

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

# **Multiport Power Electronics Circuitry for Integration of Renewable Energy Sources in Low Power Applications**

**A thesis presented in partial fulfilment of the requirements for the degree of**

**Doctor of Philosophy**

**In**

**Electrical Engineering**

**at Massey University, Palmerston North**

**New Zealand**

**Zubair Rehman**

**2017**

## **Abstract**

The increasing demand for electricity and the global concern about environment has led energy planners and developers to explore and develop clean energy sources. Under such circumstances, renewable energy sources (RES) have emerged as an alternative source of energy generation. Immense development has been made in renewable energy fields and methods to harvest it. To replace conventional generation system, these renewable energy sources must be sustainable, reliable, stable, and efficient. But these sources have their own distinguished characteristics. Due to sporadic nature of renewable energy sources, the uninterrupted power availability cannot be guaranteed. Handling and integration of such diversified power sources is not a trivial process. It requires high degree of efficiency in power extraction, transformation, and utilization. These objectives can only be achieved with the use of highly efficient, reliable, secure and cost-effective power electronics interface. Power electronics devices have made tremendous developments in the recent past. Numerous single and multi-port converter topologies have been developed for processing and delivering the renewable energy.

Various multiport converter topologies have been presented to integrate RES, however some limitations have been identified in these topologies in terms of efficiency, reliability, component count and size. Therefore, further research is required to develop a multiport interface and to address the highlighted issues.

In this work, a multi-port power electronics circuitry for integration of multiple renewable energy sources is developed. The proposed circuitry assimilates different renewable sources to power up the load with different voltage levels while maintaining high power transfer efficiency and reliability with a simple and reliable control scheme.

This research work presents a new multiport non-isolated DC-DC buck converter. The new topology accommodates two different energy sources at the input to power up a variable load. The power sources can be employed independently and concurrently. The converter also has a bidirectional port which houses a storage device like battery to store the surplus energy under light load conditions and can serve as an input source in case of absence of energy sources.

The new presented circuitry is analytically examined to validate its effectiveness for multiport interface. System parameters are defined and the design of different components used, is presented.

After successful mathematical interpretation, a simulation platform is developed in MATLAB/Simscape to conduct simulations studies to verify analytical results and to carry out stability analysis.

In the final stage, a low power, low voltage prototype model is developed to authenticate the results obtained in simulation studies. The converter is tested under different operating modes and variable source and load conditions.

The simulation and experimental results are compiled in terms of converter's efficiency, reliability, stability.

The results are presented to prove the presented topology as a highly reliable, stable and efficient multiport interface, with small size and minimum number of components, for integration of renewable energy sources.

# Research Outputs

## Journal Publications

1. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay “Multi input DC-DC Converters in Renewable Energy Applications- An Overview,” Journal of Renewable and Sustainable Energy Reviews, 41, pp 521-539 January 2015. (Cited by 18 till 29<sup>th</sup> March 2017). Journal Impact Factor: 6.798 (29<sup>th</sup> March 2017).
2. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay “Renewable Energy Harvesting for low Power Wireless Monitoring Networks”, Journal of Clean Energy Technologies vol. 5, No 6, pp. 448-453, November 2017.

## Journal (In Press)

1. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay “A Single Stage-Single Inductor Multiport DC-DC Converter for low power Electronics Devices” Submitted to Journal of Power Electronics, 2017.

## Conference Publications

1. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay “Dual Input-Dual Output Single Inductor dc-dc Converter”, Proceedings of 41<sup>st</sup> International Annual Conference of the IEEE Industrial Electronics Society, IECON 2015, pp 004848-004853, 2015.
2. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay “Dual Input-Dual Output Single Inductor dc-dc Converter for Renewable Energy Applications,” Proceedings of 4th International Conference on Renewable Energy and Research Applications ICRERA, pp 783-788, 2015.
3. Z. Rehman, I. H. Al-Bahadly and S. C. Mukhopadhyay, “A Non-Isolated DC-DC converter for Renewable Energy Based Portable Measuring Instruments,” Proceedings of IEEE Instrumentation and Measurement Technology Conference I<sup>2</sup>MTC pp. 936-941, 2013.
4. I. H. Al-Bahadly, Z. Rehman, and Joshua Pirihi, “Combining small scale Wind and Hydro Generation,” Proceedings of International Conference on

Sustainability, Green Buildings, Environmental Engineering & Renewable Energy SGER, pp 122-133, 2016.

