UNIVERSITY “POLITEHNICA” OF BUCHAREST

FACULTY OF ELECTRICAL ENGINEERING

Three Port Converters Used as Interface in Photovoltaic Energy Systems

Doctoral Thesis Summary

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This thesis is dedicated to the analysis of renewable energy systems, which harness solar energy using Photovoltaic cells while also focusing on efficient management of the available energy. Due to intermittent nature of the solar energy, the renewable energy systems are incomplete without involving the storage elements; this notion remains the central plank of this research. Furthermore, this thesis emphasizes the use of three-port converters to enable single-stage power conversion in lieu of conventional two-port converters.

Chapter 1 presents an overview of the existing multiport converter topologies. Being the introductory chapter, it draws fine distinctions between the conventional and multiport converters and then delves deeper into the different subclasses of multiport converters. In each of the subclasses, the existing literature and research work is reviewed. The two major classes of multiport converters include full-bridge and half-bridge topologies.

The chapter also discusses different topologies in reference to their roles in different applications such as Hybrid Electric Vehicles (HEV). Converters constitute an important part of the HEV's power management system. This is, of course, applicable to the renewable energy systems as well. The renewable energy systems require incessant interaction with the multiport (or conventional) converters, which enable them to drive loads at dissimilar voltage levels and during periods of poor or no production of power.

Chapter 2 introduces the elementary building blocks of the power converters by enumerating the basic topologies, over which the foundation of advanced power electronics is laid, along with the derivatives of these topologies. The list includes full-bridge, half-bridge and the multiport converter topologies. The chapter also discusses different modes of operation of the multiport converters, which are dependable on the given external conditions.

Chapter 3 deals with the power flow management in different converter topologies. Power flow management is the most important aspect of any converter design and hence demands complete introspection of the designed topology. In the domain of multiport topologies, the power flow management is further emphasized due to flexibility and mode-dependency of these converters. The multiport converters usually combine storage elements with the power sources, while also keeping an eye on the load demand. This makes the job of managing the power flow much more challenging. The power flow management can be illustrated by the Figure 1.

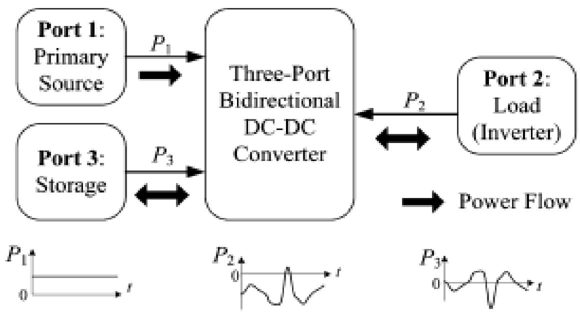


Figure 1-Energy flow in three port converters

In any standalone renewable energy system, three dimensions of power flow are present:

i. from primary source to storage element
ii. from primary source to load
iii. and from storage element to load

The total power that enters the system is equal to the total power that leaves the system, therefore:

$$P_{load} = -(P_{pv} + P_{battery})$$

The law of conservation of power for an n-port system can be written as:

$$\sum_{i=1}^{n} P_i = 0$$

The power flow management is analyzed on three different derived three-port converter topologies including isolated half-bridge, full-bridge and non-isolated dual input and single output converter topologies.

The topology of the half-bridge converter, as shown in Figure 2, contains two switches and two capacitors in each port. This converter topology is optimized for use with the renewable energy systems and also includes a PV module which contains MPPT controller.

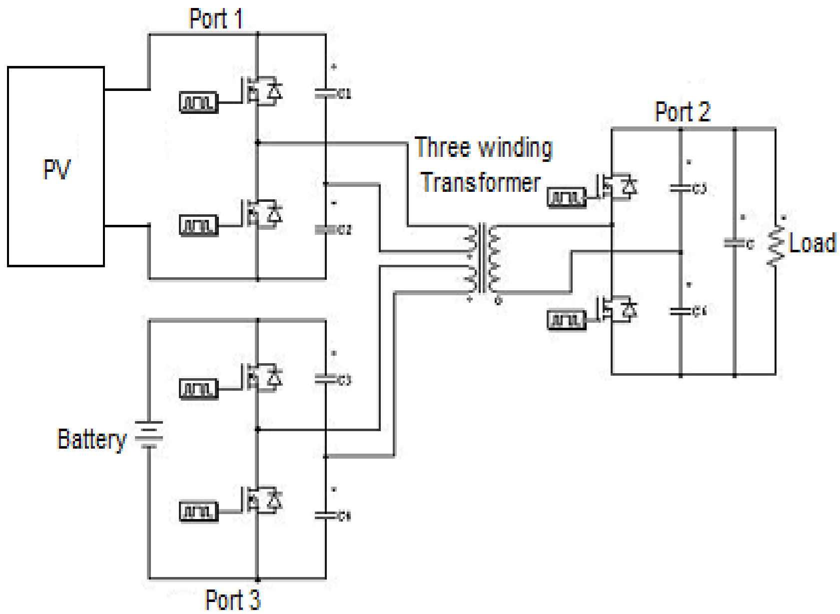


Figure 2-Three port half bridge converter

The model was developed and tested in Simulink. The parameters for the half-bridge converter simulation are shown in Table 1, while the output voltage waveform obtained from the converter is shown in Figure 3- Output Voltage of three port half-bridge converter. As obvious, the output voltage sticks to 20V within 0.2 seconds.

Table 1-Parameters for the model

Parameters	Value
C1, C2, C3, C4, C5, C6	1.0 mF
Output Capacitance C	4.7 mF
Battery	50 V
Load Resistance	5.0 Ω
Transformer Ratio	1:4:4
Magnetization inductance Lm	16 H
PV Irradiance	1000 W/m^2
PV Maximum Power	150 W

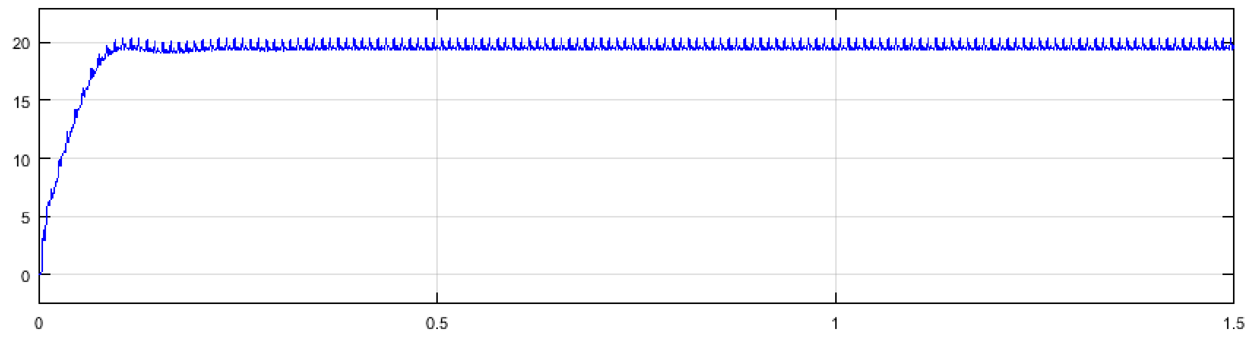


Figure 3- Output Voltage of three port half-bridge converter

A full bridge converter is displayed in Figure 4, which uses four switches (double the number of switches in half-bridge). Thus, a three-port converter contains double the number of switches on the primary side than the two-port converter, two for each port. The flow of power in the converter varies after every half cycle. For example, an input voltage V is applied to the load during the period of 0<t<T/2 and for the remaining half duration, -V is supplied. The input source can be the PV panel along with an MPPT panel.

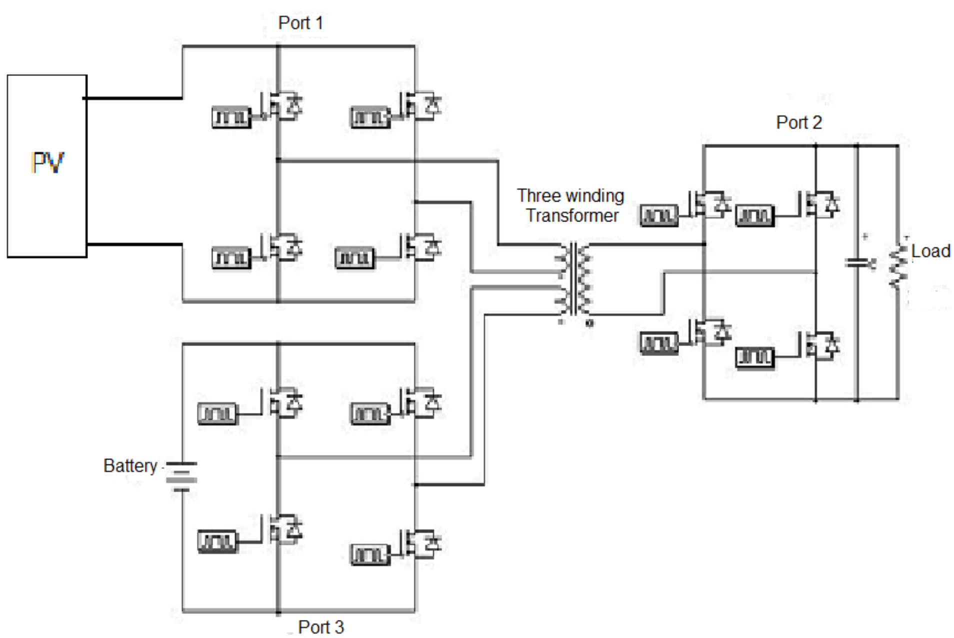


Figure 4- A three port full bridge converter

Just like the previous case, full bridge three port converter was also simulated and tested in MATLAB/Simulink, with parameter values shown in Table 2. Also shown, in Figure 5, is the output voltage, which fluctuates between 0 to 180V.

Table 2-Parameters for the model

Parameters	Value
Output Capacitance C	4.7 mF
Battery	50 V
Load Resistance	5.0 Ω
Transformer Ratio	1:4:4
Magnetization inductance Lm	16 H
PV Irradiance	1000 W/m^2
PV Maximum Power	150 W

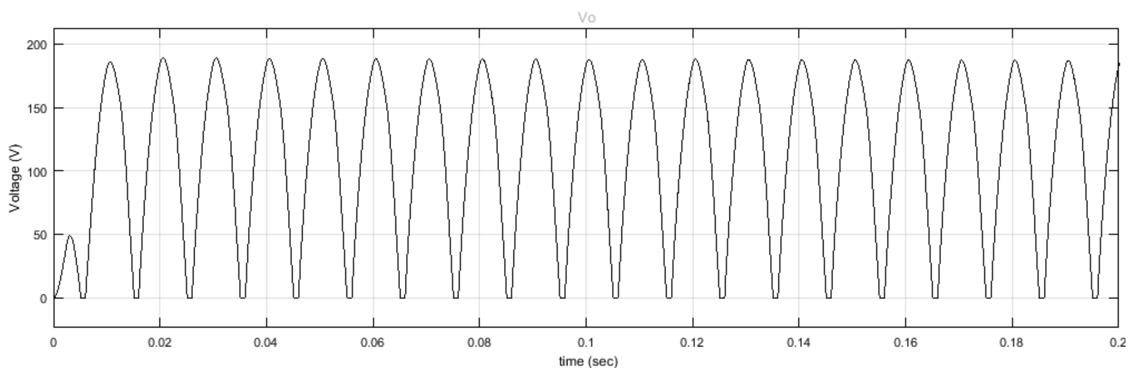


Figure 5-Output Voltage of three port full bridge converter

The use of transformer is preferred when the required step between input and output voltages is high. However the first design choice is to avoid unnecessary use of transformers because they increase switch losses and size. A non-isolated dual input and single output converter exemplifies this design choice, as shown in Figure 6, containing three switches, one inductor and two capacitors, but no transformer. It has only one inductor labelled 'L' and two capacitors C1 and C2. The single output 'Vo' is taken at the resistor R. It is assumed that Vin1 < Vin2. In the current setting, battery and PV panels provide power to the load connected at resistor R. The combination of power stored in the battery with the PV panel power provides efficient use of renewable energy.

