

**VOLTAGE AND FREQUENCY CONTROLLERS FOR  
STAND-ALONE WIND ENERGY CONVERSION SYSTEMS**

**By**

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## **CERTIFICATE**

It is certified that the thesis entitled “**Voltage and Frequency Controllers for Stand-Alone Wind Energy Conversion Systems,**” being submitted by **Mr. Shailendra Kumar Sharma** for award of the degree of **Doctor of Philosophy** in the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of the students own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for award of any other degree or diploma.

**Dated: 26.12.2011**

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## ABSTRACT

In last few decades, there has been an extensive research on harnessing the potential of renewable energy sources especially in wind, solar and tidal energies. At present, the power crisis is severe in developing countries like India due to increase in the population and an enhanced use of electricity per capita. The situation is becoming rapidly worst due to depletion of fossil fuels. Moreover, the recent changes in climate around the globe have made it mandatory for international community to reduce their carbon foot-prints. Wind power generation is proved major contributor under these efforts in sustainable energy program. Moreover, with the increasing demand for energy, it is also becoming difficult to reach the consumers in remote and isolated places. Particularly, in some remote areas, the electricity through the grid connection is not feasible due to geo-graphic and economical constraints. It is observed in such cases, stand-alone wind energy conversion systems (SWECSs) may be a sustainable option for the power generation.

This research work aims to investigate voltage and frequency controllers (VFCs) for SWECS employing an isolated asynchronous generator (IAG), a synchronous generator (SG), a permanent magnet synchronous generator (PMSG), a doubly fed induction generator (DFIG) and a permanent magnet brush-less DC generator (PMBLDCG). To cope with the intermittent nature of wind and to provide uninterrupted supply to consumers, a battery energy storage systems (BESS) is proposed with these VFC's. The BESS is used for load leveling under varying wind power and fluctuating loads demand. These SWECS are classified based on fixed speed and variable speed operation of the generator.

Various configurations of VFCs and their control algorithms are investigated for an IAG based fixed speed SWECS feeding 3P3W and 3P4W loads. A systematic procedure of design of VFC is given in detail. The control strategies such as synchronous reference

frame (SRF) theory, current synchronous detection (CSD) based algorithm and enhanced phase locked loop (EPLL) based algorithm for VFC are studied through simulation and experimental results. The VFC is realized using insulated gate bipolar transistors (IGBT's) based VSC and a BESS. A digital signal processor (DSP) dSPACE DS1104 controller is used for prototype development of VFCs in the laboratory. The performance of VFC is demonstrated for a four-leg VSC based non-isolated VFC configuration and a star-polygon transformer based integrated VSC system configuration for an IAG based fixed speed SWECS to feed 3P4W loads. The performance of VFC is found satisfactory as a load leveler, a load balancer, a neutral current compensator, a harmonic eliminator along with a voltage and frequency controller.

VFCs are also investigated for a SG based fixed speed SWECS feeding 3P3W and 3P4W loads. Different topologies and control algorithms are explored for VFC of a SG based fixed speed SWECS for achieving desired performance. An automatic voltage regulator (AVR) is used to regulate SG terminal voltage. A low pass filter (LPF) based control algorithm and an adaptive linear neuron (ADALINE) based control algorithm are used for a SG based fixed speed SWECS. These control algorithms also ensure unity power factor operation at stator terminals. The performance of VFC for a SG based fixed speed SWECS is demonstrated under linear, non-linear and dynamic loads. It is found that ADALINE based control algorithm is fast and accurate due to absence of any filter in its computation.

A PMSG based fixed speed SWECSs are also explored for feeding 3P3W and 3P4W loads. A T-connected transformer and a three-leg VSC with BESS at its DC bus are used as a VFC for feeding 3P4W loads. The design procedure of VFC is given in a systematic manner. An  $\text{Icos}\Phi$  algorithm and a power balance theory (PBT) based control algorithm are used to demonstrate the performance of a developed VFC for a PMSG based fixed

speed SWECS. Two single phase transformers are only used to form a three-phase T-connected transformer for providing stable neutral terminal.

In this research work, VFCs are investigated for a DFIG based variable speed SWECS to feed 3P3W and 3P4W loads. Two back to back connected VSC's and a BESS at its intermediate DC bus are used as a VFC. A mechanical sensor-less field oriented control algorithm is used for providing switching pulses to IGBTs of a rotor-side and a stator-side VSC. A prototype of VFC is developed to demonstrate the performance of VFC for DFIG based variable speed SWECS under linear, non-linear and dynamic loads at varying wind speeds. The performance of VFC is observed as a maximum power point tracker, load leveler, load balancer, a neutral current compensator and a harmonic eliminator.

Variable speed SWECS are also investigated employing a SG, a PMSG and an IAG using different control algorithms and system topologies of VFCs. A three-leg VSC and a voltage source inverter (VSI) along with a BESS are used as a VFC in each topology of variable speed SWECS. These VFCs are designed to feed 3P3W, 3P4W and single-phase two-wire (1P2W) loads. Design of VFCs is given for studied VFC topologies. The performance of VFCs is observed under linear, non-linear and dynamic loads. These variable speed SWECS are found highly efficient in terms of higher energy output and less energy storage requirements compared to fixed speed wind installations of similar ratings.

The PMBLDCG based small scale variable speed SWECS are also investigated for feeding 3P3W, 3P4W and 1P2W loads. A control algorithm of VFC is proposed for achieving maximum power point tracking without sensing wind speed and rotor speed, PMBLDCG voltages and their currents. A VFC is realized using an uncontrolled rectifier, a DC-DC converter, a BESS and a VSI. The performance of VFC has been demonstrated under steady state and dynamic conditions.

