ग्रिड के बीच शक्ति साझा करने के लिए वोल्टेज स्रोत कन्वर्टर्स की आवश्यकता होती है। इन VSCs के लिए पारंपरिक नियंत्रण दृष्टिकोण आम तौर पर ग्रिड स्थिति को ध्यान में नहीं रखता है। कम वोल्टेज वितरण नेटवर्क में, कम X / R अनुपात के साथ संयुक्त SCR के कारण ग्रिड की ताकत बहुत कमजोर हो सकती है। एक संतोषजनक संचालन प्रदान करने के लिए नियंत्रक को ग्रिड की तीव्रता में इस भिन्नता का ध्यान रखना भी आवश्यक है। इसके अलावा, छोटे पैमाने पर बिजली प्रणालियों को आमतौर पर माइक्रोग्रिड्स के रूप में जाना जाता है जो दूरदराज के क्षेत्रों के लिए विद्युतीकरण के लिए आवश्यक हैं जहां ग्रिड उपलब्ध नहीं है। हाइब्रिड वितरित पीढ़ियों (डीजी) (मुख्य रूप से आरईएस) के साथ माइक्रोग्रिड सिस्टम पर्यावरणीय उत्सर्जन चिंताओं और ईंधन की लागत में वृद्धि के कारण लोकप्रियता हासिल कर रहे हैं। विभिन्न डीजी के बीच पावर-शेयरिंग को एक स्थिर और विश्वसनीय सक्रिय वितरण नेटवर्क द्वारा बनाए रखा जाना चाहिए। एक अन्य ग्रिड परिदृश्य को ओपन फेज परिदृश्य कहा जाता है, जहां तीन चरणों में से एक चरण को वितरण ट्रांसफार्मर (डीटी) के प्राथमिक तरफ से काट दिया जाता है। इसका परिणाम डीटी के द्वितीयक पक्ष में तेज गिरावट है, जहां कम-अंत उपयोगकर्ता जुड़े हुए हैं। यदि खुले चरण की खराबी के दौरान ऑपरेशन जारी रहता है, तो वितरण लाइनों की अधिक सीमा से परे प्रणाली के संचालन के कारण एक स्थायी बिजली आउटलेज हो सकता है। इस अध्ययन का लक्ष्य नियंत्रण योजनाओं को स्थापित करना है जो कम वोल्टेज सक्रिय वितरण नेटवर्क से संबंधित ग्रिड कनेक्टिविटी से संबंधित विभिन्न मुद्दों को हल कर सकते हैं।

सबसे पहले, VSCs के लिए एक कमजोर ग्रिड ऑपरेटिंग स्थिति को इस थीसिस में ध्यान में रखा गया है। एक PLL कम नियंत्रक प्रस्तावित किया गया है जो अलग-अलग ग्रिड स्थिति जैसे कि स्वाग, प्रफुल्लित और आवृत्ति भिन्नता पर कमजोर ग्रिड परिदृश्यों में संतोषजनक नियंत्रण देता है। इस थीसिस में प्रस्तावित नियंत्रक समय, ओवरशूट और अंडरशूट को निपटाने के संदर्भ में न केवल गतिशील प्रदर्शन पर जोर देते हैं, बल्कि वास्तविक समय में कार्यान्वयन में आसानी, नियंत्रण के प्रयासों में कमी और मानकों की संख्या में कमी को देखते हैं। प्रस्तावित PLL कम नियंत्रण एल्गोरिथ्म में वोल्टेज सेंसर रीडिंग के तात्कालिक नमूने का उपयोग किया जाता है।