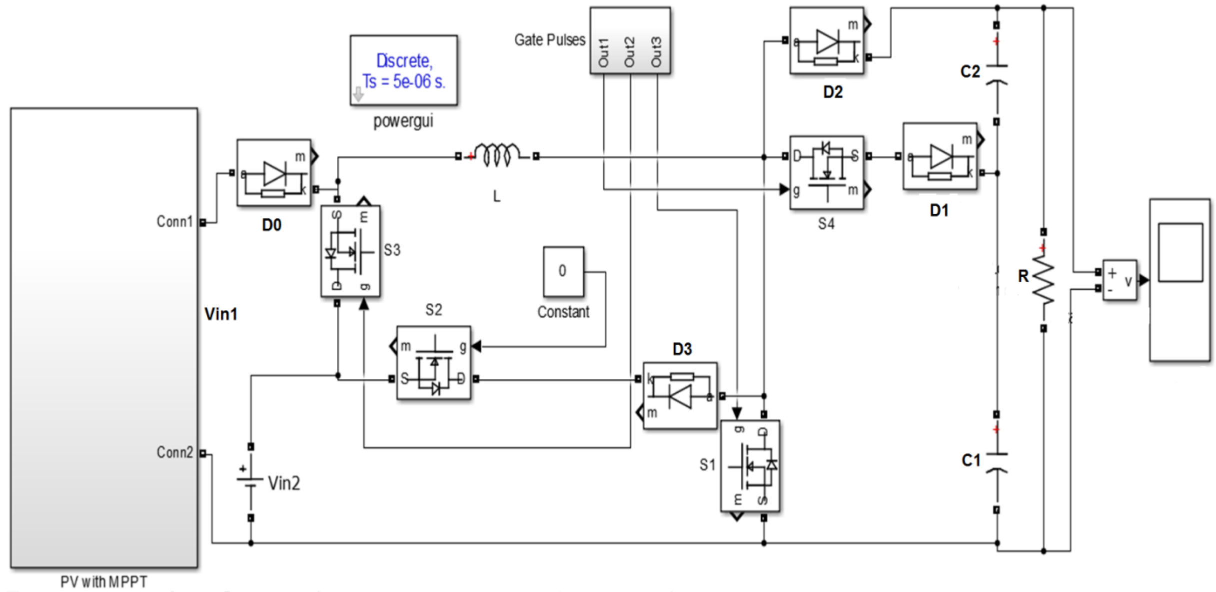


Figure 6-Dual Input Single Output Converter

The parameters for the simulation of the DISO are shown in Table 3.

Table 3- Parameters for the model

Parameters	Value
Capacitors C1, C2	1 mF
Battery (V_{in2})	20 V
Load Resistance	70 Ω
Inductance L	17 mH
PV Irradiance	1000 W/m^2
PV Maximum Power	150 W

Figure 7 and Figure 8 show the current, and voltage waveforms at the load. The load current initiates from 0 and rises to a peak value of 0.6 A, after which it stabilizes to 0.4 A. In a similar fashion, the load voltage passes through the same transient response that lasts for around 0.1 seconds, after which the voltage settles to 60V.

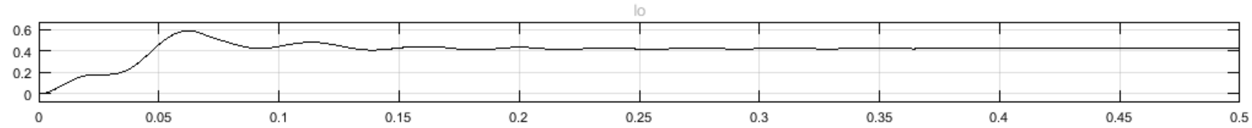


Figure 7- Load Current

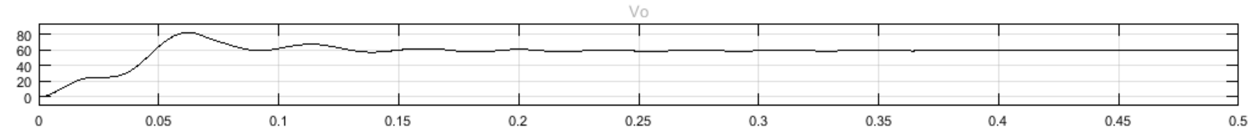


Figure 8-Load Voltage

Chapter 4 presents a comparative dynamic analysis of multiport converter topologies such as Three-port half and full-bridge converters along with the Dual Input Single Output topology, discussed in the previous chapter. The chapter also involves input and output voltage relationships and the duty cycle of different switches. Additionally, the chapter also discusses the role of transformers in different topologies.

The transformers are used in converter circuits to:

1. step-up the input voltage
2. step-down the input voltage
3. introduce magnetic isolation
4. get multiple outputs from single input
5. reduce transformer current using Delta-wye topology
6. maximize output power using impedance matching
7. reduce the stress on switches and diodes
8. reduce switching losses

Despite the above-mentioned advantages of using transformers, the first choice is to avoid transformer because of the following drawbacks:

1. Increased cost
2. Increased weight
3. increased area
4. reduced efficiency
5. Slower response

Chapter 5 compares the existing multiport converter topologies with the modified converter topologies. The chapter also compares the experimental results achieved in different existing topologies with our simulated results. The focus has remained on full-bridge converter.

The output waveforms are shown in

Figure 9 for the modified converter, while in Figure 10 for the original converter.

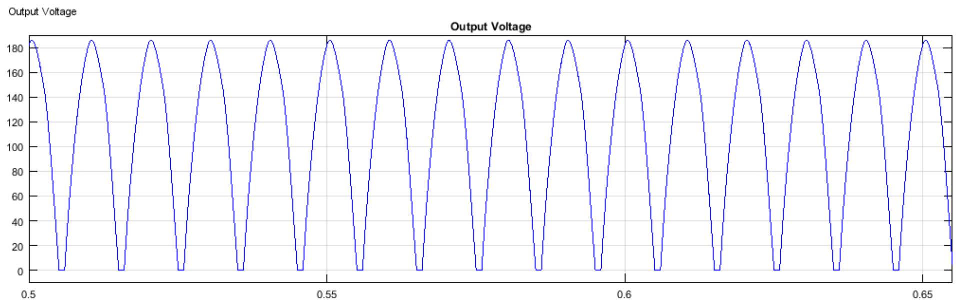


Figure 9-Output voltage of modified FB-TPC

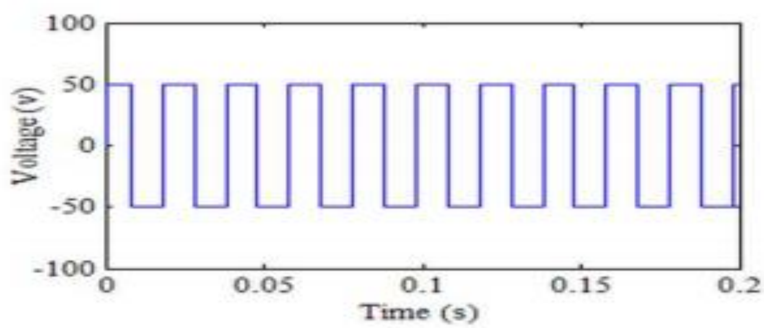


Figure 10-Output voltage of original FB-TPC

The output waveform of the modified converter oscillates between 0 and 180 V, while for the original converter it is oscillating between -50 V and 50 V. The voltage waveforms for original converter are shown in Figure 11. The waveforms are symmetrical about zero and depend on each state of the converter.

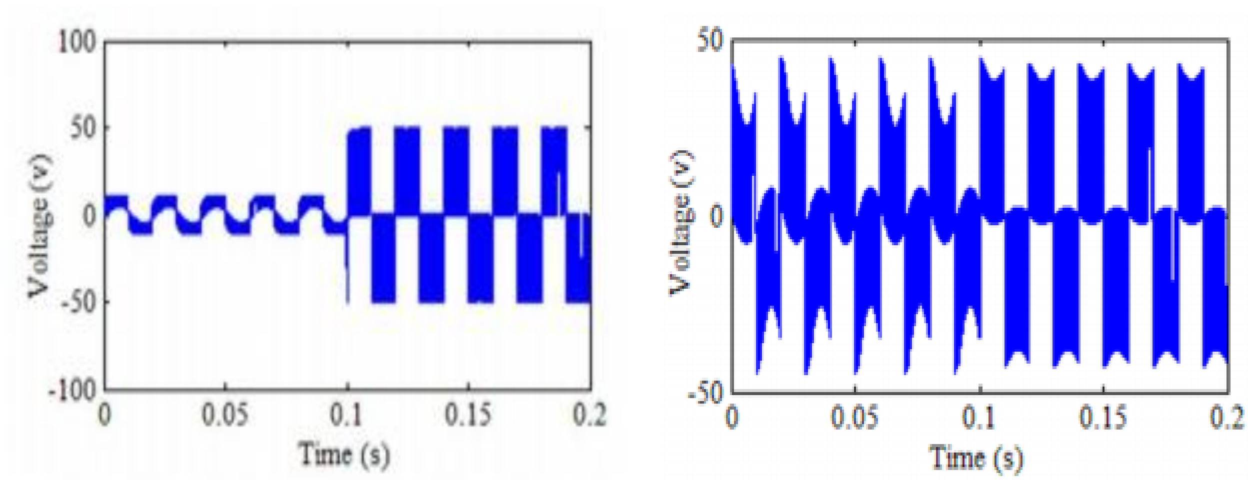
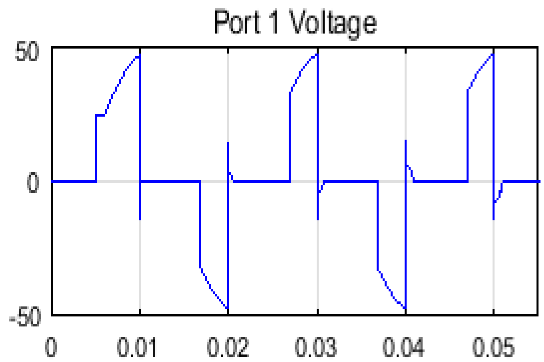
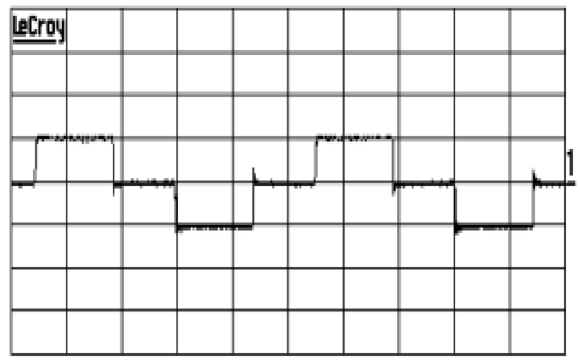


Figure 11-Original converter's output voltage at (a) Port 1 (b) Port 3

The waveforms of the modified converter can be directly compared with the experimental waveforms, as proposed in [1]. The comparison for Port 1 and Port 3 of the simulated and experimental results are shown below.