## TABLE OF CONTENTS

	Page No.
Certificate	i
Acknowledgement	ii
Abstract	v
Table of Contents	viii
List of Figures	xxvii
List of Tables	xliii
List of Symbols	xliv
<b>CHAPTER I INTRODUCTION</b>	<b>1-12</b>
1.1 General	1
1.2 Classifications of Stand-alone Wind Energy Conversion Systems	2
1.3 State of Art on SWECS	2
1.4 Scope of Work	5
1.5 Outline of Chapters	8
<b>CHAPTER II LITERATURE REVIEW</b>	<b>13-29</b>
2.1 General	13
2.2 Literature Survey	13
2.2.1 Research and Development in IAG Based Fixed Speed WECS	14
2.2.2 Research and Development in PMSG Based Fixed Speed WECS	16
2.2.3 Research and Development in SG Based WECS	17
2.2.4 Research and Development in DFIG Based Variable Speed WECS	18
2.2.5 Research and Development in PMSG Based Variable Speed WECS	20
2.2.6 Research and Development in PMBLDCG Based Variable Speed WECS	22
2.2.7 Research and Development in IAG Based Variable Speed WECS	24
2.2.8 Research and Development in Battery Energy Storage for WECS	26
2.3 Present Status of Wind Power in India	26
2.4 Identified Research Areas	27
2.5 Conclusions	29

**CHAPTER III DESIGN, MODELLING AND IMPLEMENTATION OF 30-64  
VOLTAGE AND FREQUENCY CONTROLLER FOR IAG  
BASED FIXED SPEED THREE-PHASE THREE-WIRE  
STAND-ALONE WIND ENERGY CONVERSION  
SYSTEMS**

3.1	General	30
3.2	System Configuration of VFC for IAG Based Fixed Speed 3P3W SWECS	31
3.3	Working Principle of VFC for IAG Based Fixed Speed 3P3W SWECS	31
3.4	Design of VFC of IAG Based Fixed Speed 3P3W SWECS	32
	3.4.1 Selection of Terminal Capacitors	32
	3.4.2 Selection of Battery Energy Storage System	33
	3.4.3 Selection of AC Inductors	34
	3.4.4 Selection of VSC	34
	3.4.5 Selection of Specifications of Wind Turbine	35
3.5	Control Algorithm of VFC for IAG Based Fixed Speed 3P3W SWECS	36
	3.5.1 Direct Axis Component of Reference Source Currents	38
	3.5.2 Quadrature Axis Component of Reference Source Currents	38
	3.5.3 Three Phase Reference Source Currents	40
	3.5.4 PWM Current Controller	40
3.6	MATLAB Model of VFC for IAG In Fixed Speed 3P3W SWECS	40
3.7	Hardware Implementation of VFC for IAG In Fixed Speed 3P3W SWECS	41
	3.7.1 DSP dSPACE DS1104 Controller	41
	3.7.2 Signal Scaling and Conditioning Circuits	43
	3.7.3 Driver Circuits	44
3.8	Results and Discussion	46
	3.8.1 Simulated Performance of VFC for IAG Based 3P3W SWECS under Linear Loads	47
	3.8.2 Experimental Performance of VFC for IAG Based 3P3W SWECS under Linear Loads	47
	3.8.3 Simulated Performance of VFC for IAG Based 3P3W SWECS under Non-linear Loads	49
	3.8.4 Experimental Performance of VFC for IAG Based 3P3W SWECS under Non-linear Loads	51
	3.8.5 Simulated Performance of VFC for IAG Based 3P3W SWECS under Dynamic Loads	54
	3.8.6 Experimental Performance of VFC for IAG Based 3P3W SWECS under Dynamic Loads	58
	3.8.7 Simulated Performance of VFC for IAG Based 3P3W SWECS under Change in Wind Speed	60

3.8.8	Experimental Performance of VFC for IAG Based 3P3W SWECS under Change in Wind Speed	62
3.9	Conclusions	64
<b>CHAPTER IV DESIGN, MODELLING AND IMPLEMENTATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR ISOLATED ASYNCHRONOUS GENERATOR BASED FIXED SPEED THREE-PHASE FOUR-WIRE STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>65-133</b>
4.1	General	65
4.2	Configurations of VFC for IAG Based Fixed Speed 3P4W SWECS	65
	4.2.1 Integrated VSC Based System Configurations	66
	4.2.2 Non-Isolated VSC Based System Configurations	69
4.3	Operating Principle of VFC for IAG In Fixed Speed 3P4W SWECS	72
4.4	Design of VFC for IAG In Fixed Speed 3P4W SWECS	73
	4.4.1 Selection of Excitation Capacitors	73
	4.4.2 Selection of Battery Energy Storage System	74
	4.4.3 Selection of Transformers	75
	4.4.3.1 Design of a star-delta transformer	75
	4.4.3.2 Design of a zig-zag transformer	76
	4.4.3.3 Design of a star-hexagon transformer	77
	4.4.3.4 Design of a star-Polygon transformer	79
	4.4.3.5 Design of a T-connected transformer	80
	4.4.4 Selection of AC inductors	82
	4.4.5 Selection of VSC	83
	4.4.6 Selection of Specifications of Wind Turbine	83
4.5	Control Algorithms of VFC for IAG In Fixed Speed 3P4W SWECS	83
	4.5.1 Enhanced Phase Locked Loop Based Control Algorithm for Four-leg VSC Based VFC of IAG In Fixed Speed 3P4W SWECS	83
	4.5.1.1 Estimation of frequency and templates	83
	4.5.1.2 Extraction of amplitude of active and reactive power components of load currents	84
	4.5.1.3 Estimation of amplitude of active power component of reference source currents	86
	4.5.1.4 Estimation of amplitude of reactive power component of reference source currents	87
	4.5.1.5 Estimation of reference source currents	87
	4.5.1.6 PWM current controller	88
	4.5.1.7 Neutral current compensation	88

