

Contents

| | |
|------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Abstract | v |
| Acknowledgment | ix |
| List of Figures | xi |
| List of Tables | xv |
| List of Acronyms | xvi |
| Symbols Used | xviii |
| | |
| Chapter 1. Introduction..... | 1 |
| 1.1 Background and Motivation..... | 1 |
| 1.2 Literature Review..... | 5 |
| 1.2.1 Hybrid output..... | 5 |
| 1.2.2 Minimum Phase Behavior..... | 9 |
| 1.2.3 Minimization of Leakage Current..... | 12 |
| 1.2.4 Grid Integration..... | 15 |
| 1.3 Challenges with the Existing Systems..... | 17 |
| 1.4 Objectives of Thesis..... | 18 |
| 1.4 Organisation of the Thesis..... | 21 |
| | |
| Chapter 2. Topology Development and Operation of Wide Operating Range Transformerless Interleaved Hybrid Converter..... | 23 |
| 2.1 Introduction..... | 23 |
| 2.2 Topology Development..... | 24 |
| 2.2.1 Topology Development of TLMPHC..... | 24 |
| 2.2.2 Topology Development of TLIHC | 25 |
| 2.3 Propose Circuit Operation and Switching Behaviour..... | 27 |
| 2.3.1 Operation of TLMPHC | 27 |
| 2.3.2 Switching Behaviour of TLMPHC..... | 30 |

| | |
|----------------------------------------------------------------|----|
| 2.3.3 Operation of TLIHC..... | 32 |
| 2.3.4 Switching Behaviour of TLIHC..... | 35 |
| 2.4 Operational Waveforms..... | 37 |
| 2.4.1 Operational Waveforms of TLMPHC..... | 37 |
| 2.4.2 Operational Waveforms of TLIHC | 38 |
| 2.5 Design of Passive Components..... | 40 |
| 2.6 Comparison of Some Key Features of TLIHC and TLMPHC..... | 42 |
| 2.7 Simulation and Experimental Verifications..... | 43 |
| 2.7.1 Simulation and Experimental Verifications of TLMPHC..... | 44 |
| 2.7.2 Simulation and Experimental Verifications of TLIHC..... | 46 |
| 2.8 Summary..... | 49 |

Chapter 3. Modelling and Analysis of Wide Operating Range

| | |
|----------------------------------------------------------------|-----------|
| Transformerless Interleaved Hybrid Converter..... | 51 |
| 3.1 Introduction..... | 51 |
| 3.2 Mathematical Modelling..... | 51 |
| 3.2.1 Mathematical Modelling of TLMPHC..... | 52 |
| 3.2.2 Small Signal Analysis of TLMPHC..... | 54 |
| 3.2.3 Mathematical Modelling of TLIHC..... | 56 |
| 3.2.4 State Space Averaging of TLIHC..... | 59 |
| 3.3 Key Features..... | 61 |
| 3.3.1 Simultaneous DC and AC outputs..... | 61 |
| 3.3.2 Leakage Current Minimization..... | 62 |
| 3.3.3 Minimum Phase Behaviour..... | 66 |
| 3.4 Performance Analysis..... | 70 |
| 3.5 Verifications of Steady-State Response..... | 73 |
| 3.5.1 Simulation and Experimental Verifications of TLMPHC..... | 73 |
| 3.5.2 Simulation and Experimental Verifications of TLIHC..... | 76 |
| 3.6 Loss Distribution and Efficiency Comparison..... | 82 |
| 3.6.1 Loss Distribution of TLMPHC..... | 82 |
| 3.6.2 Loss Distribution of TLIHC..... | 84 |

| | |
|--------------------------------------------------------------------------|------------|
| 3.6.3 Efficiency Comparison..... | 88 |
| 3.7 Limitations and Applications..... | 89 |
| 3.7.1 Limitations..... | 89 |
| 3.7.2 Applications..... | 90 |
| 3.8 Summary..... | 90 |
| | |
| Chapter 4. Dynamic Analysis and Loop Operation of Transformerless | |
| Hybrid Converter with Reduced Leakage Current..... | 93 |
| 4.1 Introduction..... | 93 |
| 4.2 Close Loop Control of TLIHC..... | 93 |
| 4.3 DC output Close Loop Control..... | 94 |
| 4.3.1 Performance of DC Side Controller..... | 98 |
| 4.4 AC output Close Loop Control..... | 101 |
| 4.4.1 Synchronous Reference Frame Control Strategy..... | 101 |
| 4.4.2 D-Q Modelling of AC Side of TLIHC..... | 103 |
| 4.4.3 Performance of AC Side Controller | 108 |
| 4.5 Verifications of Dynamic Response of TLIHC..... | 110 |
| 4.5.1 Simulation Results of TLIHC..... | 111 |
| 4.5.2 Experimental Verifications of Cross Regulation Behaviour..... | 117 |
| 4.5.3 Leakage Current Comparison..... | 118 |
| 4.6 Summary..... | 119 |
| | |
| Chapter 5. Grid Integration of Transformerless Interleaved Hybrid | |
| Converter with Reduced Leakage Current..... | 121 |
| 5.1 Introduction..... | 121 |
| 5.2 Grid Integration of TLIHC..... | 121 |
| 5.3 Close Loop Control Strategy for Grid Current..... | 124 |
| 5.4 Phase Locked Loop..... | 126 |
| 5.5 LCL Filter Design..... | 128 |
| 5.6 Simulation Results of Grid Integrated TLIHC..... | 130 |
| 5.7 FFT Analysis of Grid Current..... | 140 |

| | |
|----------------------------------------------------|------------|
| 5.8 Summary..... | 140 |
| Chapter 6. Conclusions and Future Work..... | 143 |
| 6.1 Introduction..... | 143 |
| 6.2 Conclusions..... | 143 |
| 6.3 Future Work..... | 146 |
| Bibliography | 149 |
| List of Publications | 163 |