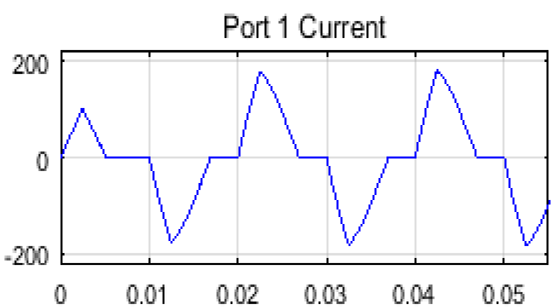


(a) Modified Converter

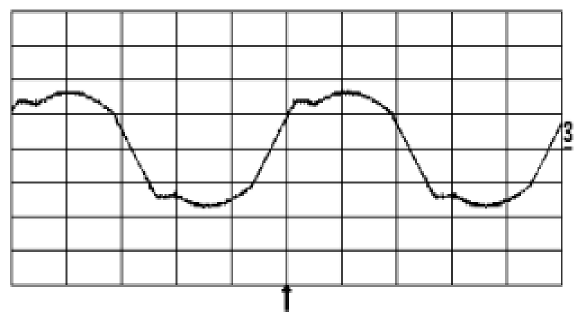


(b) Experimental result with 50V/div [1]

Figure 12-Port 1 Voltage Waveforms

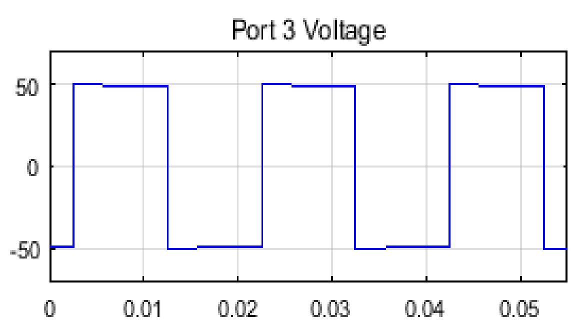


(a) Modified Converter

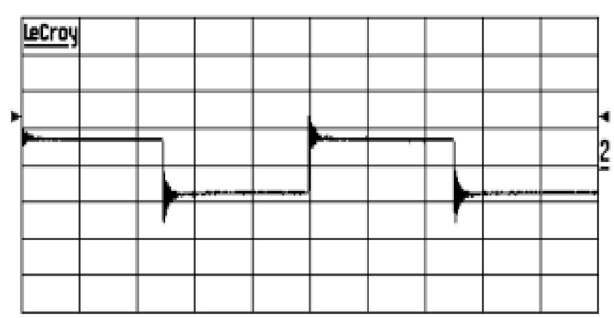


(b) Experimental result with 4A/div [1]

Figure 13-Port 1 Current Waveforms

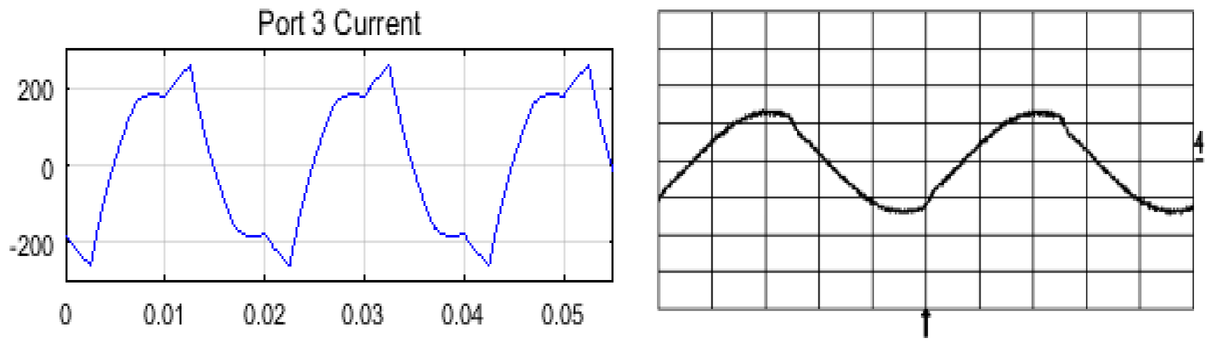


(a) Modified Converter



(b) Experimental result with 50V/div [1]

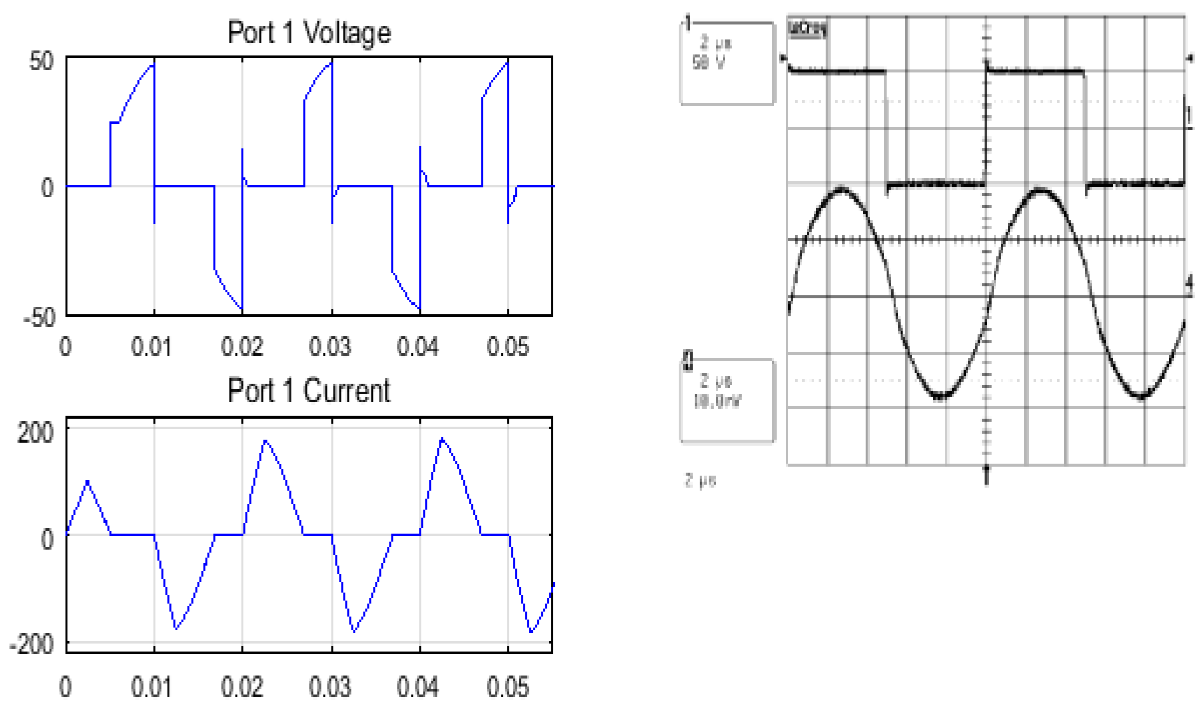
Figure 14-Port 3 Voltage Waveforms



(a) Modified Converter *(b) Experimental result with 10A/div [1]*

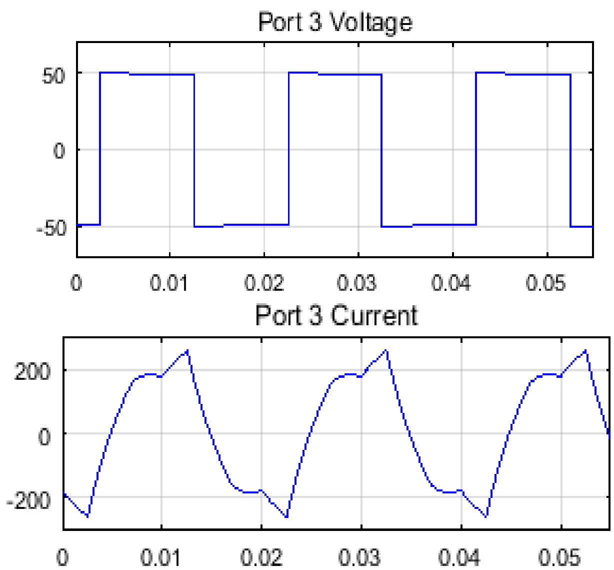
Figure 15-Port 3 Current Waveforms

In another study [2], the authors have provided experimental results for another full-bridge three-port converter containing LC tank, especially suitable for renewable energy applications. The comparison for Port 1, Port 3 and Port 2 of our simulated and experimental results are shown below.

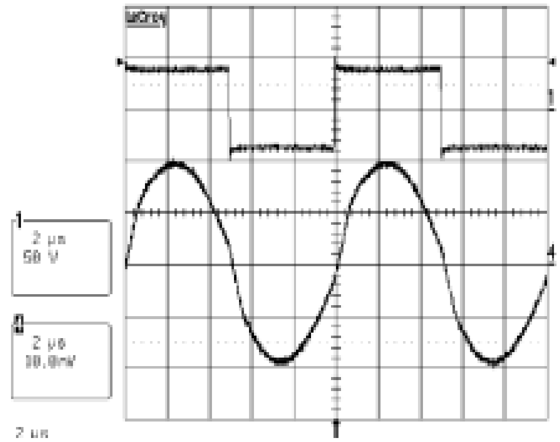


(a) Modified Converter *(b) Experimental results with Voltage (Top) 50V/div and current (Bottom) with 5A/div [2]*

Figure 16-Port 1 Waveforms

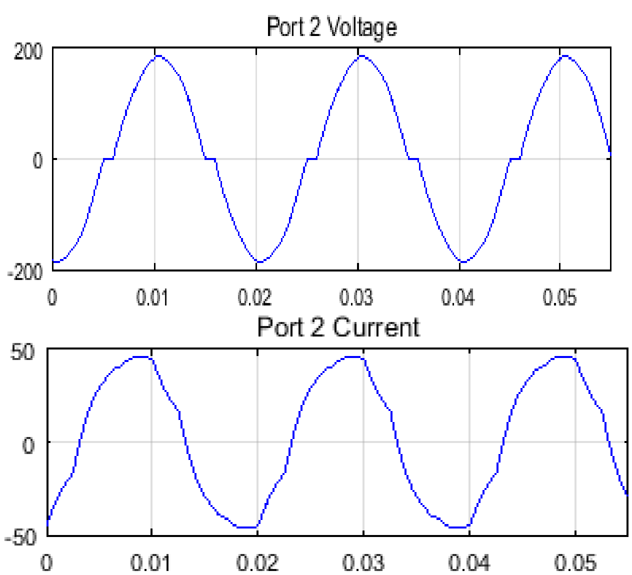


(a) Modified Converter

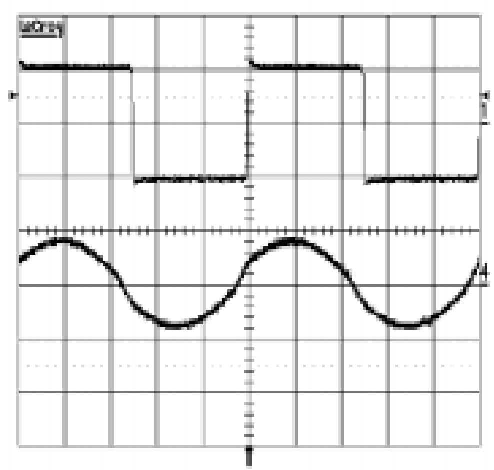


(b) Experimental results with Voltage (Top) 50V/div and current (Bottom) with 5A/div [2]

Figure 17-Port 3 Waveforms



(a) Modified Converter



(b) Experimental results with Voltage (Top) 200V/div and current (Bottom) with 5A/div [2]

Figure 18-Port 2 Waveforms

The experimental results shown in above figures closely resemble our simulations, in which the voltage at port 1 oscillates between 50 V and -50 V, while the voltage at battery port oscillates between 50V and -50 V.