	4.5.2	Current Synchronous Detection Algorithm for Integrated VSC Based VFC of IAG In Fixed Speed 3P4W SWECS	88
	4.5.2.1	Computation of quadrature voltages	89
	4.5.2.2	Peak phase voltage detection	90
	4.5.2.3	Estimation of active power of loads	90
	4.5.2.4	Estimation of reactive power of loads	90
	4.5.2.5	Estimation of reference active power of source	91
	4.5.2.6	Estimation of reference reactive power of source	92
	4.5.2.7	Computation of active power component of three-phase source currents	93
	4.5.2.8	Estimation of reactive power component of reference source currents	94
	4.5.2.9	Estimation of three-phase reference source currents	95
	4.5.2.10	PWM current controller	95
4.6		MATLAB Models of VFC for IAG Based Fixed Speed 3P4W SWECS	96
	4.6.1	MATLAB Model of Four-leg VSC Based VFC for IAG in 3P4W SWECS	96
	4.6.2	MATLAB Model of Integrated VSC Based VFC for IAG in 3P4W Fixed Speed SWECS	96
4.7		Hardware Implementation of VFC for IAG In Fixed Speed 3P4W SWECS	97
	4.7.1	Details of Hardware Implementation for Four-leg VSC Based VFC for IAG In Fixed Speed 3P4W SWECS	98
	4.7.2	Details of Hardware Implementation for Star-Polygon Transformer Based VFC for IAG In Fixed Speed 3P4W SWECS	101
4.8		Results and Discussion	101
	4.8.1	Performance of Four-leg VSC Based VFC for IAG In Fixed Speed 3P4W SWECS	101
	4.8.1.1	Simulated performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under balanced/unbalanced linear loads	102
	4.8.1.2	Experimental performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under balanced linear loads	103
	4.8.1.3	Simulated performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under balanced/unbalanced non-linear loads	104
	4.8.1.4	Experimental performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under non-linear loads	105

4.8.1.5	Simulated performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under fall in wind speed	111
4.8.1.6	Experimental performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under fall in wind speed	114
4.8.1.7	Simulated performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under rise in wind speed	115
4.8.1.8	Experimental performance of four-leg VSC based VFC for IAG in fixed speed 3P4W SWECS under rise in wind speed	115
4.8.2	Performance of Integrated VSC Based VFC for IAG In Fixed Speed 3P4W SWECS	116
4.8.2.1	Simulated performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under balanced/unbalanced linear loads	117
4.8.2.2	Experimental performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under linear consumer loads	118
4.8.2.3	Simulated performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under non-linear loads	121
4.8.2.4	Experimental performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under non-linear loads	124
4.8.2.5	Simulated performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under change in wind speed	130
4.8.2.6	Experimental performance of integrated VSC based VFC for IAG in fixed speed 3P4W SWECS under change in wind speed	131
4.9	Conclusions	133
<b>CHAPTER V DESIGN, MODELLING AND SIMULATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR SYNCHRONOUS GENERATOR BASED FIXED SPEED STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>134-162</b>
5.1	General	134
5.2	Configurations of VFC for SG Based Fixed Speed SWECS	134
5.3	Operating Principle of VFC for SG Based Fixed Speed SWECS	135
5.4	Design of VFCS for SG Based Fixed Speed SWECS	136
5.4.1	VFC for SG Based Fixed Speed 3P3W SWECS	136
5.4.1.1	Selection of a battery energy storage system	137

	5.4.1.2	Selection of Wind Turbine	138
	5.4.1.3	Selection of AC interface inductors	138
	5.4.1.4	Selection of a VSC	139
	5.4.1.5	Selection of Ripple Filter	139
	5.4.2	VFC for SG Based Fixed Speed 3P4W SWECS	139
	5.4.2.1	Selection of a battery energy storage system	140
	5.4.2.2	Selection of Wind Turbine	140
	5.4.2.3	Selection of AC interface inductors	141
	5.4.2.4	Selection of a VSC	141
	5.4.2.5	Selection of ripple filter	141
5.5		Control Algorithms for SG Based Fixed Speed SWECS	141
	5.5.1	Low-Pass Filter Based Control Algorithm of VFC for SG in Fixed Speed 3P3W SWECS	142
	5.5.1.1	Estimation of active and reactive power components of load currents	142
	5.5.1.2	Estimation of amplitude of active power component of reference source currents	144
	5.5.1.3	Estimation of amplitude of reactive power component of reference source currents	144
	5.5.1.4	Estimation of reference source currents	145
	5.5.1.5	PWM current controller	145
	5.5.1.6	Automatic voltage regulator	146
	5.5.2	ADALINE Based Control Algorithm of VFC for SG in Fixed Speed 3P4W SWECS	146
	5.5.2.1	Extraction of weights for active power component of load currents	146
	5.5.2.2	Extraction of weights for reactive power component of load currents	147
	5.5.2.3	Estimation of active power component of reference source currents	147
	5.5.2.4	Estimation of reactive power component of reference source currents	148
	5.5.2.5	Estimation of reference source currents	148
	5.5.2.6	PWM current controller	149
	5.5.2.7	Automatic voltage regulator	149
	5.5.2.8	Neutral current compensation	150
5.6		MATLAB Models of SG Based Fixed Speed SWECS	150
	5.6.1	MATLAB Model of SG in Fixed Speed 3P3W SWECS	150
	5.6.2	MATLAB Model of SG in Fixed Speed 3P4W SWECS	150
5.7		Results and Discussion	151