5. I. H. Al-Bahadly, James Tingey and Z. Rehman “Portable Energy Unit for Natural Energy disaster” Proceedings of International Conference on Sustainability, Green Buildings, Environmental Engineering & Renewable Energy SGER, pp 134-140, 2016.

### **Seminars and Presentations**

1. Z. Rehman “Renewable Energy Harvesting for low Power Wireless Monitoring Networks”. Presented at the 5<sup>th</sup> International Conference on Power Science and Engineering, (ICPSE 2016), Venice, Italy.
2. Z. Rehman, “Combining small scale Wind and Hydro Generation,” Presented at International Conference on Sustainability, Green Buildings, Environmental Engineering & Renewable Energy (SGER, 2016), Kuala Lumpur, Malaysia.
3. Z. Rehman, “Portable Energy Unit for Natural Energy disaster” Presented at the International Conference on Sustainability, Green Buildings, Environmental Engineering & Renewable Energy (SGER, 2016), Kuala Lumpur, Malaysia.
4. Z. Rehman “Dual Input-Dual Output Single Inductor dc-dc Converter”, Presented at 41<sup>st</sup> International Annual Conference of the IEEE Industrial Electronics Society, IECON 2015, Yokohama, Japan.
5. Z. Rehman, “Dual Input-Dual Output Single Inductor dc-dc Converter for Renewable Energy Applications,” Presented at the 4<sup>th</sup> International Conference on Renewable Energy and Research Applications (ICRERA, 2015), Palermo, Italy.
6. Z. Rehman, “A Non-Isolated DC-DC converter for Renewable Energy Based Portable Measuring Instruments,” Presented at the IEEE Instrumentation and Measurement Technology Conference (I<sup>2</sup>MTC 2013), Montevideo, Uruguay.
7. Z. Rehman “Multi-port converters for Renewable Energy Applications”, Presented at SEAT PG Seminar Day Program, 2015.
8. Z. Rehman “Design of a non-isolated DC-DC converter” Presented at SEAT Doctoral Seminar Day Program, 2014.

9. Z. Rehman “A Non-Isolated DC-DC Converter for Renewable Energy Based Portable Measuring Instrument”, Presented at EICS Cluster Seminar Series, SEAT, 2013.
10. Z. Rehman “Multi Input Power Electronics Circuitry for Integration of Renewable Energy Sources” PhD Conformation Seminar 2013.
11. Z. Rehman “A Single Inductor Dual Input-Dual Output DC-DC Buck Converter for Standalone Hybrid Energy System” Presented at IEEE Post Graduate Seminar, SEAT, Massey University, 2013.

### **Awards**

1. Massey University Doctoral Completion Bursary 2016.
2. Universities New Zealand Claude McCarthy Fellowship 2015.
3. HEC Pakistan MS leading to PhD Scholarship (2012-2017).

## **Acknowledgements**

All the praise and thanks to Almighty Allah for His countless blessings.

I would like to acknowledge the contributions of all the people who have helped and supported me throughout my PhD studies.

I would like to express sincere gratitude to my Supervisors, Associate Professor Ibrahim H. Al-Bahadly and Professor Subhas Chandra Mukhopadhyay for their valuable guidance, help and support in my studies. I sincerely thank my supervisors for their able supervision, optimism inspiration, and confidence to conduct and complete this research work.

I am grateful to Dr. Jesus M. Corres from Public University of Navarra, Pamplona, Spain for his help, guidance, and support in this study. I am also thankful to Mr. Ken Mercer and SEAT administrative staff for their help and support.

Thanks to all my family members for their love and care.

Special thanks to my wife Beenish, daughter Romesa and son Abdul Mohaiman, for their love, patience, care, and support to successfully complete this research work.

I am thankful to Massey University Palmerston North for providing a wonderful research atmosphere, equipment, and resources.

I am also grateful to Higher Education Commission Pakistan (HEC) for providing me the opportunity for higher studies abroad and for providing all the financial support to complete this project.



