

SLIDING MODE CONTROL FOR PARALLEL INVERTERS OF DISTRIBUTIVE ENERGY RESOURCES IN MICROGRID

BY

MUHAMMAD ALI

01-244162-024

SUPERVISED BY

DR. MUHAMMAD AAMIR



Session-2016-18

A Report submitted to the Department of Electrical Engineering

Bahria University, Islamabad

in partial fulfilment of the requirement for the degree of MS(EE)

CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS (EE).

Head of Department

Supervisor

Internal Examiner

External Examiner

DECLARATION OF AUTHORSHIP

I hereby acknowledge that this thesis is my own work and contains no materials previously submitted for a degree or diploma in any institution or university of higher education. To the best of my knowledge, it contains no material previously published or written by another person except where due reference is made in the text; or contain any defamatory material.

Student's Signature: _____

Name (In Capital): _____

Date: _____

ACKNOWLEDGEMENTS

My sincere gratitude goes to my supervisor, Dr. Muhammad Aamir for his encouragement, skilled guidance, critical reviews, continuous support and wide knowledge. I would also like to thanks Dr. Asad Waqar for his guidance and provide me necessary support throughout my research journey.

I am also grateful to my class fellows and friends (Ahmed, Bilal, Aziz, Ali, Adil, Haseeb, Mohsin & Hussain) for their immense support and optimism they provided me, also for being my surrogate family during my research study. Finally, I would like to thanks Engr. Abdul Aziz Khan for his help and sharing valuable information with me.

ABSTRACT

The inverter-based distributed generation (DG) units in Microgrid calls for robust control techniques that attain high performance not only during normal operating conditions but also under unbalanced conditions. Microgrid contains a cluster of loads along with distributed generators operating as a unified controlled system. Interconnecting DGs with a grid using power electronic converters has enhanced concerns regarding safe operation and protection of the equipment. Many control strategies have been proposed for enhancing the stability of microgrid for proper load sharing. This work proposes two separate controllers based on the sliding mode control for an autonomous mode and grid-tied mode of operation. Frictional-Order Sliding Mode Voltage Control (FOSMVC) technique is developed for single and parallel voltage source inverter (VSI) in autonomous mode maintains the quality of the output voltage of the DG system despite unbalanced and/or non-linear load currents. Also, this controller improves the steady state and dynamic response under sudden load fluctuation. Droop control approach and virtual output impedance (VOI) loop are investigated to guarantee the accurate power-sharing among DG units in parallel operation. Sliding Mode Current Control (SMCC) approach is adopted for the grid-tied mode where the controller works as a current controller. The proposed controller effectively abandons the grid voltage disturbances and the parameter uncertainties. Furthermore, PQ sharing control is designed for the parallel operating of DG units by delivering available power to the grid side in order to ensure power-sharing requirements. The stability of the proposed controllers is proven by applying the Lyapunov stability theorem. Both controllers have been simulated in the real-time domain of Simulink/MATLAB environment. Finally, the performance of the proposed FOSMVC is compared with the conventional proportional integral (PI) controller. The simulation results show the THD of the output voltage of 0.40% and 1.53% for FOSMVC, and 1.82% and 6.84% for PI controller under linear and nonlinear load, respectively. The results also validate that the proposed control technique is quite effective due to its robust response and less sensitive to external disturbances.

TABLE OF CONTENTS

Certificate.....	ii
Dedication	iii
Declaration of Authorship.....	iv
Acknowledgements	v
Abstract.....	vi
Table of Contents	vii
List of Figures	x
List of Tables.....	xiv
Abbreviations	xv
CHAPTER 1. Introduction.....	2
1.1. Hierarchal Control Structure:	6
1.1.1. Primary Control:	7
1.1.2. Secondary Control:.....	8
1.1.3. Tertiary Control:	9
1.2. Challenges in Microgrid Control and Management:	10
1.3. Problem Description:	12
1.4. Objectives:	13
1.5. Thesis Motivation:	14
1.6. Thesis Organization	15