5.7.1	Performance of LPF Based VFC for SG In Fixed Speed 3P3W SWECS	152
5.7.1.1	Performance of VFC for SG in fixed speed 3P3W SWECS under fall in wind speed	152
5.7.1.2	Performance of VFC for SG in fixed speed 3P3W SWECS under rise in wind speed	152
5.7.1.3	Performance of VFC for SG in fixed speed 3P3W SWECS under balanced/unbalanced linear loads	153
5.7.1.4	Performance of VFC for SG in fixed speed 3P3W SWECS under balanced/unbalanced non-linear loads	154
5.7.1.5	Performance of VFC for SG in fixed speed 3P3W SWECS under dynamic loads	155
5.7.2	Performance of ADALINE Based Control Algorithm of VFC for SG in Fixed Speed 3P4W SWECS	157
5.7.2.1	Performance of four-leg VSC based VFC for SG in fixed speed 3P4W SWECS under fall in wind speed	158
5.7.2.2	Performance of four-leg VSC based VFC for SG in fixed speed 3P4W SWECS under rise in wind speed	159
5.7.2.3	Performance of four-leg VSC based VFC for SG in fixed speed 3P4W SWECS under linear loads	159
5.7.2.4	Performance of four-leg VSC based VFC for SG in fixed speed 3P4W SWECS under non-linear loads	160
5.8	Conclusions	162
<b>CHAPTER VI DESIGN, MODELLING AND IMPLEMENTATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR PERMANENT MAGNET SYNCHRONOUS GENERATOR BASED FIXED SPEED THREE-PHASE THREE-WIRE STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>163-190</b>
6.1	General	163
6.2	Configuration and Principle of Operation of VFC for PMSG Based Fixed Speed 3P3W SWECS	163
6.3	Design of VFC for PMSG Based Fixed Speed 3P3W SWECS	164
6.3.1	Selection of Ripple Filter	164
6.3.2	Selection of Battery Energy Storage System	165
6.3.3	Selection of AC Inductors	165
6.3.4	Selection of Specifications of Wind Turbine	166
6.3.5	Selection of VSC	166
6.4	Control Algorithm of VFC for PMSG Based Fixed Speed 3P3W SWECS	166
6.4.1	Line to Phase Voltage Transformation	167

6.4.2	Extraction of Amplitude of Active Power Component of Load currents	168
6.4.3	Extraction of Amplitude of Reactive Power Component of Load currents	168
6.4.4	Estimation of Reference Active Power Component of Source Currents	169
6.4.5	Estimation of Reference Reactive Power Component of Source Currents	170
6.4.6	Estimation of Reference Source Currents	172
6.4.7	PWM Current Controller	172
6.5	MATLAB Model of VFC for PMSG Based Fixed Speed 3P3W SWECS	172
6.6	Hardware Implementation of VFC for PMSG Based Fixed Speed 3P3W SWECS	174
6.7	Results and Discussion	174
6.7.1	Simulated Performance of VFC for PMSG In Fixed Speed 3P3W SWECS under Linear Loads	175
6.7.2	Experimental Performance of VFC for PMSG In Fixed Speed 3P3W SWECS under Linear Loads	177
6.7.3	Simulated Performance of VFC for PMSG in Fixed Speed 3P3W SWECS under Non-linear Loads	180
6.7.4	Experimental Performance of VFC for PMSG in Fixed Speed 3P3W SWECS under Non-linear Loads	181
6.7.5	Simulated Performance of VFC for PMSG in Fixed Speed 3P3W SWECS under Change in Wind Speed	184
6.8	Conclusions	190
<b>CHAPTER VII DESIGN, MODELLING AND IMPLEMENTATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR PERMANENT MAGNET SYNCHRONOUS GENERATOR BASED FIXED SPEED THREE-PHASE FOUR-WIRE STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>191-221</b>
7.1	General	191
7.2	Configurations of VFC's for PMSG Based Fixed Speed 3P4W SWECS	192
7.3	Operating Principle of VFC's for PMSG Based Fixed Speed 3P4W SWECS	192
7.4	Design of VFC of PMSG Based Fixed Speed 3P4W SWECS	194
7.4.1	Selection of Ripple Filter	195
7.4.2	Selection of Battery Energy Storage System	195
7.4.3	Selection of Rating of VSC	195
7.4.4	Selection of AC Interface Inductors	196