# Table of Contents

Abstract.....	i
Research Outputs .....	iii
Acknowledgements.....	vi
List of Figures .....	xi
List of Tables .....	xv
Abbreviated Terms .....	xvi
<b>1 Introduction .....</b>	<b>1</b>
1.1 Background.....	1
1.2 Electricity Generation .....	1
1.3 Integration of Multiple Sources .....	3
1.4 Challenges in integration of Multiple Sources .....	4
1.5 Power Electronics Interface .....	5
1.6 DC-DC Converters .....	8
1.7 Statement of Research Problem.....	8
1.8 Aims and Objectives .....	9
1.9 Scope of Work .....	9
1.10 Research Methodology .....	10
1.10.1 Mathematical Modelling .....	10
1.10.2 Simulation Studies.....	10
1.10.3 Experimental Studies.....	10
1.11 Research Contribution .....	11
1.12 Applications .....	11
1.13 Thesis Organisation .....	12
<b>2 Non-Isolated DC-DC Converter Topologies .....</b>	<b>14</b>
2.1 Introduction.....	14
2.2 Single-Port Non-Isolated DC-DC converters .....	14
2.2.1 DC-DC Boost Converters.....	14
2.2.2 DC-DC Buck Converters.....	14
2.2.3 DC-DC Buck-Boost Converters .....	15
2.2.4 DC-DC Cuk Converter .....	15

2.2.5	DC-DC SEPIC Converter.....	15
2.3	Multi-Port Non-Isolated DC-DC converters.....	16
2.4	Dual Input-Single Output DC-DC Converters (DISO).....	17
2.5	Single Input-dual output DC-DC Converters (SIDO) .....	24
2.6	Multi Input-Multi Output Converters .....	28
2.6.1	Dual Output Mode.....	29
2.6.2	Dual Input Mode.....	31
2.6.3	Single Input Single Output Mode.....	32
2.7	Comparison of Multi Input Non-Isolated DC-DC Converter Topologies..	34
2.7.1	Cost of Converter .....	34
2.7.2	Reliability .....	35
2.7.3	Flexibility .....	35
2.7.4	Efficiency .....	36
2.8	Limitations in Multiport Topologies.....	36
2.9	Need of Further Research .....	37
2.10	Conclusion .....	38
<b>3</b>	<b>New Multiport Converter Topology .....</b>	<b>39</b>
3.1	Architecture of New Topology.....	39
3.2	Modes of Operation .....	40
3.2.1	Dual input-Single output mode .....	41
3.2.2	Dual input-Dual output mode.....	50
3.2.3	Single input-Dual output mode .....	58
3.2.4	Single Input-Single output mode.....	58
3.3	Design of Components.....	60
3.3.1	Inductor Rating.....	60
3.3.2	Output Capacitor Rating.....	61
3.3.3	Diode Rating.....	61
3.3.4	MOSFET Rating.....	62
3.4	Conclusion .....	62
<b>4</b>	<b>Control of Novel Multiport Converter Topology .....</b>	<b>63</b>
4.1	Introduction.....	63
4.2	Control Objectives for Multiport Buck Converter.....	64
4.3	Dynamic Representation of New Topology .....	66

4.4	Small Signal Modelling .....	68
4.5	Power Stage Transfer Functions .....	70
4.6	Design of Compensator .....	72
4.6.1	Review of PID Control .....	73
4.7	Multi-Input Multi Output System .....	75
4.8	Decoupling Control.....	75
4.9	Conclusion .....	78
<b>5</b>	<b>Simulation Setup .....</b>	<b>79</b>
5.1	Open Loop Simulation model.....	79
5.2	Close loop Simulation Model .....	83
5.2.1	Line Regulation .....	84
5.2.2	Load Regulation .....	91
5.2.3	Cross Regulation .....	93
5.3	Conclusion .....	93
<b>6</b>	<b>Experimental Verification .....</b>	<b>95</b>
6.1.1	Dual input-Dual output mode (DIDO) .....	96
6.1.2	Dual input-Single output mode (DISO) .....	99
6.1.3	Single input-Dual output mode (SIDO) .....	102
6.1.4	Single input-Single output Mode (SISO) .....	104
6.2	Conclusion .....	106
<b>7</b>	<b>Results Analysis and Discussion .....</b>	<b>107</b>
7.1	Efficiency Analysis.....	107
7.1.1	Power Dissipation in Diode.....	108
7.1.2	Power Dissipation in MOSFET.....	109
7.1.3	Power Dissipation in Inductor .....	109
7.1.4	Power Loss in Capacitor.....	110
7.1.5	Efficiency of Converter in DIDO mode .....	110
7.1.6	Efficiency of Converter in SIDO mode.....	111
7.1.7	Efficiency of Converter in DISO mode.....	112
7.1.8	Efficiency of Converter in SISO mode .....	113
7.2	Stability Analysis .....	116
7.3	Voltage Regulation .....	123
7.3.1	Line Regulation .....	123

