Fuzzy Logic Power Flow Control in divide Full Bridge Three-Port Converter

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Abstract. On this work, the three-port converter derivative from the full-bridge converter is analysed and control. The full-bridge converter is made up of two parts, A and B. Each part contains two switches with independent input sources. The inputs drive the load through a transformer that boosts voltage and provides isolation. The controller is an important portion of the converter. It controls the pass of power between the three ports. The controller uses Fuzzy Logic Control to make decisions regarding the two control signals for each part. These decisions are based on the variance between the whole energy generated by the photovoltaic panel and the energy demand at the load. The proposed design is verified through MATLAB and Simulink.

1. Introduction
Renewable energy sources are all the hype these days. These include geothermal, wind energy and photovoltaic solar cell, et cetera. They are now widely being deployed in industry. The integration of different energy sources is a better option than using different sources separately as it will save the cost of having multiple converters for each energy source. Multiport power converters are in use to convert ac to dc, dc to ac, or dc to dc [1-3]. To isolate a three-port converter an AC link via high-frequency transformer is used. It is a cost-effective solution designed for safety [4].

Stable current flow is needed for the converter, inverter and the electric power appliances to work well. Batteries or supercapacitors are used to stabilize the output power in the photovoltaic power system connected with the full-bridge in the different port converter. These batteries or supercapacitors are generally unstable.

Recently, S. J. AL-Chliaihawi [5] surveyed multiport renewable energy systems [6]. Three ports converter has the following advantages:
- Higher efficiency
- Fewer components
- Speedy steady state response
- Small size

With these reasons important features of the three-port converter, it finds applications in a wide variety of domains such as: Renewable energy source [7], loads and energy storage elements [8], et cetera.
The latest research has exploited the domains of full-bridge three-port converters, such as a multi-input inverter. It contains a buck/buck-boost fused multi-input dc-dc converter and a full bridge dc-ac inverter [9]. The proposed inverter in [9] reduces the cost of the photovoltaic/wind system. A multi-input inverter is proposed here to simplify the power system and to decrease the cost of a PV/wind system. A number of conversion phases are interfaced through three port converters as unparalleled shared dc bus [10].

J. Zheng out forth the designing of a single three-port bi-directional dc-dc, dc converter for photovoltaic systems that store energy using the least number of switches. He used inductor–capacitor-inductor (LCL)-resonant circuit to induce soft switching in the main switch of half and full-bridge. N. Zhang.et.al proposed a review of topologies of three-port dc-dc converters [11] for integrating renewable energy with the energy storage system. It improves the power density and efficiency of the system.

A collection of bi-directional pulsate voltage cells. (buck/boost) constitutes this multiport converter family. Dual-Input dc-dc converters with full-bridge or half-bridge current sources form another family of quasi-switched-capacitor circuits. This is used to integrate a photovoltaic system (PV) and battery energy storage [12]. In [13], a novel method is devised to control a LiFePO4 battery storage system attached to a grid. They used a Takagi-Sugeno-Kang type probabilistic fuzzy neural network. Mira.et.al [14] developed a full-bridge dc-dc converter with the pulse width modulation (PWM) controller to operate hybrid renewable energy systems. Phase shift control is also added to this system. Saravana.et.al proposed a multi-input converter that uses fuzzy logic controller in combination with neural networks. It does an online estimation of battery charge and integrates that with different renewable energy sources (solar energy, and fuel cell energy) [15]. Derrouazin performed a comparative analysis of two techniques of supervision and control of fuzzy and classical logics for the management of multiple converter integrated with the system of hybrid energy. It was for a housing system powered by wind and solar power [16].

Used full-bridge 3 port converter with PV panel and analyzed results [17]. Implemented fuzzy logic controller with maximum power point tracking (MPPT) to operate the PV system [18]. Implemented fuzzy logic based maximum power point tracking controller and optimized fuzzy logic controller (FLC) parameters using a genetic algorithm. Experimental results show that this fuzzy logic based MPPT controller provides the best steady-state performance [19] and [20]. Corradini.et.al [21] devised a switching technique for bidirectional dc-dc converters [21] that is based on zero voltage. [22] proposed a modulation scheme for power-sharing and control. In this scheme isolated half-bridge converter is adjusted to get the full-bridge converter. This isolated half-bridge converter has three operation modes and a uni- frequency switching cycle that gives two independent control variables. When combined, the four bridge switches provide synchronous boost conversion and drive the transformer.