7.4.5	Design of T-connected Transformer	196
7.4.6	Selection of Specifications of Wind Turbine	197
7.5	Power Balance Theory Based Control Algorithm of VFC for PMSG in fixed speed 3P4W SWECS	197
7.5.1	Computation of In-Phase and Quadrature Unit Templates	198
7.5.2	Estimation of PMSG Frequency	198
7.5.3	Estimation of Active Power of Loads and Amplitude of Active Power Component of Load Currents	199
7.5.4	Estimation of Reactive Power of Loads and Amplitude of Reactive Power Component of Load Currents	199
7.5.5	Computation of Fundamental Active Power Component of Reference Source Currents	200
7.5.6	Computation of Fundamental Reactive Power Component of Reference Source Currents	201
7.5.7	Estimation of Three Phase Reference Source Currents	202
7.5.8	PWM Signal Generation	202
7.6	MATLAB Based Model of VFC for PMSG Based Fixed Speed 3P4W SWECS	202
7.7	Hardware Implementation of VFC for PMSG Based Fixed Speed 3P4W SWECS	204
7.8	Results and Discussion	205
7.8.1	Simulated Performance of VFC for PMSG Based Fixed Speed 3P4W SWECS under Linear Loads	207
7.8.2	Experimental Performance of VFC for PMSG Based Fixed Speed 3P4W SWECS under Linear Loads	207
7.8.3	Simulated Performance of VFC for PMSG Based Fixed Speed 3P4W SWECS under Non-linear Loads	210
7.8.4	Experimental Performance of VFC for PMSG Based Fixed Speed 3P4W SWECS under Non-linear Loads	211
7.8.5	Simulated Performance of VFC for PMSG Based Fixed Speed 3P4W SWECS under Change in Wind Speed	216
7.9	Conclusions	221
<b>CHAPTER VIII DESIGN, MODELLING AND IMPLEMENTATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR DOUBLY FED INDUCTION GENERATOR BASED VARIABLE SPEED THREE-PHASE THREE-WIRE STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>222-258</b>
8.1	General	222
8.2	Configuration of VFC for DFIG Based Variable Speed 3P3W SWECS	222
8.3	Working Principle of VFC for DFIG Based Variable Speed 3P3W SWECS	223

8.4	Design of DFIG Based Variable Speed 3P3W SWECS	224
	8.4.1 Selection of Specifications of Wind Turbine	224
	8.4.2 Selection of Battery Energy Storage System	225
	8.4.3 Design of Ripple Filter	225
	8.4.4 Selection of Rating of SSC and RSC	226
	8.4.5 Design of AC Interface Inductors	227
	8.4.6 Selection of Star-Delta Transformer	227
8.5	Control Algorithm of VFC for DFIG Based Variable Speed 3P3W SWECS	228
	8.5.1 Control of Rotor-side Converter	228
	8.5.2 Control of Stator-side Converter	230
8.6	MATLAB Model of VFC for DFIG Based Variable Speed 3P3W SWECS	234
	Hardware Implementation of VFC for DFIG Based Variable Speed 3P3W SWECS	235
8.7		
	8.7.1 DSP dSPACE DS1104 Controller	236
	8.7.2 Hall Effect Current Sensors	236
	8.7.3 Hall Effect Voltage Sensors	237
	8.7.4 Speed Sensing Circuit	238
	8.7.5 Gate Driver Circuit	238
8.8	Results and Discussion	239
	8.8.1 Simulated Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under Linear Loads	240
	8.8.2 Experimental Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under Linear Loads	240
	8.8.3 Simulated Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under Non-linear Loads	244
	8.8.4 Experimental Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under Non-linear Loads	247
	8.8.5 Simulated Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under change in Wind Speed	251
	8.8.6 Experimental Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under change in Rotor Speed	252
	8.8.7 Simulated Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under Dynamic Loads	253
	8.8.8 Experimental Performance of VFC for DFIG Based Variable Speed 3P3W SWECS under dynamic loads	255
8.9	Conclusions	258

**CHAPTER IX DESIGN, MODELLING AND IMPLEMENTATION OF 259-  
VOLTAGE AND FREQUENCY CONTROLLER FOR 290  
DOUBLY FED INDUCTION GENERATOR BASED  
VARIABLE SPEED THREE-PHASE FOUR-WIRE STAND-  
ALONE WIND ENERGY CONVERSION SYSTEM**

9.1	General	259
9.2	Configuration of VFC for DFIG Based Variable Speed 3P4W SWECS	259
9.3	Working Principle of VFC for DFIG Based Variable Speed 3P4W SWECS	260
9.4	Design of VFC for DFIG Based Variable Speed 3P4W SWECS	261
	9.4.1 Selection of Specifications of Wind Turbine	261
	9.4.2 Selection of Battery Energy Storage System	261
	9.4.3 Selection of SSC and RSC	262
	9.4.4 Design of Ripple Filter	262
	9.4.5 Selection of AC Interface Inductors	262
	9.4.6 Selection of Star-Delta Transformer	262
9.5	Control Algorithm of VFC for DFIG Based Variable Speed 3P4W SWECS	263
	9.5.1 Control of Rotor-side Converter	263
	9.5.2 Control of Stator-side Converter	266
9.6	MATLAB Model of VFC for DFIG Based Variable Speed 3P4W SWECS	267
9.7	Hardware Implementation of VFC for DFIG Based Variable Speed 3P4W SWECS	270
9.8	Results and Discussion	271
	9.8.1 Simulated Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Linear Loads	272
	9.8.2 Experimental Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Linear Loads	273
	9.8.3 Simulated Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Non-linear Loads	278
	9.8.4 Experimental Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Non-linear Loads	280
	9.8.5 Simulated Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Change in Wind Speed	284
	9.8.6 Experimental Performance of VFC for DFIG Based Variable Speed 3P4W SWECS under Change in Wind Speed	286
	9.8.7 Experimental Comparison of Sensed and Estimated Rotor Speed	288
9.9	Conclusions	290

**CHAPTER X DESIGN, MODELLING AND SIMULATION OF 291-  
VOLTAGE AND FREQUENCY CONTROLLER FOR 321  
SYNCHRONOUS GENERATOR BASED VARIABLE  
SPEED STAND-ALONE WIND ENERGY CONVERSION  
SYSTEMS**