7.3.2	Load Regulation .....	125
7.3.3	Cross Regulation .....	126
7.4	Comparison of new topology with the other work .....	127
7.4.1	Reliability .....	127
7.4.2	Number of Components/size .....	127
7.4.3	Efficiency .....	128
7.5	Conclusion .....	128
<b>8</b>	<b>Conclusions and Future Work.....</b>	<b>130</b>
8.1	Conclusions.....	130
8.2	Future Opportunities .....	132
	References.....	134
	Appendix A: DRC 16 Statement of Contribution.....	147
	Appendix B: Altium Model for Multiport Converter .....	152
	Appendix C: Altium Simulation Results in DIDO mode .....	154
	Appendix D: Computer Program to control the converter .....	156

## List of Figures

Figure 1-1 Share of electricity generation by fuel (2000-2040) [1] .....	2
Figure 1-2 Share of Renewable Energy Generation by source [1].....	2
Figure 1-3 Typical Hybrid Energy System .....	4
Figure 1-4 PE interface for RES (a) AC Generating units (b) DC generating Units ..	7
Figure 2-1 Conventional single-port Structure.....	16
Figure 2-2 Multiport DC-DC converter structure .....	17
Figure 2-3 Double Input Buck-Buck Boost Converter.....	18
Figure 2-4 Typical current and voltage waveforms of double input converter.....	19
Figure 2-5 Unidirectional Multi input buck-boost converter .....	20
Figure 2-6 Bidirectional multi input converter.....	20
Figure 2-7 Dual Input Buck-Buck Converter.....	21
Figure 2-8 Dual input buck boost-buck boost converter .....	22
Figure 2-9 Typical waveforms of dual input buck-buck converter .....	22
Figure 2-10 Single input-dual output buck converter.....	25
Figure 2-11 Single inductor dual output converter with multi variable control.....	27
Figure 2-12 Single input-double output unidirectional buck converter .....	27
Figure 2-13 Single input-double output bidirectional buck converter .....	27
Figure 2-14 Multi input-Multi output converter topology .....	28
Fig. 2-15 Three-port Converter .....	29
Figure 2-16 Equivalent circuit of three ports converter in Dual Output mode .....	30
Figure 2-17 Typical waveforms of three ports converter in Dual Output mode.....	31
Figure 2-18 Equivalent circuit of three ports converter in Dual Input mode .....	32
Figure 2-19 Typical waveforms of three ports converter in Dual Input mode.....	33
Figure 2-20 Three port converter in single input-single output mode.....	33
Figure 2-21 Three input DC-DC Converter .....	34
Figure 3-1 Dual input-Dual output DC-DC Buck Converter .....	40
Figure 3-2 Switching Schemes for Dual Input-Single Output mode .....	43
Figure 3-3 Equivalent Circuits for dual input sub mode 1 (a) Switching State 1 (b) Switching State 2 (c) Switching State 3 (d) Switching State 4 .....	46
Figure 3-4 Gate signals and inductor current waveforms for dual input sub mode	147