Chapter 6 is focused on the use of photovoltaic cells for electricity generation in renewable energy systems. The discussion starts with a brief overview of the PV cells modeling and maximum power point tracking and further moves with a design of a PV module. This PV module is then implemented on a model of full-bridge converter topology, which is shown in Figure 19. This converter is a three-port converter with single-stage power conversion between different ports. The input and output terminals are isolated using the transformer. The primary side of the converter circuit has two legs, one for the PV panel and the other for the storage device.

The topology of the converter circuit is based on three different modes of operation, based on which, the switching waveforms are calculated. The modes are Dual Input Single Output, Single Input Dual Output and Single Input Single Output.

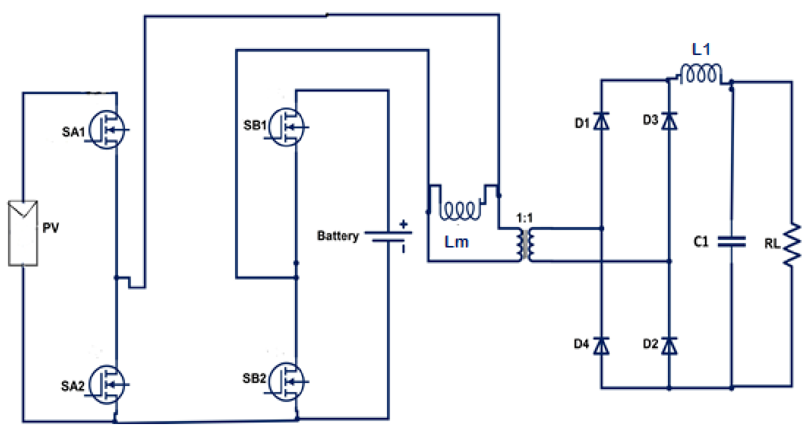


Figure 19-Modified Full Bridge Three port converter

Another important aspect of the design is the controller, which is used to manipulate the power flow through different ports by proper generation of switching waveforms. The controller is designed in Simulink and can make intelligent decisions to turn OFF or ON certain switches according to the present conditions. The controller's schematic is shown in Figure 20.

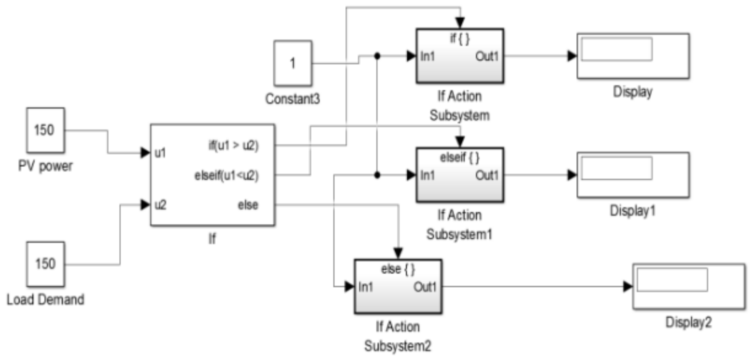


Figure 20- Controller design for power flow management

The controller generates a signal waveform by comparing both the PV panel and load demand at each instant and generating three logical outputs according to the mode.

The parameters which are used in design specification of PV panels used in our Simulink model are shown in Table 4. The parameters are displayed in the Simulink environment in Figure 21, containing different fields and options for PV panels. The current view enshrines our used parameters in the model. As seen, the model uses single solar power API-150 module for simulations, which generates a maximum power of 150.075 W.

In order to measure the efficiency of the PV panels, typical PV and IV curves are plotted in Figure 22, with an array of 72 cells, which are interconnected in series. The curves show the variance of current I and power P with the PV voltages, as the IR-radiance is varied from 0.25 kW/m^2 to 1 kW/m^2.

Table 4- Parameters for photovoltaic cell

Parameters	Value
Maximum power	150.075 Watts
Cell number	72
Open circuit voltage	41.8 V
Maximum voltage	34.5 V
Short circuit current	5.05 A
Maximum current	4.35 A
Light generated current	5.0831 A
Reverse saturation current	1.4617e-10 A
Diode ideality factor	0.93584
Shunt resistance	69.2646 Ω
Series resistance	0.45367 Ω

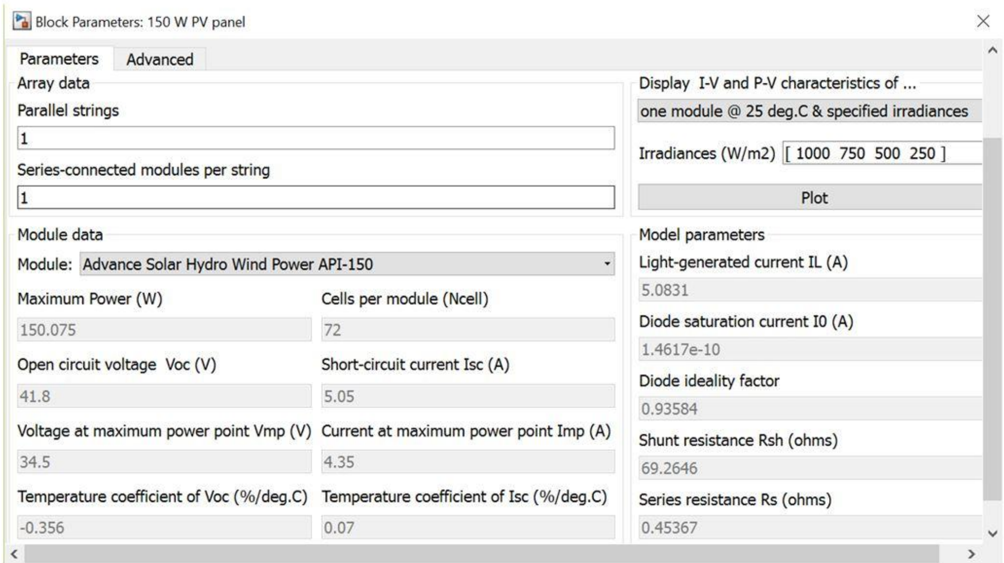


Figure 21-PV parameters utilized in Simulink

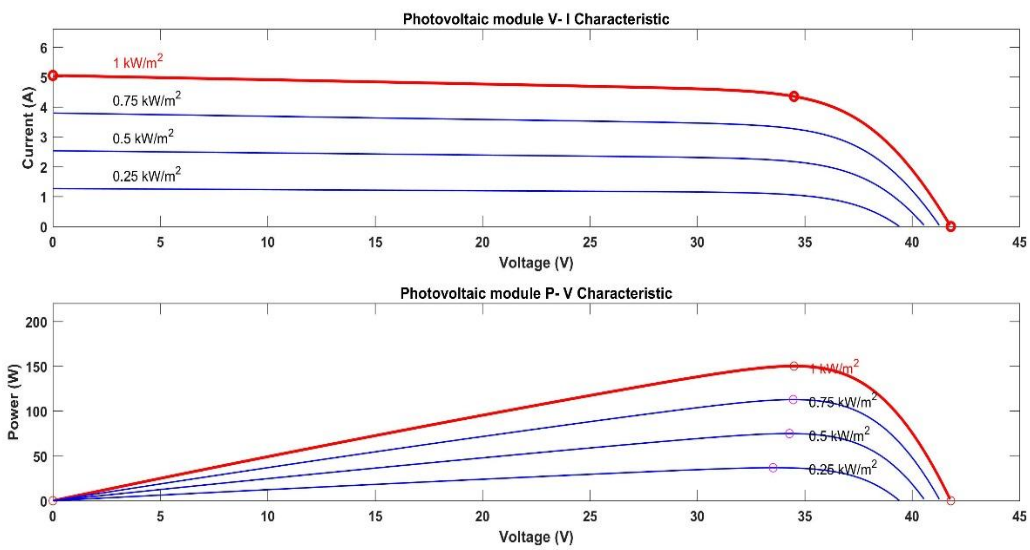


Figure 22-PV and IV curves for the PV cells assumed in the model

The output voltage waveforms of the converter in each of the three modes are discussed next.

The output load voltage waveform of the converter in Mode 1 is shown in Figure 23. In Mode 1, PV panels generate enough power to feed the load and charge the batteries; hence it is the Dual Output mode. According to the design, the PV panels produce 150 W and the load demand is 100 W. The controller turns on switches SA1 and SB2. As obvious from the figure, the output voltage remains constant at 40V. This operation continues throughout this mode and the power flows in the same fashion as mentioned earlier.

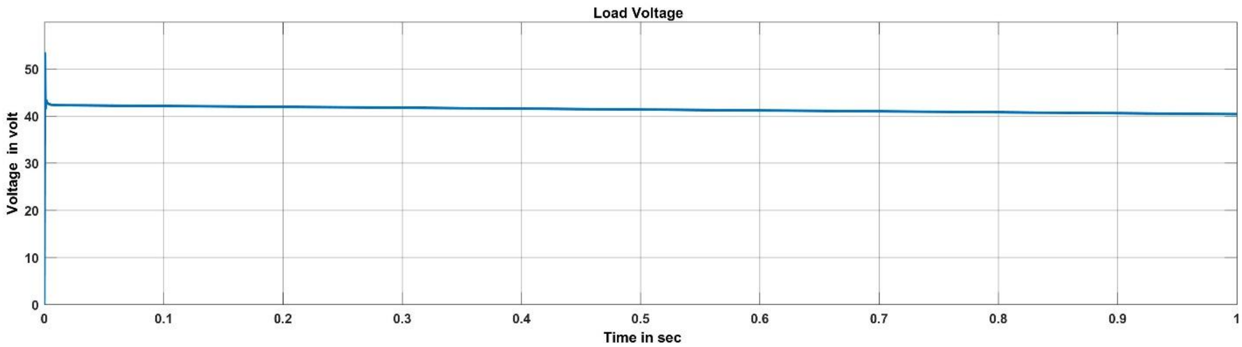


Figure 23-Output Voltage in Mode 1

When the PV power is not enough to support the load, the storage device jumps in to provide power to the load. In this scenario, the load demand was increased to 200 W. The controller turns on the switches SA1 and SB1. The output voltage in Mode 2 is shown in Figure 24.