10.1	General	291
10.2	Configurations of VFC for SG Based Variable Speed SWECS	291
10.3	Control Strategy of VFC for SG Based Variable Speed SWECS	292
10.4	Design of VFC's for SG Based Variable Speed SWECS	293
	10.4.1 Design of VFC for SG Based Variable Speed 3P3W SWECS	293
	10.4.1.1 Selection of a wind turbine	293
	10.4.1.2 Selection of battery energy storage system	293
	10.4.1.3 Design of AC interfacing inductors and LSI	294
	10.4.1.4 Design of MSC	295
	10.4.1.5 Design of high pass ripple filter	295
	10.4.2 Design of VFC for SG Based Variable Speed 3P4W SWECS	295
	10.4.2.1 Selection of a wind turbine	296
	10.4.2.2 Selection of battery energy storage system	296
	10.4.2.3 Design of T-connected transformer	296
	10.4.2.4 Design of AC interfacing inductors, LSI and MSC	297
	10.4.2.5 Design of high pass ripple filter	297
	10.4.3 Design of VFC for SG Based Variable Speed 1P2W SWECS	298
	10.4.3.1 Selection of a wind turbine	298
	10.4.3.2 Selection of battery energy storage system	298
	10.4.3.3 Design of LC filters	298
	10.4.3.4 Design of LSI and MSC	299
10.5	Control Algorithm for VFC of SG Based Variable Speed 3P3W SWECS	299
	10.5.1 Control of Machine Side Converter	299
	10.5.2 Control of Load Side Inverter	301
10.6	Control Algorithm for VFC of SG Based Variable Speed 3P4W SWECS	302
10.7	Control Algorithm for VFC of SG Based Variable Speed 1P2W SWECS	304
10.8	MATLAB Models of SG Based Variable Speed SWECS	304
	10.8.1 SG Based Variable Speed 3P3W SWECS	305
	10.8.2 SG Based Variable Speed 3P4W SWECS	306
	10.8.3 SG Based Variable Speed 1P2W SWECS	307
10.9	Results and Discussion	308

10.9.1	Performance of VFC for SG based Variable Speed 3P3W SWECS	308
10.9.1.1	Performance of VFC for SG in variable speed 3P3W SWECS under fall in wind speed	308
10.9.1.2	Performance of VFC for SG in variable speed 3P3W SWECS under rise in wind speed	308
10.9.1.3	Performance of VFC for SG in variable speed 3P3W SWECS under balanced/unbalanced linear loads	309
10.9.1.4	Performance of VFC for SG in variable speed 3P3W SWECS with balanced/unbalanced non-linear loads	310
10.9.2	Performance of VFC for SG based Variable Speed 3P4W SWECS	311
10.9.2.1	Performance of VFC for SG in variable speed 3P4W SWECS under fall in wind speed	313
10.9.2.2	Performance of VFC for SG in variable speed 3P4W SWECS under rise in wind speed	314
10.9.2.3	Performance of VFC for SG in variable speed 3P4W SWECS under linear loads	315
10.9.2.4	Performance of VFC for SG based variable speed 3P4W SWECS under non-linear loads	316
10.9.3	Performance of VFC for SG based Variable Speed 1P2W SWECS	317
10.9.3.1	Performance of VFC for SG based variable speed 1P2W SWECS under fall in wind speed	317
10.9.3.2	Performance of VFC for SG based variable speed 1P2W SWECS under rise in wind speed	318
10.9.3.3	Performance of VFC for SG based variable speed 1P2W SWECS under linear loads	318
10.9.3.4	Performance of VFC for SG in variable speed 1P2W SWECS under non-linear loads	319
10.10	Conclusions	321

**CHAPTER XI DESIGN, MODELLING AND SIMULATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR PERMANENT MAGNET SYNCHRONOUS GENERATOR BASED THREE-PHASE FOUR-WIRE VARIABLE SPEED STAND-ALONE WIND ENERGY CONVERSION SYSTEMS**

11.1	General	322
11.2	Configurations of VFC for PMSG Based Variable Speed SWECS	323
11.3	Working Principle of VFC's for PMSG Based Variable Speed SWECS	324
11.4	Design of VFC's for PMSG Based Variable Speed SWECS	325

11.4.1	Design of VFC for PMSG Based Variable Speed 3P3W SWECS	325
11.4.1.1	Selection of a wind turbine	325
11.4.1.2	Selection of battery energy storage system	325
11.4.1.3	Selection of AC interfacing inductors	326
11.4.1.4	Design of high pass ripple filter	326
11.4.1.5	Selection of GSC and LSI	327
11.4.2	Design of VFC for PMSG Based Variable Speed 3P4W SWECS	327
11.4.2.1	Selection of a wind turbine	327
11.4.2.2	Selection of battery energy storage system	327
11.4.2.3	Design of star-delta transformer	327
11.4.2.4	Design of AC interfacing inductors	328
11.4.2.5	Design of high pass ripple filter	328
11.4.2.6	Selection of GSC and LSI	329
11.4.3	Design of VFC for PMSG Based Variable Speed 1P2W SWECS	329
11.4.3.1	Selection of a wind turbine	329
11.4.3.2	Selection of battery energy storage system	329
11.4.3.3	Design of LC filter	329
11.4.3.4	Selection of GSC and LSI	330
11.5	Control Algorithms of VFC for PMSG Variable Speed Based SWECS	330
11.5.1	Control Algorithm of VFC for PMSG Based Variable Speed 3P3W SWECS	330
11.5.1.1	Control of GSC	330
11.5.1.2	Control of LSI	332
11.5.2	Control Algorithm of VFC for PMSG Based Variable Speed 3P4W SWECS	333
11.5.2.1	Control of GSC	334
11.5.2.2	Control of LSI	335
11.5.3	Control Algorithm of VFC for PMSG Based Variable Speed 1P2W SWECS	335
11.5.3.1	Control of GSC	336
11.5.3.2	Control of single-phase LSI	336
11.6	MATLAB Models of PMSG Based Variable Speed SWECS	337
11.7	Results and Discussion	338
11.7.1	Performance of VFC for PMSG Based Variable Speed 3P3W SWECS	339
11.7.1.1	Performance of VFC for PMSG in variable speed 3P3W SWECS under fall in wind speed	340