Figure 3-5 Equivalent Circuits for dual input sub mode 2 (a) Switching State 1 (b) Switching State 2 (c) Switching State 3 .....	49
Figure 3-6 Waveforms for dual input sub mode 2 .....	50
Figure 3-7 Equivalent Circuits for dual input-dual output mode .....	51
Figure 3-8 Equivalent Circuit DIDO mode: Case 1 (a) switching state 1 (b) Switching state 2 (c) Switching state 3.....	53
Figure 3-9 Waveforms for gate signals and inductor current (a) case 1 (b) case 2 (c) case 3 .....	56
Figure 3-10 Equivalent Circuits for single input-single output mode.....	58
Figure 3-11 Equivalent Circuit (a) source two energizing (b) source one energizing (c) battery energizing.....	59
Figure 4-1 Feedback Control System .....	65
Figure 4-2 Small Signal Model of dual input-dual output Converter.....	69
Figure 4-3 Equivalent Small Signal Model of dual input-dual output Converter.....	69
Figure 4-4 Feedback loop block diagram .....	70
Figure 4-5 Inputs, Outputs and Transfer Function of the converter .....	71
Figure 4-6 Inclusion of Proportional Term in feedback path .....	73
Figure 4-7 Inclusion of Derivative Term in feedback path .....	74
Figure 4-8 Inclusion of Integral Term in feedback path.....	74
Figure 4-9 PID System combining all the three coefficients .....	75
Figure 4-10 2x2 Decoupling control system .....	76
Figure 5-1 Inductor Current and Duty Cycles.....	80
Figure 5-2 Open Loop Simulation model for Dual Input Dual Output Converter ....	81
Figure 5-3 Open loop Output Voltage $V_{o1}$ in Dual input-Dual output mode.....	82
Figure 5-4 Open loop Output Voltage $V_{o2}$ in Dual input-Dual output mode.....	82
Figure 5-5 Inductor Current.....	82
Figure 5-6 Variation in Input Voltage .....	85
Figure 5-7 Inductor current .....	86
Figure 5-8 Output voltage Regulation without compensation .....	86
Figure 5-9 Output voltage Regulation with compensation.....	86
Figure 5-10 Close loop Simulation model for Dual Input Dual Output Converter...	87
Figure 5-11 Flow chart for detection of mode of operation .....	88
Figure 5-12 Variation in Input Voltages .....	89

Figure 5-13 Change in Output Voltages $V_{o1}$ and $V_{o2}$ .....	90
Figure 5-14 Regulation of Output Voltage $V_{o1}$ during mode transition.....	90
Figure 5-15 Change in Duty Cycles $d_3$ and $d_5$ .....	90
Figure 5-16 Decrease in Inductor Current due to decrease in load .....	91
Figure 5-17 Regulated output voltage ( $V_{o1}$ ) after increase in load current .....	91
Figure 5-18 Increase in Load current from 0.65 A to 0.8 A.....	92
Figure 5-19 Output Voltage ( $V_{o2}$ ) Regulation after increase in load current.....	92
Figure 5-20 Output Voltage ( $V_{o1}$ ) Regulation after increase in load current.....	92
Figure 5-21 Increase in Inductor Current due to increase in load current.....	93
Figure 6-1 Experimental setup for Prototype Converter .....	95
Figure 6-2 Equivalent Circuits for Dual input-Dual output mode .....	97
Figure 6-3 Input Duty Cycles $d_1$ and $d_2$ in DIDO mode .....	98
Figure 6-4 Output Duty Cycles $d_3$ and $d_5$ in DIDO mode.....	98
Figure 6-5 Duty Cycle $d_1$ and Inductor Current $I_L$ in DIDO mode .....	99
Figure 6-6 Regulated Output Voltages in DIDO mode.....	99
Figure 6-7 Equivalent Circuits for Dual input-Single output mode .....	100
Figure 6-8 Duty Cycles $d_1$ and $d_2$ in DISO mode .....	101
Figure 6-9 Duty Cycle $d_1$ and Inductor Current $I_L$ in DISO mode.....	101
Figure 6-10 Duty Cycles $d_1$ and $d_5$ in DISO mode .....	101
Figure 6-11 Regulated Output Voltage in DISO mode.....	102
Figure 6-12 Equivalent Circuits for Single input-Dual output mode .....	102
Figure 6-13 Duty Cycle $d_1$ and Inductor Current $I_L$ in SIDO mode.....	103
Figure 6-14 Duty Cycles $d_1$ and $d_5$ in SIDO mode .....	103
Figure 6-15 Regulated Output Voltages in SIDO mode .....	104
Figure 6-16 Equivalent Circuits for Single input-Single output mode.....	104
Figure 6-17 Duty Cycles $d_4$ and $d_5$ in SISO mode.....	105
Figure 6-18 Duty Cycle $d_4$ and Inductor Current $I_L$ in SISO mode.....	105
Figure 6-19 Regulated Output Voltage in SISO mode.....	106
Figure 7-1 Equivalent circuit of DIDO converter in synchronous mode .....	111
Figure 7-2 Power loss Pie Chart in DIDO mode under full load .....	111
Figure 7-3 Efficiency of the converter in different modes of operation.....	114
Figure 7-4 Power loss Pie Chart in SISO mode .....	114
Figure 7-5 Efficiency of the converter in DIDO mode with different load current	115