| Table 1. Comparison of multi-port converter & conventional converter. |
|---------------------------------------------------------------|
| **Integrated multiport structure** | **Conventional multi-converter structure** |
| Conversion stage | One | More than one |
| Control design | Complicated and little-reported | Conventional and well-known |
| Component count | Low | High |
| Control structure | Centralized | Separated |
| Overall mass | Low | High |
| Control Input | n-1 | One |
Under controlled conditions, the proposed scheme achieves zero voltage switching (ZVS) of all bridge switches [22]. Multi-port constructions can either be isolated or non-isolated. The isolated converter uses bridge construction and is used for the following reasons.

Wide voltage range
- Soft switching for higher efficiency
- Transformers with high frequency

Isolation is a strict requirement for specific applications. The integrated boost converter has a wider range than the traditional boost converter. In integrated multiport converters control of power, integration is centralized. Also, they are cheaper yet reliable and because of centralized power integration, they give a dynamic performance. There are different types of converters as shown in table 1 and the multiport converter is one of them having multiple inputs and outputs.

A three-port converter having one input and two outputs is presented in this work. The full-bridge converter (FBC) is made up of two parts with a power supply connected to each of them. The fuzzy logic controller governs the power flow.

Section 2 analyses the full-bridge three-port converter (FB-TPC). Section 3 discusses the modes of operation for the converter. Section 4 explains control analysis for the converter. Section 5 shows the results of the simulation. Section 6 shows the transition between each two modes and section 7 concludes the paper.

2. Analyses of full bridge three port converter
In Figure 1 is presented a 2-port full-bridge converter. Each leg has a pair of switches. The input source is placed parallel to the legs. The transformer has a magnetizing inductance that uses a volt-second balance to save its core from saturation. Figure 1 (b) shows that each leg of the primary side is split into two parts- part A and part B. Figure 1 (c) shows how both cells can be linked to different sources.

![Figure 1. Derived full bridge three-port converter.](image)

Transformers are used to isolate the output. The source contains an electromotive force (EMF). The potential gradient between the two sources is the most prominent feature of this three-port converter. Through the transformer, sources carter to the load demand. Basic transformer side has a magnetizing
inductance $L_m$, its secondary side (output) inductance $L_f$. Combined, $L_f$ and production capacitor make a rectifier by creating an LC filter. This smooth's out the distortions of the output voltage for DC voltage smooth production.

There is power consumption among the sources that charges the batteries as shown in figure 2. Part switches control power flow. At a time, only one switch can operate (decide the power flow) in a part. If both switches are made to operate together, it will short circuit the path and damage the sources. The two sources of this converter are:

- Photovoltaic panel
- Battery bank

![Figure 2. Power flow of primary side.](image)

PV cells control the intensity of the sunlight using Maximum Power Point Tracker (MPPT) in the first panel. It includes a boost converter as well to step-up the DC voltage of the photovoltaic cell. The important parameters of the multiport converter mentioned in this research are enlisted in table 2 under the following assumptions:

- Load power is supplied from both sources
- Power source is shared between source and load
- Regenerative power charges the battery

| Requirement             | Value          |
|-------------------------|----------------|
| Photocell panel         | 150 W          |
| Stored element          | 20 V           |
| Transformation ratio    | 1:1            |
| Output capacitor        | 0.01e-6 µF     |
| Output inductor         | 470e-6 H       |
| Mutual inductance       | 53.052 H       |

3. Modes of operation

The Proposed system has two sources and power flows between each of sides windings of the transformer. Our proposed converter works in three modes on the basis of irradiance and load demand. If more power ($P_{pv}$) is being generated than the demand ($P_o$), mode 1 is applied. Mode 2 is operated if load demand exceeds the total panel production. Mode 3 will work if load demand and solar production are equal.

There is an exceptional case for mode 2 when PV power becomes zero. However, for both situations of mode 2, the load is driven by the power provided by the batteries. While in mode 1, extra power is provided to the batteries for recharging them. A Mathematical model for ideal power flow in all modes is written as:

$$Q_{pv} + Q_b = Q_o$$  \hspace{1cm} (1)
During model 1, photovoltaic plate provides energy to both load and batteries. In model 2, load is driven by batteries and the PV panel, because solar panels are not producing sufficient energy to drive the load. The Power flow in three port converter is shown in Figure 3.