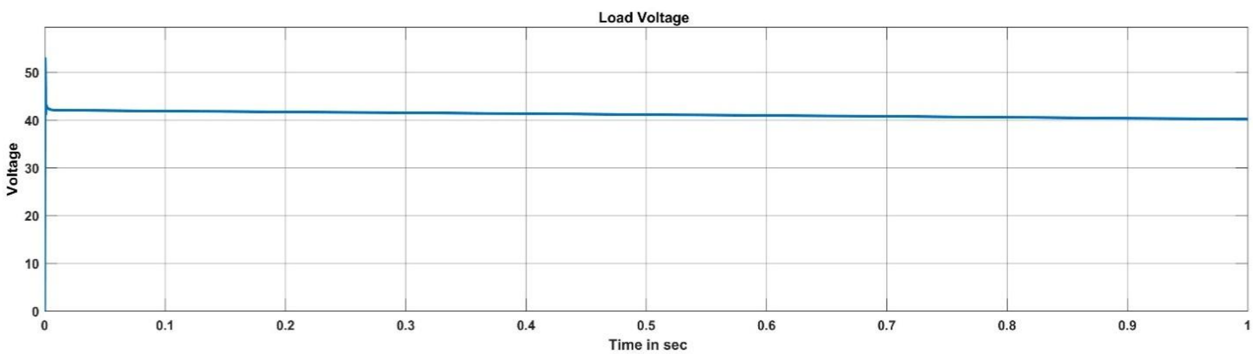


Figure 24-Output Voltage in Mode 2

When the power generation in the PV panel and the load demand are matched, the Mode 3 is initiated. In this scenario, the load is assumed to be 150 W and the controller turns on switches SA2 and SB1.

Furthermore, in order to observe the system response for the varying IR-radiations, these radiations were varied and the corresponding power generation was noted. This scheme is plotted in Figure 26. The irradiations are taken as 100 W/M2, 250 W/m2, 500 W/m2, 750 W/m2 and 1000 W/m2.

Similarly, the output voltage for each of the irradiance scenario is shown in Figure 27. As obvious, the output voltage varies with the irradiation in a proportional fashion. In Figure 28, the effect of irradiance on the PV panel's power, voltage and current is shown.

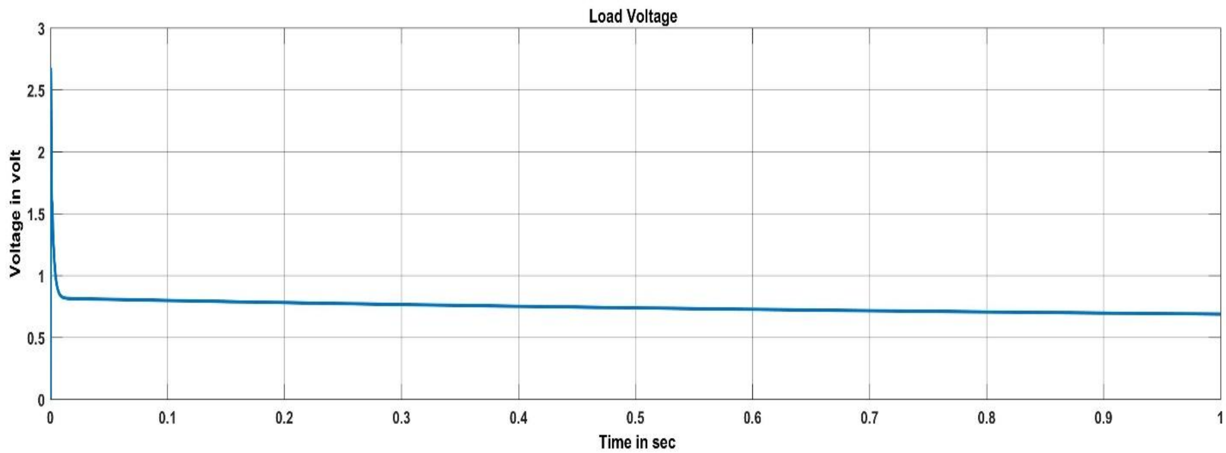


Figure 25- Output Voltage in Mode 3

The general parameters for the converter are shown in Table 5.

Table 5-Parameters for Simulation

Parameters	Value
Output Capacitor C1	1 µF
Output Inductor L1	1 mH
Battery (V_{in2})	42 V
Load Resistance (R_L)	150 Ω
Magnetizing Inductance (L_m)	50 mH
PV Irradiance	1000 W/m^2
PV Maximum Power	150 W

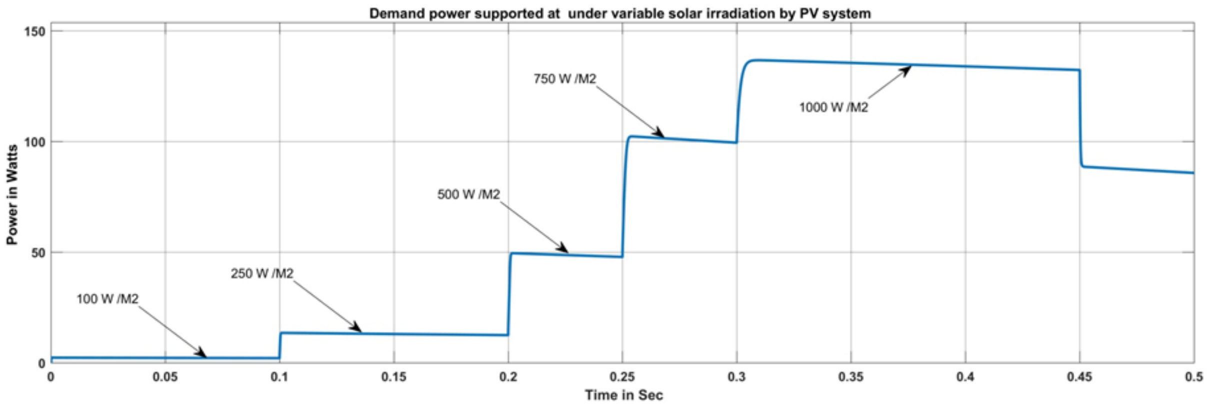


Figure 26-Demand power supported for various irradiation scenarios

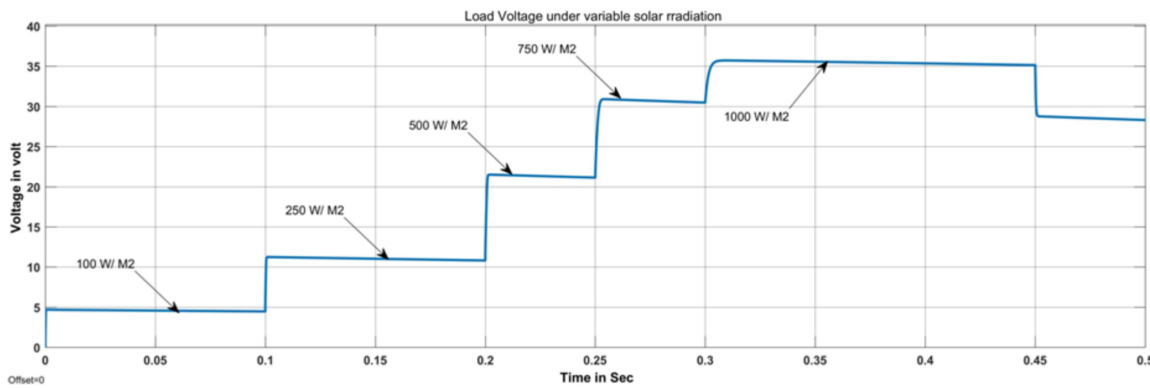


Figure 27-Output voltage for different irradiation cases

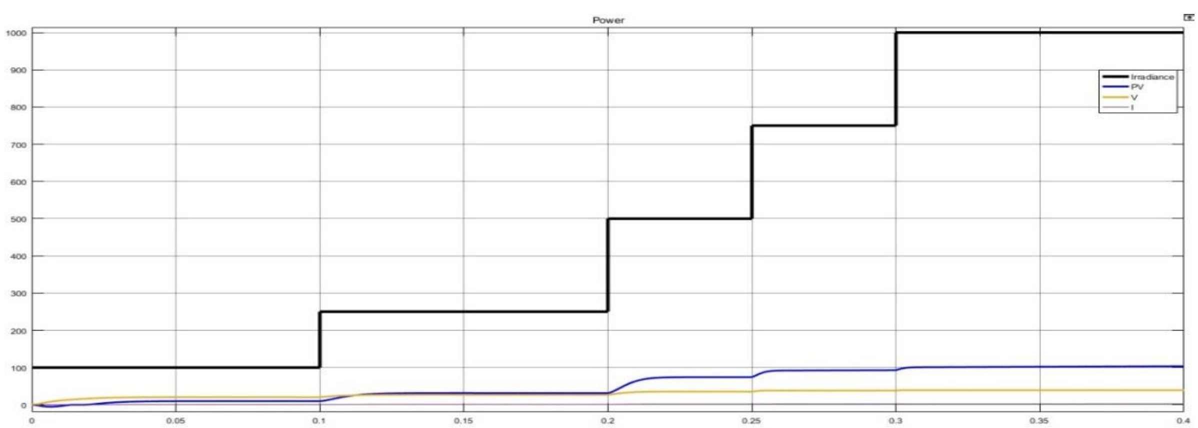


Figure 28-The effect of irradiance on PV power, voltage and current

In order to weigh the performance of the PV cells, voltage waveform of the cells, at constant 800 W/m^2 in the mode 1 case with load demand equal to 100W, are plotted in Figure 29

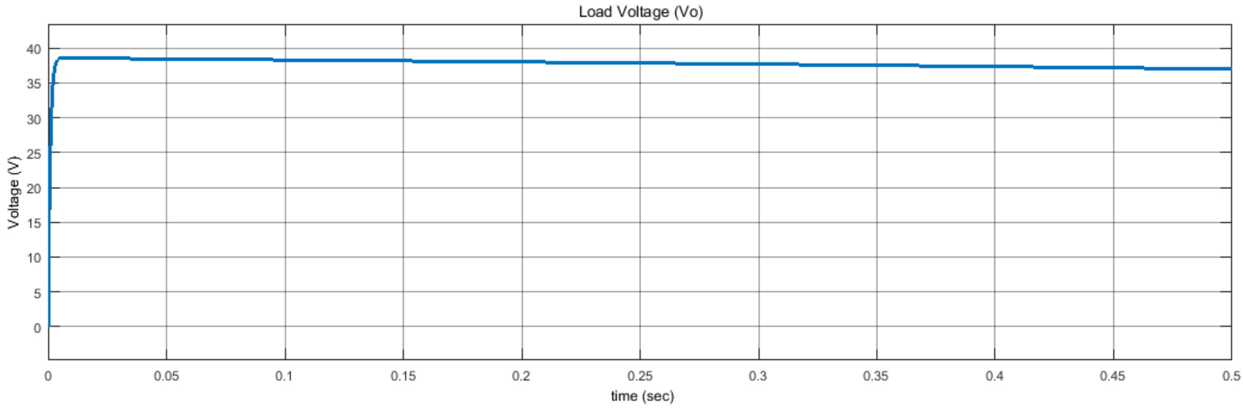


Figure 29-Output voltage at 800 W/m^2

Another important aspect of the converter is the effect of change in load conditions on the modes of operations. Since the controller has been designed to dynamically change the mode of the converter if there is some variation in the load demand or in the PV generated power. The operation of converter with changing condition at the load side, while keeping the irradiance fixed at 1000 W/m2 (PV power=150 W), is shown in Figure 30.