11.7.1.2	Performance of VFC for PMSG in variable speed 3P3W SWECS under rise in wind speed	340
11.7.1.3	Performance of VFC for PMSG in variable speed 3P3W SWECS under linear loads	341
11.7.1.4	Performance of VFC for PMSG in variable speed 3P3W SWECS under non-linear loads	342
11.7.1.5	Performance of VFC for PMSG in variable speed 3P3W SWECS under dynamic loads	344
11.7.2	Performance of VFC for PMSG Based Variable Speed 3P4W SWECS	345
11.7.2.1	Performance of VFC for PMSG in variable speed 3P4W SWECS under fall in wind speed	345
11.7.2.2	Performance of VFC for PMSG in variable speed 3P4W SWECS under rise in wind speed	345
11.7.2.3	Performance of VFC for PMSG in variable speed 3P4W SWECS under linear loads	346
11.7.2.4	Performance of VFC for PMSG in variable speed 3P4W SWECS under non-linear loads	348
11.7.3	Performance of VFC for PMSG Based Variable Speed 1P2W SWECS	350
11.7.3.1	Performance of VFC for PMSG in variable speed 1P2W SWECS under fall in wind speed	350
11.7.3.2	Performance of VFC for PMSG in variable speed 1P2W SWECS under rise in wind speed	351
11.7.3.3	Performance of VFC for PMSG in variable speed 1P2W SWECS under linear loads	352
11.7.3.4	Performance of VFC for PMSG in variable speed 1P2W SWECS under non-linear loads	353
11.8	Conclusions	355
<b>CHAPTER XII DESIGN, MODELLING AND SIMULATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR PERMANENT MAGNET BRUSH-LESS DC GENERATOR BASED THREE-PHASE FOUR-WIRE VARIABLE SPEED STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>356-389</b>
12.1	General	356
12.2	System Configurations and Principle of Operation of VFC for PMBLDCG Based Variable Speed SWECS	357
12.3	Control Strategy of VFC's for PMBLDCG Based Variable Speed SWECS	357
12.4	Design of VFC's for PMBLDCG Based Variable Speed SWECS	358
12.4.1	Design of PMBLDCG Based Variable Speed 3P3W SWECS	359

	12.4.1.1	Selection of specifications of a wind turbine	359
	12.4.1.2	Selection of battery energy storage system	360
	12.4.1.3	Design of a boost converter	361
	12.4.1.4	Design of LC Filters	362
	12.4.1.5	Selection of LSI	362
	12.4.2	Design of PMBLDCG Based Variable Speed 3P4W SWECS	362
	12.4.2.1	Selection of a wind turbine	362
	12.4.2.2	Selection of battery energy storage system	363
	12.4.2.3	Design of a boost inductor	363
	12.4.2.4	Design of LC Filters	363
	12.4.2.5	Selection of LSI	363
	12.4.3	Design of PMBLDCG Based Variable Speed 1P2W SWECS	364
	12.4.3.1	Selection of specifications of wind turbine	364
	12.4.3.2	Selection of battery energy storage system	364
	12.4.3.3	Design of a buck-boost converter	364
	12.4.3.4	Design of LC filter	365
	12.4.3.5	Selection of single-phase LSI	365
12.5		Control Algorithms of VFC for PMBLDCG Based Variable Speed SWECS	366
	12.5.1	Control Algorithm of VFC for PMBLDCG Based Variable Speed 3P3W and 3P4W SWECS	366
	12.5.1.1	Maximum power point tracking control of PMBLDCG	366
	12.5.1.2	Load side inverter control	367
	12.5.2	Control Algorithm of VFC for PMBLDCG Based Variable Speed 1P2W SWECS	368
	12.5.2.1	Maximum power point tracking control of PMBLDCG	369
	12.5.2.2	Control of single-phase LSI	370
12.6		MATLAB Models of VFC for PMBLDCG Based Variable Speed SWECS	370
	12.6.1	MATLAB Model of PMBLDCG Based Variable Speed 3P3W SWECS	370
	12.6.2	MATLAB Model of PMBLDCG Based Variable Speed 3P4W SWECS	370
	12.6.3	MATLAB Model of PMBLDCG Based Variable Speed 1P2W SWECS	372
12.7		Results and Discussion	372
	12.7.1	Performance of VFC for PMBLDCG Based Variable Speed 3P3W SWECS	372