Figure 7-6 Comparison of calculated, simulated and measured efficiency.....	115
Figure 7-7 Simulink model of Multiport Converter for time and frequency domain analysis .....	117
Figure 7-8 Simulink model of Multiport Converter for time and frequency domain analysis (Sub System).....	118
Figure 7-9 Multiport Converter State Equations Block .....	119
Figure 7-10 Bode Plot for Single Input-Dual output mode $v_{o1}/d5$ .....	120
Figure 7-11 Bode Plot for Single Input-Dual output mode $v_{o2}/d5$ .....	120
Figure 7-12 Bode Plot for Single Input-Dual output mode $v_{o2}/d3$ .....	121
Figure 7-13 Bode Plot for Single Input-Dual output mode $v_{o1}/d3$ .....	121
Figure 7-14 Bode Plot for Dual Input-Single output mode $v_{o1}/d5$ .....	121
Figure 7-15 Bode Plot for Dual Input-Dual output mode $v_{o1}/d5$ .....	122
Figure 7-16 Bode Plot for Dual Input-Dual output mode $v_{o2}/d5$ .....	122
Figure 7-17 Bode Plot for Dual Input-Dual output mode $v_{o1}/d3$ .....	122
Figure 7-18 Bode Plot for Dual input- Dual output mode $v_{o2}/d3$ .....	123
Figure 7-19 Output voltage $Vo1$ regulation due to decrease in input voltage.....	124
Figure 7-20 Output voltage $Vo1$ regulation due to increase in input voltage.....	124
Figure 7-21 Output voltage $Vo1$ regulation due to decrease in input voltage.....	124
Figure 7-22 Output voltage $Vo2$ regulation due to decrease in input voltage.....	125
Figure 7-23 Output voltage $Vo1$ regulation due to decrease in load Current.....	125
Figure 7-24 Output voltage $Vo2$ regulation due to increase in load current .....	126
Figure 7-25 Increase in Inductor current due to increase in load current.....	126



## **List of Tables**

Table 2-1 Comparison of MI DC-DC Converter Topologies .....	36
Table 2-2 Identified Limitations in existing Multiport topologies .....	37
Table 3-1 Switching Schemes for Dual input -Single output mode .....	42
Table 3-2 Switching Schemes for Dual Input-Dual output mode .....	57
Table 5-1 System Parameters for simulation studies .....	79
Table 5-2 Duty Cycle and Output Voltage for open loop Converter .....	80
Table 6-1 Design Parameters for Experimental Setup .....	96
Table 6-2 Components Value for Experimental setup .....	96
Table 6-3 Measured values for DIDO mode .....	97
Table 6-4 Measured values for DISO mode .....	100
Table 6-5 Measured values for SIDO mode .....	103
Table 6-6 Measured values for SISO mode .....	105
Table 7-1 Parameters used for efficiency calculation .....	108
Table 7-2 Power loss in DIDO mode .....	110
Table 7-3 Power loss in SIDO mode .....	112
Table 7-4 Power loss in DISO mode .....	112
Table 7-5 Power loss in SISO mode .....	113
Table 7-6 Multiport Converter Parameters block .....	119
Table 7-7 Comparison of Converter with other topologies .....	129
Table 7-8 Efficiency Comparison .....	129

## Abbreviated Terms

School of Engineering and Advanced Technology	SEAT
Higher Education Commission	HEC
Giga Watt	GW
Annual Energy Outlook	AEO
Hybrid Energy System	HES
Renewable Energy System	RES
Photovoltaic	PV
Power Electronics	PE
Single input-Single Output	SISO
Dual input-Single Output	DISO
Single input-Dual Output	SIIDO
Dual input-Dual Output	DIDO
Pulsating Source Cells	PSC
Multi-Input Converter	MIC
Three Port Converter	TPC
Multiport Converter	MPC
Pulsating Voltage-Source Cell	PVSC
Pulsating Current-Source Cell	PCSC
Pulse Width Modulation	PWM
Pulse-Skipping Modulation	PSM
Pulse-Frequency Modulation	PFM
Single input Multi Output	SIMO
Single Inductor Multi Output	SIMO
Continuous Conduction Mode	CCM

Multi Input Multi Output	MIMO
Multi Input	MI
Multi Output	MO
Discontinuous Conduction Mode	DCM
State Space Averaging	SSA
Relative Gain Array	RGA