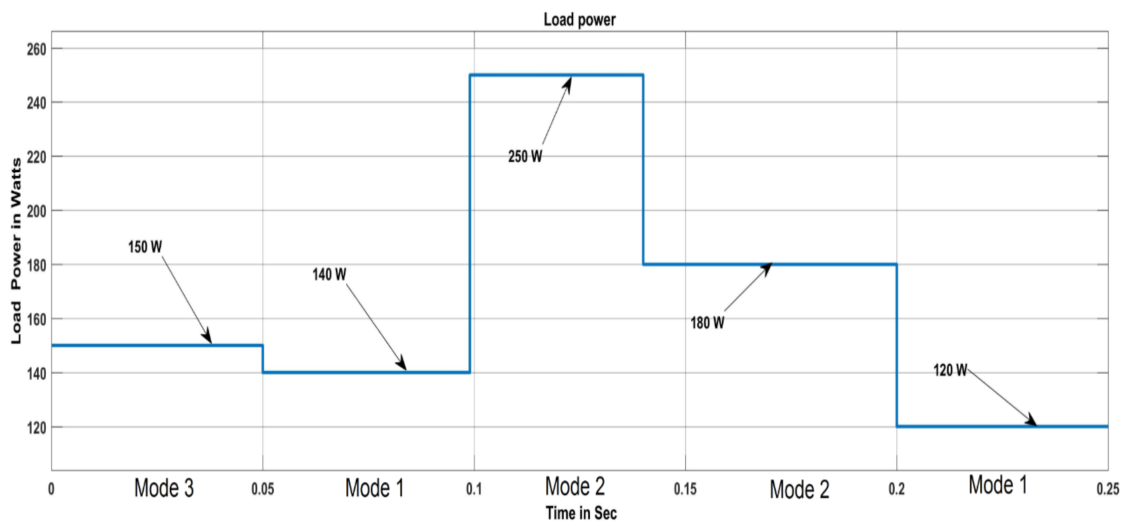


Figure 30-The change in Modes with the load demand

Chapter 7 further extends the study of the three-port full-bridge converter by studying the topology as derived from the two-port full-bridge converter. The modeled converter is suitable for systems which combine renewable energy sources and energy storing devices. The most suitable energy storing devices are Lithium-Ion battery or hybrid battery and super-capacitors. Any input power can be transferred to output load in a single-stage. In order to eliminate switch losses, the converter can be operated with Zero-Voltage Switching for all switches by using primary inductance Lm as energy storage component. The chapter also intends to find volt-second and capacitor-charge balance equations and works on small-signal approximation and linearization of the converter model.

The parameters of the Simulink model are presented in Table 6.

Table 6-Parameters of the proposed converter

Component	Value
Transformer Frequency	10kHz
Transformer ratio	1:1
Output Capacitor (C1)	0.01F
Capacitor(Buck-boost)	4700µF
Inductor (Buck-boost)	47mH
Capacitor (PV panel)	100µF
Magnetizing Inductance (L_m)	50 H
Battery	12 V
Load	100 W
PV Irradiance	500 W/m^2
PV Maximum Power	150 W

The controller for the converter is designed in Simulink which generates PWM signal for the four switches used in this converter, which is shown in Figure 31. It consists of a MATLAB function block with two inputs, which decide the mode of operation of the converter. On the other side, there are 3 outputs of the MATLAB based controller. One for each leg of switches, while the third output C is a control output that controls the delay in the pulses SA and SB.

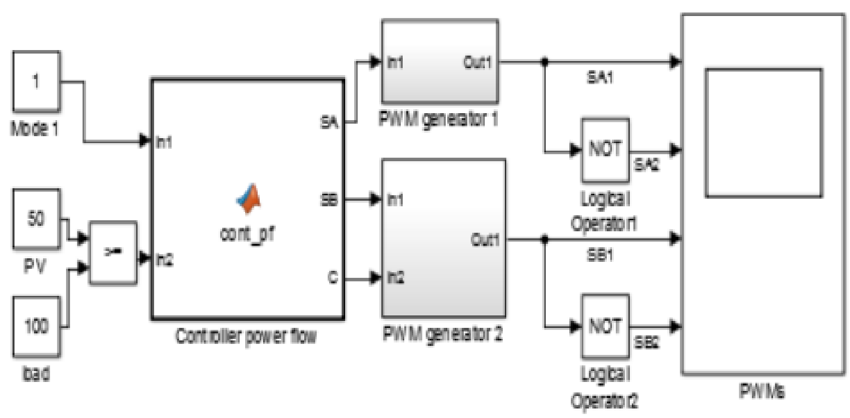


Figure 31- Design of controller for PWM Generation

The controller operation can represented using the flowchart as shown in Figure 32.

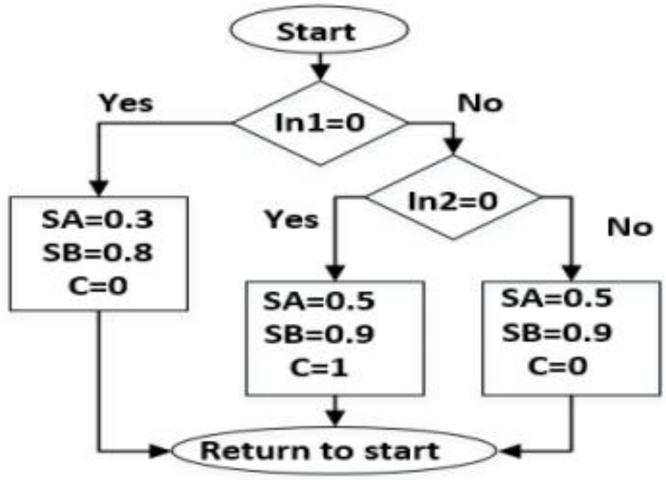


Figure 32- Flow chart for the controller operation

The converter has three modes of operation. In each mode, the controller generates appropriate signals for the switches. The load voltage and power curves are shown below, for each of the three modes.