12.7.1.1	Performance of VFC for PMBLDCG based variable speed 3P3W SWECS under fall in wind speed	373
12.7.1.2	Performance of VFC for PMBLDCG based variable speed 3P3W SWECS under rise in wind speed	374
12.7.1.3	Performance of VFC for PMBLDCG based variable speed 3P3W SWECS under linear loads	375
12.7.1.4	Performance of VFC for PMBLDCG based variable speed 3P3W SWECS under non-linear loads	376
12.7.1.5	Performance of VFC for PMBLDCG based variable speed 3P3W under dynamic loads	377
12.7.2	Performance of VFC for PMBLDCG Based Variable Speed 3P4W SWECS	378
12.7.2.1	Performance of VFC for PMBLDCG based variable speed 3P4W SWECS as maximum power point tracker	378
12.7.2.2	Performance of VFC for PMBLDCG based variable speed 3P4W SWECS under linear loads	379
12.7.2.3	Performance of VFC for PMBLDCG based variable speed 3P4W SWECS under rise in wind Speed	380
12.7.2.4	Performance of VFC for PMBLDCG based variable speed 3P4W SWECS under Fall in Wind Speed	381
12.7.3	Performance of VFC for PMBLDCG Based Variable Speed 1P2W SWECS	383
12.7.3.1	Performance of VFC for PMBLDCG based variable speed 1P2W SWECS under fall in wind speed	384
12.7.3.2	Performance of VFC for PMBLDCG based variable speed 1P2W SWECS under rise in wind speed	385
12.7.3.3	Performance of VFC for PMBLDCG based variable speed 1P2W SWECS under linear loads	386
12.7.3.4	Performance of VFC for PMBLDCG based variable speed 1P2W SWECS under non-linear loads	387
12.8	Conclusions	389
<b>CHAPTER XIII DESIGN, MODELLING AND SIMULATION OF VOLTAGE AND FREQUENCY CONTROLLER FOR ISOLATED ASYNCHRONOUS GENERATOR BASED VARIABLE SPEED THREE-PHASE FOUR-WIRE STAND-ALONE WIND ENERGY CONVERSION SYSTEMS</b>		<b>390-421</b>
13.1	General	390
13.2	Configurations of IAG Based Variable Speed SWECS	390
13.3	Working Principle of VFC's for IAG Based Variable Speed SWECS	391
13.4	Design of VFC's for IAG Based Variable Speed SWECS	392

13.4.1	Design of VFC for IAG Based Variable Speed 3P3W SWECS	392
13.4.1.1	Selection of specifications of a wind turbine	392
13.4.1.2	Selection of battery energy storage system	393
13.4.1.3	Design of AC interfacing inductors	394
13.4.1.4	Selection of GSC and LSI	394
13.4.1.5	Design of high pass ripple filter	395
13.4.2	Design of VFC for IAG Based Variable Speed 3P4W SWECS	395
13.4.2.1	Selection of specifications of a wind turbine	395
13.4.2.2	Selection of battery energy storage system	396
13.4.2.3	Design of AC interfacing inductors	396
13.4.2.4	Selection of GSC and LSI	396
13.4.2.5	Design of high pass ripple filter	397
13.4.3	Design of VFC for IAG Based Variable Speed 1P2W SWECS	397
13.4.3.1	Selection of specifications of a wind turbine	397
13.4.3.2	Selection of battery energy storage system	397
13.4.3.3	Design of LC filter	398
13.4.3.4	Selection of GSC and LSI	398
13.5	Control Algorithms for VFC of IAG Based variable speed SWECS	398
13.5.1	Control Algorithm for VFC of IAG Based Variable Speed 3P3W SWECS	398
13.5.1.1	Control of GSC	399
13.5.1.2	Control of LSI	401
13.5.2	Control Algorithm of VFC for IAG Based Variable Speed 3P4W SWECS	402
13.5.3	Control Algorithm of VFC for IAG Based Variable Speed 1P2W SWECS	403
13.6	MATLAB Models of IAG Based variable speed SWECS	404
13.6.1	MATLAB Model of IAG Based Variable Speed 3P3W SWECS	404
13.6.2	MATLAB Model of IAG Based Variable Speed 3P4W SWECS	405
13.6.3	MATLAB Model of IAG Based Variable Speed 1P2W SWECS	405
13.7	Results and Discussion	406
13.7.1	Performance of VFC for IAG Based Variable Speed 3P3W SWECS	406
13.7.1.1	Performance of VFC for IAG in variable speed 3P3W SWECS under fall in Wind Speed	407
13.7.1.2	Performance of VFC for IAG in variable speed 3P3W SWECS under rise in Wind Speed	408

13.7.1.3	Performance of VFC for IAG in variable speed 3P3W SWECS under linear loads	409
13.7.1.4	Performance of VFC for IAG in variable speed 3P3W SWECS under non-linear loads	409
13.7.1.5	Performance of VFC for IAG in variable speed 3P3W SWECS under dynamic loads	410
13.7.2	Performance of VFC for IAG Based Variable Speed 3P4W SWECS	411
13.7.2.1	Performance of VFC for IAG in variable speed 3P4W SWECS under fall in wind speed	411
13.7.2.2	Performance of VFC for IAG in variable speed 3P4W SWECS under rise in wind speed	412
13.7.2.3	Performance of VFC for IAG in variable speed 3P4W SWECS under linear loads	413
13.7.2.4	Performance of VFC for IAG in variable speed 3P4W SWECS under non-linear loads	414
13.7.3	Performance of VFC for IAG Based Variable Speed 1P2W SWECS	416
13.7.3.1	Performance of VFC for IAG in variable speed 1P2W SWECS under fall in wind speed	417
13.7.3.2	Performance of VFC for IAG in variable speed 1P2W SWECS under rise in wind speed	418
13.7.3.3	Performance of VFC for IAG in variable speed 1P2W SWECS under linear loads	419
13.7.3.4	Performance of VFC for IAG in variable speed 1P2W SWECS under non-linear loads	419
13.8	Conclusions	421
<b>CHAPTER XIV MAIN CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK</b>		<b>422-428</b>
14.1	General	422
14.2	Main Conclusions	423
14.3	Suggestions for Further Work	427
<b>REFERENCES</b>		<b>429-450</b>
<b>APPENDICES</b>		<b>451-466</b>
<b>LIST OF PUBLICATIONS</b>		<b>467-471</b>
<b>BIO-DATA</b>		<b>472</b>