CHAPTER 2. Literature Review	17
2.1. SMC with other nonlinear control techniques:	18
2.1.1. Present-day SMC:	20
2.2. Slide Mode Control.....	21
2.3. Boundary-Layer Approach:	23
2.4. Observer-Based Chattering Reduction:.....	24
2.5. Fractional-Order Sliding Mode Control:.....	26
CHAPTER 3. Methodology	28
3.1. Fractional-Order Slide Mode Voltage Control (SMVC) for Autonomous mode: ..28	
3.1.1. System Descriptions:	28
3.1.2. Mathematical Model of the Autonomous DG system:	29
3.2. Parallel Operation of DG Units:	34
3.3. Droop Control Method:.....	35
3.3.1. Inductive Output Impedance case: $Z = jX$	36
3.3.2. Resistive Output Impedance Case: $Z = R$	36
3.3.3. Droop Slope/Coefficient Design:	39
3.4. Virtual Impedance loop:.....	39
3.5. Slide-Mode Current Controlled (SMCC) for Grid-Connected DG Units:.....	43
3.5.1. PQ Control:	46
CHAPTER 4. results.....	48

4.1. For Single DG Unit	51
4.1.1. Balanced Linear Load Condition:	51
4.1.2. Unbalanced Linear Load Condition:	52
4.1.3. Balanced Non-linear Load Condition:	54
4.1.4. Step Load Change Condition:	58
4.2. For Parallel Operation of Two DG Units	61
4.2.1. Parallel Operation when one DG is switched off:.....	64
4.2.2. Without Virtual Output Impedance:.....	65
4.3. Grid-tied Mode	66
4.3.1. For Parallel Operation of Two DG units	67
4.3.2. PQ Sharing Control	70
CHAPTER 5. Conclusions and future work	73
5.1. Conclusion	73
5.2. Future Works	73
References	75

LIST OF FIGURES

Figure 1.1. World Energy Consumption (quadrillion Btu) [1].	3
Figure 1.2. Architecture of a Microgrid.....	5
Figure 1.3. Hieratical Control structure of Microgrid	7
Figure 1.4. Control block diagram of Primary level.....	8
Figure 1.5. Control block diagram of secondary level.....	9
Figure 1.6. Control block diagram of tertiary level.....	10
Figure 2.1. Reaching phase & Sliding phase.....	23
Figure 2.2. Chattering Phenomena.....	24
Figure 2.3. Boundary layer approach for chattering elimination.....	25
Figure 3.1. Schematic diagram of an Islanded DG unit.....	29
Figure 3.2. Schematic diagram of proposed Frictional-order SMVC.....	32
Figure 3.3. Schematic diagram of two parallel-connected DG units.....	34
Figure 3.4. Droop control scheme for parallel-connected VSI: (a) inductive output impedance; (b) resistive output impedance.....	36
Figure 3.5. Equivalent model of two parallel-connected inverters to an ac common bus with: (a) output inductive impedance; (b) output resistive impedance.....	37
Figure 3.6. Virtual impedance control: (a) phasor diagram; (b) virtual output impedance loop.....	40
Figure 3.7. Block diagram of droop control with virtual output impedance. LPF: low pass filter.....	40

Figure 3.8. SPWM for gate signals.....	42
Figure 3.9. Proposed DG unit control structure & Mode Selection Switch.....	42
Figure 3.10. Schematic diagram of DG unit in grid-tied mode.....	43
Figure 3.11. Schematic diagram of proposed Frictional-order SMCC for grid-tied mode..	45
Figure 4.1. Microgrid under consideration.....	50
Figure 4.2. Simulated Microgrid in MATLAB/Simulink.....	50
Figure 4.3. Waveform of voltage and current of proposed FOSMVC under balanced linear load current. (a) phase-voltage u_{oabc} (upper row) and current i_{oabc} (lower row); (b) voltage d-axis and q-axis.....	51
Figure 4.4. Waveform of the output voltage and current under unbalanced linear load current: (a) phase-voltage u_{oabc} (upper row) and current i_{oabc} (lower row) when proposed FOSMVC is employed; (b) phase-voltage u_{oabc} (upper row) and current i_{oabc} (lower row) when conventional PI controller is employed.....	53
Figure 4.5. Direct and quadrature components of voltage and current.	53
Figure 4.6. Voltage error.....	54
Figure 4.7. Waveform of output voltage and current under nonlinear load current: (a) phase-voltage u_{oabc} (upper row) and current i_{oabc} (lower row) when proposed FOSMVC is employed; (b) phase- voltage u_{oabc} (upper row) and current i_{oabc} (lower row) when conventional PI controller is employed.....	55
Figure 4.8. (a) Direct and quadrature components of voltage and current: (b) Voltage error.....	56
Figure 4.9. (a) THD of output voltage: (b) THD of output current.....	57