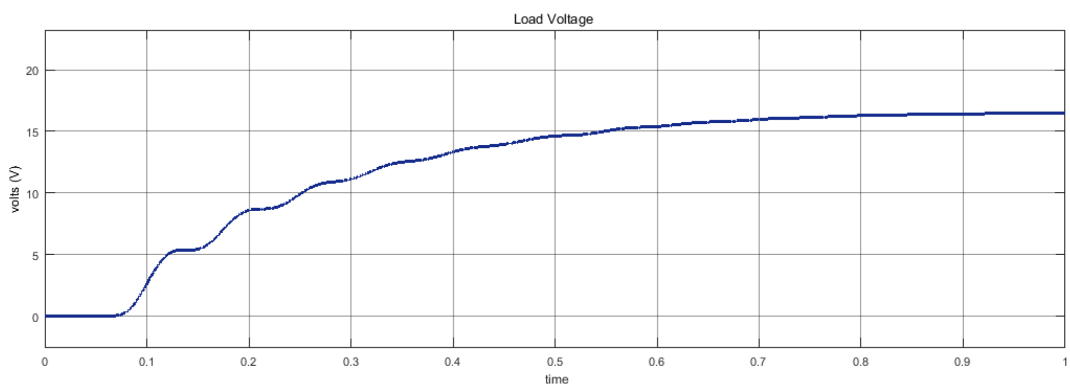


Figure 33- Load Voltage in Mode 1

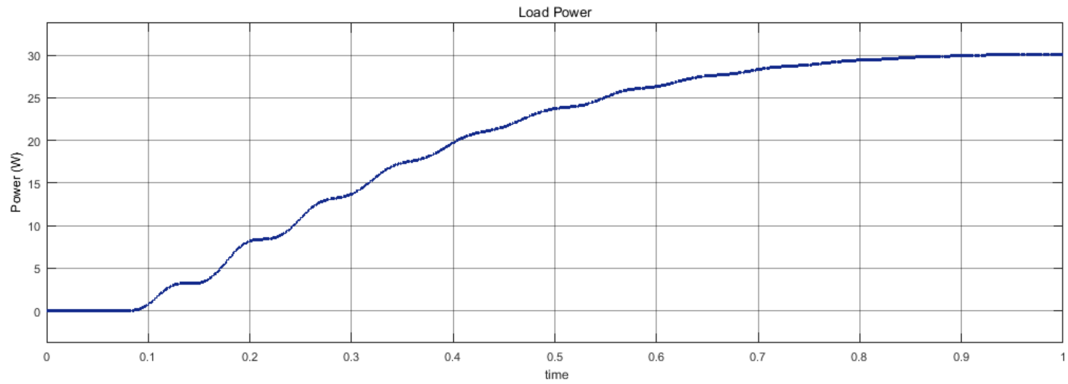


Figure 34- Load Power in Mode 1

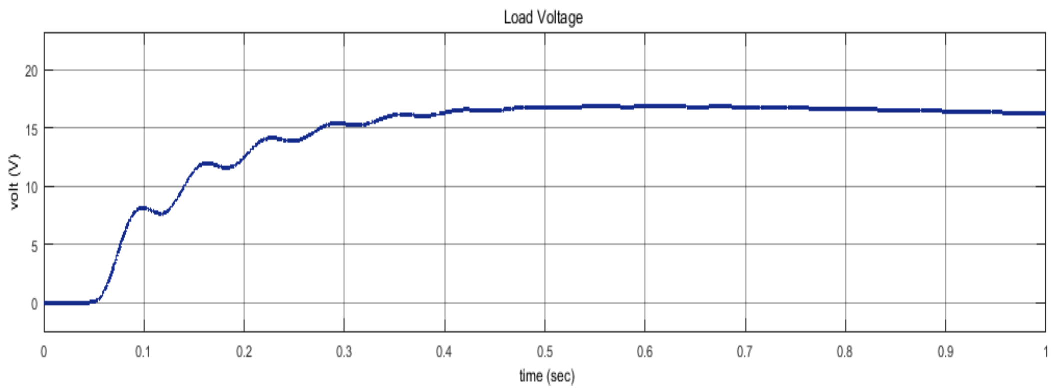


Figure 35- Load Voltage in Mode 2

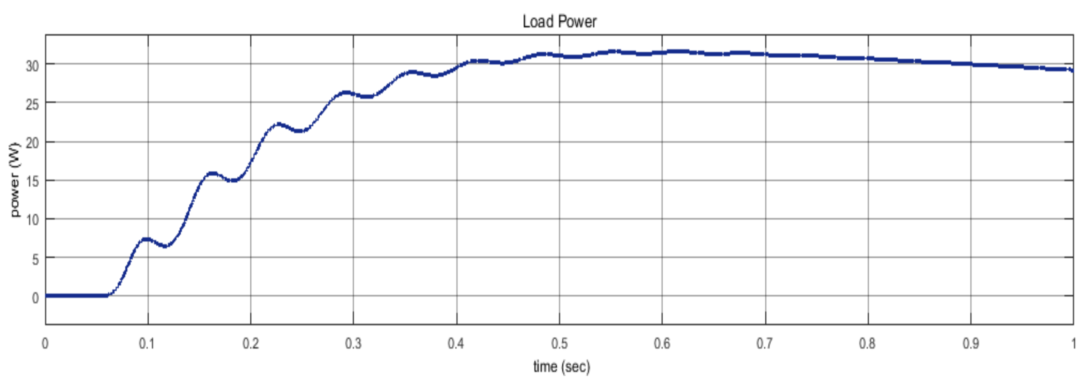


Figure 36- Load Power in Mode 2

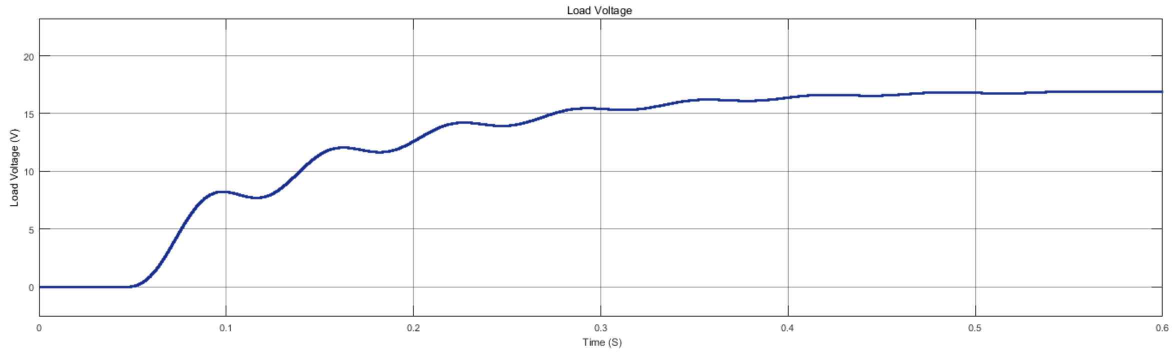


Figure 37-Load Voltage in Mode 3

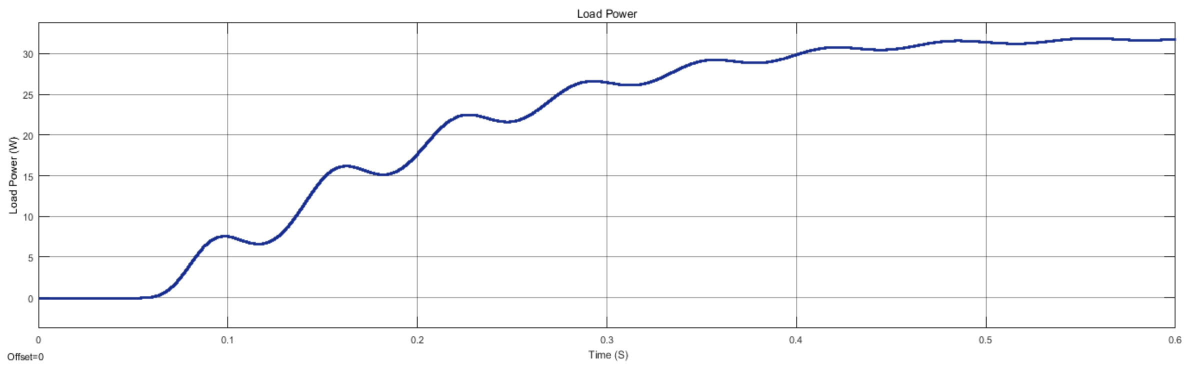


Figure 38- Load power in Mode 3

Chapter 8 analyzes another topology of full-bridge converter with three ports which is derived from full-bridge converter by splitting into two cells A and B, each of which engages a different input source such as PV panel and storage devices. The main focus of this chapter is the fuzzy logic control design, which is used for the power flow management in the converter.

Like the previous case, the converter under study has three different modes of operations. The modes determine the duty cycle of each switch. This is summarized in Table 7.

Table 7- Different modes of operation

Operation Modes	SA1	SA2	SB1	SB2
PV Power>load demand	High Duty Cycle	Low Duty Cycle	High Duty Cycle	Low Duty Cycle
PV Power<load demand	Low Duty Cycle	High Duty Cycle	High Duty Cycle	Low Duty Cycle
PV Power=load demand	High Duty Cycle	Low Duty Cycle	Low Duty Cycle	High Duty Cycle

This can be observed by the table that during Single Input mode, SA1 remains on for higher time interval to provide a path to the PV panel. During the interval in which batteries are either charged or discharged, SB1 also remains on for higher time to provide path to the batteries.

The controller makes decisions about the switches by taking the difference between the PV power generation and the load demand and produces two control signals. The simulations are carried out in MATLAB/Simulink for the verification of the design.

The choice of fuzzy logic based controller is due to the efficiency and simplicity of the fuzzy systems. On the input side, it takes the difference between PV power and load demand and generates two signals for each cell.

Each fuzzy logic control contains different membership functions which are shown in. There are thee membership functions shown for PV panel control which are low, equal and greater; each one's shape is triangular. As obvious, the range of the controller input is defined between -150W to 150W, since the maximum power that PV can generate is assumed to be 150W as in Figure 39-Membership function for PV.

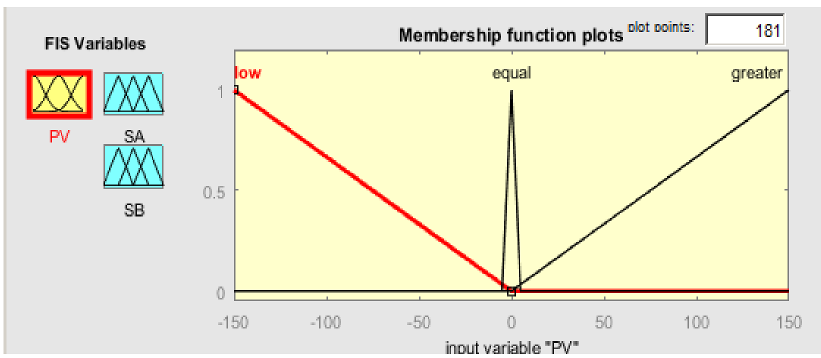


Figure 39-Membership function for PV

The membership functions have three parameters which define their lower and upper limit and function value. The lower limit is symbolized as 'l', the upper limit as 'h' and function value as 'v'.

Fuzzy logic controller generates waveforms for two switches, which are enough to drive all the switches, using the NOT operation. In Figure 40, one of the outputs is shown named SA with two triangular functions.

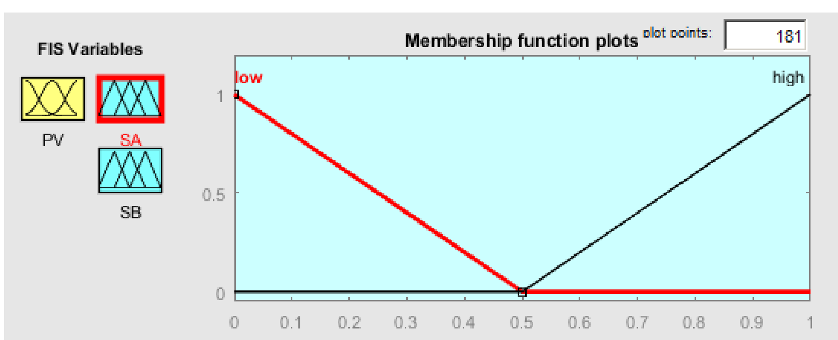


Figure 40- Membership function for SA

Similarly in Figure 41, the output of SB switch is shown.

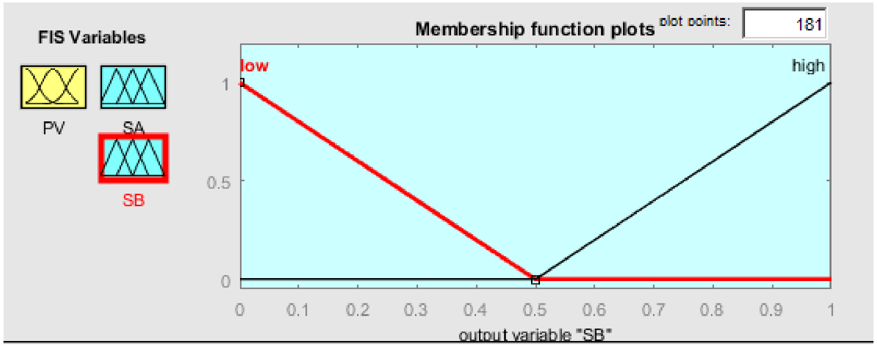


Figure 41- Membership function for SB

For the mode 1, the output voltage is shown in

Figure 42 and the power generated by PV panel is shown in Figure 43, which can be seen to be constant at 150 W.

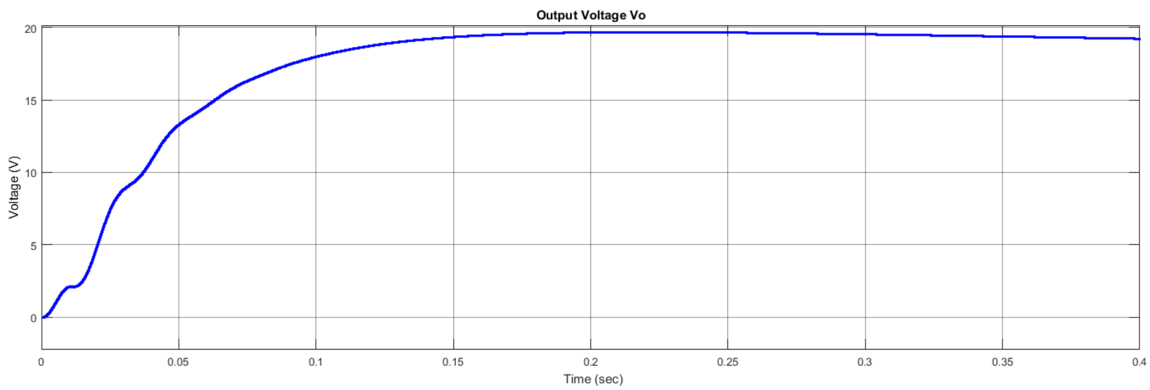


Figure 42- Output Voltage in mode 1

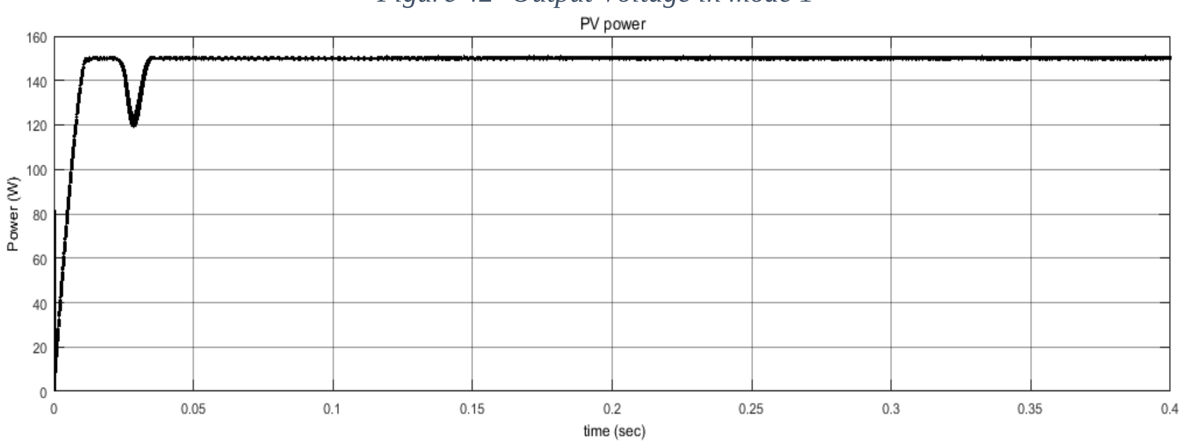


Figure 43-PV power characteristics

The mode 2 is the dual input mode, in which battery and PV panel provide power to the load. The output voltage is shown in Figure 44.