दूसरा राज्य जहां ग्रिड की पूर्ण अनुपस्थिति को ध्यान में रखा जाता है जिसे एक स्वायत्त या द्वीप की स्थिति के रूप में जाना जाता है। कम वोल्टेज वाले द्वीप ग्रिड स्थितियों के मामले में, मुख्य उद्देश्य वितरित भार के सुचारू संचालन के लिए अपने पूरे नेटवर्क में स्थिर वोल्टेज और आवृत्ति बनाए रखना है। अन्य उद्देश्य वोल्टेज स्रोत कन्वर्टर्स (वीएससी) द्वारा जुड़े कई स्रोतों के बीच बिजली का एक आनुपातिक वितरण बनाए रखना है। इस मामले में समानांतर VSCs के बीच सक्रिय शक्ति साझाकरण के लिए एक विकेंद्रीकृत फास्ट टर्मिनल स्लाइडिंग मोड नियंत्रण रणनीति प्रस्तावित की गई है। ल्युपुनोव की स्थिरता सिद्धांत-आधारित अध्ययन पर आधारित एक विस्तृत गणितीय मॉडल प्रस्तावित नियंत्रक के ऑपरेटिंग स्थिरता को स्थापित करने के लिए डिज़ाइन किया गया है। हालाँकि, इस नियंत्रक के साथ चैटिंग समस्या एक समस्या बनी हुई है। बकबक की समस्या को दूर करने के लिए, यह थीसिस आगे स्वायत्त माइक्रोग्रिड्स में समानांतर इनवर्टर के बीच सक्रिय शक्ति साझा करने के लिए विकेंद्रीकृत अनुकूल ड्रॉप-आधारित नियंत्रण प्रस्तुत करती है। एक गतिशील ड्रॉप गुणांक को गतिशील लोडिंग के दौरान बेहतर क्षणिक प्रदर्शन प्राप्त करने के लिए डिज़ाइन किया गया है।

तीसरे और अंतिम परिदृश्य में, डीटी के निम्न वोल्टेज पक्ष से जुड़े अंतिम उपभोक्ताओं की बिजली आपूर्ति पर खुले चरण की गलती का प्रभाव प्रस्तुत किया गया है। वोल्टेज स्तर (11 kV) पर खुले चरण की स्थिति कम वोल्टेज (एलवी) वोल्टेज

(400 V) पर निरंतर वोल्टेज शिथिलता के परिणामस्वरूप होगी जो विभिन्न प्रकार के भार, विशेष रूप से निरंतर बिजली भार के लिए हानिकारक हो सकती है। ग्रिड-कनेक्टेड फोटोवोल्टिक बैटरी ऊर्जा भंडारण (बीईएस) प्रणाली के साथ कई मांग-संबंधित मुद्दों के लिए उपयोग किया गया है। यह अध्ययन वितरण प्रणाली में एक खुले चरण की गड़बड़ी की स्थिति में BESS के साथ ग्रिड से जुड़े पीवी के उपयोग की पड़ताल करता है। प्रस्तावित विन्यास की उपयोगिता एमवी स्तर पर एक खुले चरण दोष के दौरान एलवी स्तर पर सभी चरणों में वोल्टेज बहाली के साथ प्रदर्शित की जाती है, MATLAB सिमुलेशन के साथ-साथ चयनित संभावित लोडिंग परिस्थितियों के लिए प्राप्त वास्तविक समय प्रयोगात्मक परिणाम प्रस्तुत किए गए हैं।

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Abbreviations

PCC	Point of Common Coupling
LT	Low Tension
MV	Medium Voltage
PV	Photovoltaic
WECS	Wind energy conversion system
FC	Fuel cell
RES	Renewable energy sources
PI	Proportional integral
PID	Proportional integral derivative
ID	Integral derivative
DT	Distribution Transformer
VSC	Voltage Source Converter
DG	Distributed generation
DER	Distributed energy resources
BESS	Battery energy storage system
PLL	Phase Locked Loop
DGs	Distributed generators
LVRT	Low Voltage Ride Through
FRT	Fault Ride Through
SOGI	second order generalized integrator
LV	Low voltage
MPPT	Maximum power point tracking
CPL	Constant power load