Figure 4.10. Waveform of voltage u_{oabc} (upper row) and current i_{oabc} (lower row) under step load change current when proposed FOSMVC is employed.....	58
Figure 4.11. Direct and quadrature components of voltage and current.....	58
Figure 4.12. Waveform of voltage u_{oabc} (upper row) and current i_{oabc} (lower row) under linear load for parallel operation of DG-1 and DG-2.....	62
Figure 4.13. Waveform of voltage u_{oabc} (upper row) and current i_{oabc} (lower row) under nonlinear load for parallel operation of DG-1 and DG-2.....	63
Figure 4.14. Waveform of active power P (blue) and reactive power Q (red) under linear load for parallel operation of DG-1 and DG-2.....	63
Figure 4.15. Waveform of voltage u_{oabc} (upper row) and current i_{oabc} (lower row) under linear load for parallel operation of DG-1 and DG-2 when DG-1 is switched off.....	64
Figure 4.16. Waveform of active power P (blue) and reactive power Q (red) under linear load for parallel operation of DG-1 and DG-2 when DG-1 unit is switched off.....	65
Figure 4.17. Gate Signals.....	67
Figure 4.18. (a). Waveform of voltage (upper row) and current (lower row) for parallel operation of DG-1 and DG-2 in grid-tied mode; (b). Zoomed view of voltage (upper row) and current (lower row) for parallel operation of DG-1 and DG-2 in grid-tied mode.....	67-68
Figure 4.19. d and q-axis of current.....	68
Figure 4.20. Waveform of active power P1 (blue) and reactive power Q1 (red) of DG-2 for parallel operation in grid-tied mode.....	69
Figure 4.21. Waveform of active power P1 (blue) and Q2 (red) of DG-1 for parallel operation in grid-tied mode.....	70
Figure 4.22. Load Current THD for grid-tied mode.....	70

Figure A.1. Simulation model of Two Parallel Operating DG units in Islanded mode.....	81
Figure A.2. Simulation model of Proposed Control Structure.....	82
Figure A.3. Topology of Three-phase Inverter in Simulink.....	82
Figure A.4. Simulation model of Proposed Sliding Surface & Control Law in d-axis.....	83
Figure A.5. Simulation model of Proposed Sliding Surface & Control Law in q-axis.....	83
Figure A.6. Non-linear Function in d-axis.....	84
Figure A.7. Non-linear Function in q-axis.....	84
Figure A.8. Droop Control for Islanded mode.....	85
Figure A.9. PQ Calculation.....	85
Figure A.10. Virtual Output Impedance Loop.....	86
Figure A.11. Simulation model of two DG units operating in Grid-tied mode.....	86
Figure A.12. Block Diagram of Proposed Slide mode Current Control.....	87
Figure A.13. PQ Sharing Control Simulink Model.....	87

LIST OF TABLES

Table 2-1. Linear controller vs Non-linear controller	25
Table 4-1. DG unit circuit parameters for FOSMVC	48
Table 4-2. Parameters of FOSMVC	49
Table 4.3. Comparison between Proposed FOSMVC and PI Controller. THD: total harmonic distortion.....	59
Table 4.4. Comparison of different control strategies.....	60
Table 4.5. Some characteristics comparison between the proposed FOSMVC and existing SMC schemes.....	60
Table 4-5. DG Unit Circuit & Control Parameters for SMCC	66