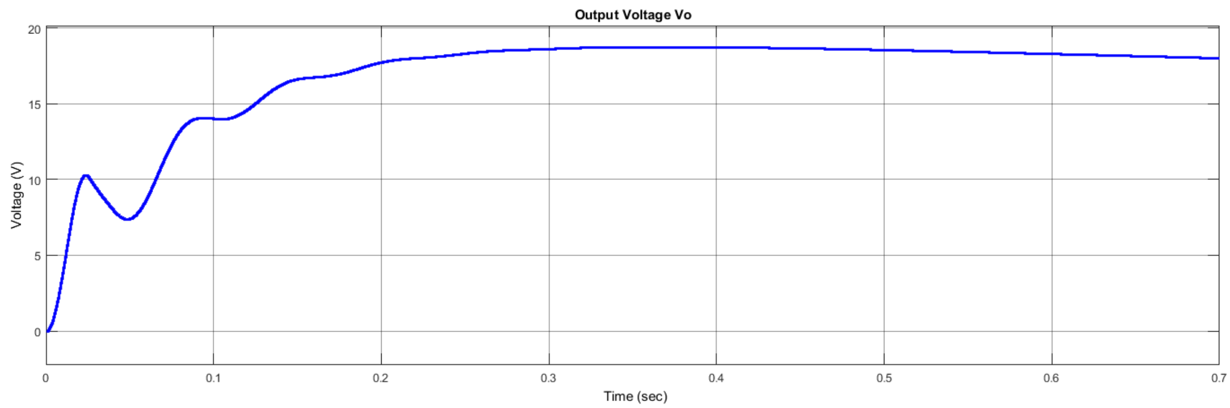


Figure 44-Output voltage in mode 2

In mode 3, the PV generated power and the load demand are balanced. The output voltage sticks to 15V, as shown in Figure 45.

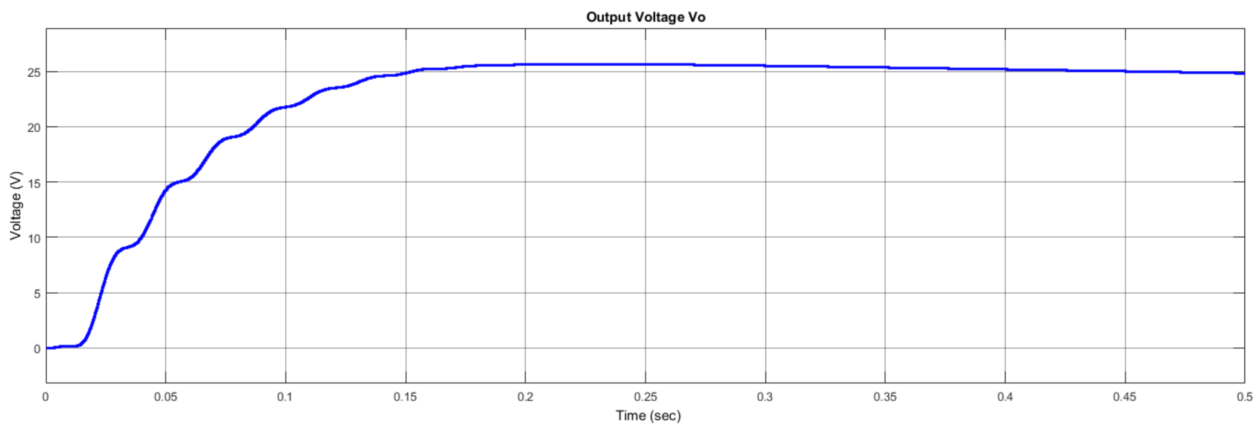


Figure 45- Output voltage in mode 3

Original Contributions

This thesis constitutes an array of different efforts all concerned with achieving better performance from the multiport converter topologies in renewable energy applications. Converter topologies were analyzed for renewable systems, different power flow management schemes in multiport converters were also developed and controllers for power extraction from PV panels were designed. The controllers and converter developed in this thesis were tested with varying input and output conditions and their impact on the load were studied to establish the veracity of the design.

Original contributions have been put in the derivation of three-port converter topology from the isolated full-bridge converter topology, by breaking it into two cells and introducing the transformer between the two cells, which connects the two cells to the output on the secondary side. The transformer model contains an inherent magnetizing inductance on the primary side. This magnetizing inductance can be used as an inductor on the primary side to introduce a buck-boost characteristic into this three-port converter. The converter now contains three ports, one of which is bidirectional port on the primary side, which is used for the storage device; the second port is unidirectional port for the PV panel, while the output port on the secondary side is isolated output port. Furthermore, the mathematical modeling of this converter is performed using the volt-second and capacitor-charge balance and a linearized mathematical model is achieved using small-signal approximation. This converter also supports Zero-Volt Switching (ZVS) for the power efficiency.

Original contribution is also done in designing a controller for the power flow management in three-port topology. The controller uses Fuzzy Logic Control (FLC); all the membership functions for the controller are defined in MATLAB/Simulink. The converter can work in three different modes governed by the controller. To determine the mode of the converter, the controller works by taking the difference between the powers generated at the PV panel and the load demand and generates output waveforms for the switches. It has been verified through key waveforms that drive signal to each switch in the converter depends on the conditions in the systems i.e. the mode. As the mode changes, a variation in the drive signal is observed and duty cycle of each switch changes accordingly. With this topology, the converter can work efficiently by combining the PV and battery power to feed the load or it can recharge the batteries when PV panels generate enough power. It is verified through simulations that output power that is fed to the load is smooth and stable.

Another contribution is the designing of another control algorithm for the power flow management between the three ports of the converter. This algorithm is also designed in MATLAB/Simulink and decides the mode of the converter by taking the inputs from PV power and the load, makes comparison between the two and adjust the mode of the converter. The simulation results establish the efficacy of this controller as it manages to shift the mode of the converter effectively and the effect can be seen on the shifted waveforms of the converter switches.

Original contribution is also done in comparative study of few multiport converter topologies and results through research and simulation in Simulink. Meanwhile, mathematical modeling of these converters, which include three port half-bridge, full-bridge and dual input single output converters, is also done using the volt-second balance and capacitor-charge balance on all the passive energy storing elements. Comparison is also done between the transformer isolated topologies of full-bridge and half-bridge and for transformer-less topology of Dual Input Single Output topologies.

Publications

In order to support our research objective, we have published several research papers in different international conferences and journals, which are listed below:

International Conference Papers

1- **S. J. AL-Chlaihawi** and A. G. Al-GIZI, "A Survey of Multiport Converters used in Renewable Energy," 2016 *International Symposium on Fundamentals of Electrical*

Engineering (ISFEE), Bucharest, Romania, 30 June- 2 July, 2016, pp. 1-4, doi:10.1109/ISFEE.2016.7803185

2- A. G. Al-Gizi and **S. J. Al-Chlaihawi**, "Study of FLC based MPPT in comparison with P&O and InC for PV systems," 2016 International Symposium on Fundamentals of Electrical Engineering (ISFEE), Bucharest, Romania, 30 June -2 July, 2016, pp. 1-6, doi: 10.1109/ISFEE.2016.7803187

3- **S. J. Al-Chlaihawi,** "Comparative study of the multiport converter used in renewable energy systems," 2016 *International Conference on Applied and Theoretical Electricity (ICATE)*, Craiova, Romania, October 6-8, 2016, pp. 1-6, doi: 10.1109/ICATE.2016.7754650

4- **S. Al-Chlaihawi** and M. Louzazni, "Hybrid Photovoltaic – Battery Energy Management System Using Multiport DC-DC Converter," 2016 *International Renewable and Sustainable Energy Conference (IRSEC'16)*, November 14-17, 2016,Marrakech-Morocco.

5- **S. J. AL-Chlaihawi,** A. Craciunescu and A. G. Al-Gizi, "Power Flow Management in Three Port Converter Using PV Panel with Maximum Power Point Tracker," *2017 10th IEEE International Symposium on Advanced Topics in Electrical Engineering (ATEE 2017),* Bucharest, Romania, March 23-25, 2017, pp. 585-590, doi: 10.1109/ATEE.2017.7905136

6- A. G. Al-Gizi, A. Craciunescu, and **S. J. Al-Chlaihawi**, "The use of ANN to supervise the PV MPPT based on FLC," *2017 10th IEEE International Symposium on Advanced Topics in Electrical Engineering (ATEE 2017),* Bucharest, Romania, March 23-25, 2017, pp. 703-708, doi: 10.1109/ATEE.2017.7905128

7- A. Al-Gizi, A. Craciunescu, and **S. Al-Chlaihawi**, "Improving the performance of PV system using genetically-tuned FLC based MPPT," *2017 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) & 2017 Intl Aegean Conference on Electrical Machines and Power Electronics (ACEMP),* Brasov, Romania, May 25-27, 2017, pp. 642-647, doi:10.1109/OPTIM.2017.7975041

8- **S. J. Al-Chlaihawi**, A. Craciunescu, M. Louzazni, A. G. Al-Gizi, "Full bridge three port converter power flow control using fuzzy logic controller," *17th IEEE International Conference on Environmental and Electrical Engineering 1st Industrial and Commercial Power Systems Europe,* Milan, Italy, June 6-9, 2017, pp. 2694-2699, doi: 10.1109/EEEIC.2017.7977868

9- A. Al-Gizi, **S. Al-Chlaihawi**, and A. Craciunescu, "Comparative study of some FLC-based MPPT methods for photovoltaic systems," *19th International Conference on Researches in Science & Technology (ICRST),* Barcelona, Spain, July 27-28, 2017.

International Journal Papers

1- **S. J. M. AL-Chlaihawi**, "Multiport Converter in Electrical Vehicles-A Review," *International Journal of Scientific and Research Publications,* vol. 6, no. 5, May 2016, pp. 378-382.
2- **S. Al-Chlaihawi**, A. Al-Gizi, and A. Craciunescu, "The analysis and comparison of multiport converter used for renewable energy sources" *Advances in Science, Technology and Engineering Systems Journal (ASTESJ)*, vol. 2, no. 3, pp. 906-912, 2017.
3- A. Al-Gizi, **S. Al-Chlaihawi**, and A. Craciunescu, "Efficiency of photovoltaic maximum power point tracking controller based on a fuzzy logic," *Advances in Science, Technology and Engineering Systems Journal (ASTESJ)*, vol. 2, no. 3, pp. 1245-1251, 2017.
4- A. Al-Gizi, **S. Al-Chlaihawi**, and A. Craciunescu, "Comparative study of some FLC-based MPPT methods for photovoltaic systems," *MATTER: International Journal of Science and Technology*, vol. 3, no. 3, pp. 36-50, 2017. doi: https://dx.doi.org/10.20319/mijst.2017.32.3650
5- A. Al-Gizi, **S. Al-Chlaihawi**, M. Louzazni, and A. Craciunescu, "Genetically optimization of an asymmetrical fuzzy logic based photovoltaic maximum power point tracking controller," *Advances in Electrical and Computer Engineering*, vol. 17, no. 4, pp. 69-76, 2017. doi: 10.4316/AECE. 2017.04009
6- **S. Al-Chlaihawi**, and A. Craciunescu, "Fuzzy logic power flow control in split full bridge three-port converter," *U. P. B. Sci. Bull., Series C*, vol. , no. , pp. - , 2018. (**submitted for publication**)

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