**Figure 3.** The flowing of power in three port converter.

4. Control analysis for the converter

The Fuzzy logic controller works on a non-linear and adaptive technique and it gives fabulous results regardless of parameters. In our system, this controller adjusts its parameters automatically with the variation in load. Its rules are based on the power difference between energy generated by solar panels and energy demand by the load. This difference in powers is used by the Fuzzy controller as an input. Figure 4. Is representing the fuzzy logic control being used in our system. Since the maximum power of the PV panel is 150 W so we assigned a maximum value of +150 to the input function, while the minimum value is -150. Triangular functions with the lower limit as ‘1’, higher limit as ‘t’ and function value as ‘u’ are used Three-member functions (low, equal, and greater) are used along having values between -5 to +5. The fuzzy controller has 2 output values and the pulse of the battery is being controlled using the output of the fuzzy controller. Table 3. Is showing the pulse chart needed for our operation.

**Figure 4.** For two inputs Membership functions

**Figure 5.** For output SA membership functions.

**Table 3.** Output required from fuzzy logic controller.
### Table 1

| Condition                  | SA  | SB  |
|----------------------------|-----|-----|
| PV greater than load       | On  | On  |
| PV smaller than load       | Off | On  |
| PV equal the load          | On  | Off |

The fuzzy logic controller generates two signals for each switch. By overturn the SA and SB signals, SA2 and SB2 are generated. Following are the rules of fuzzy logic:

- If panels energy is low, SA will be low and SB will be high.
- If panels energy is equal to the load demand, SB will be low and SA will be high.
- If panels energy is greater than load demand, both SA and SB will be high.

Fuzzification is done, based on rules mentioned above and then de-fuzzification is done using a method called the centre of gravity.

**Figure 6.** For output SB membership functions.

### 5. Simulation results

The three modes will be discussed in the following.

#### 5.1. Model 1: Photocell energy is higher than load energy

On this model, the system has one input and two outputs. For this mode, Figure 7. Shows voltage of the output $V_O$, and Figure 8. Shows the pulse switching. The switch SA1 and SA2, and also SB1 and SB2 work in complementary mode. It is to be noted that SB1 and SA1 work for a remarkable period, according to the prognosis made earlier. Figure 9 is showing the power produced by a solar panel. This power has a peak value of 150W and it reaches its peak value when irradiance is highest. To optimize the PV power, MPPT controller along with the Boost converter is used. The primary voltage for this model is shown in Figure 10.

**Figure 7.** Output $V_O$ for model 1.  
**Figure 8.** Pulse switching for model 1.
5.1.1. working steps for the converter

Status 1: On this status, both switches SA and SB for group one switches are closed while switches for group two switches are open. A positive voltage is applied by coupling solar panels power with primary windings of the transformer. The battery is also connected with the panel and load simultaneously. The battery gets power from PV power in this scenario.

Inductor voltages $U_{Lm}$, $U_{Lf}$ and capacitor current $Q_{co}$ are given as:

\[
U_{Lm} = U_{SA} - U_{SB}
\]

\[
U_{Lf} = n(U_{SA} - U_{SB}) - U_O
\]

\[
\frac{dQ_{Lm}}{dt} = \frac{U_{SA} - U_{SB}}{L_m}
\]

\[
\frac{dQ_{Lf}}{dt} = \frac{n(U_{SA} - U_{SB}) - U_O}{L_f}
\]

\[
Q_{co} = Q_{Lf} - \frac{U_O}{R}
\]

Current ($Q_p$) on first side of transformer is given as:

\[
Q_p = Q_{Lm} + n Q_{Lf}
\]

Status 2 [11-12]: In this period, switches SA and SB switches for group two are closed, while switches SA and SB switches for group one are open. There is no connection between PV plates and batteries with the load. This state is governed by following equations:

\[
U_{Lm} = 0, U_{Lf} = 0, \frac{dQ_{Lm}}{dt} = 0, \frac{dQ_{Lf}}{dt} = 0, Q_{co} = -\frac{U_O}{R}
\]

5.2. Model 2: Photocell energy is lower than Load energy

In this model power is provided to the load by the battery and PV panel. Figure 11 shows the output voltage which becomes stable at 0.18 seconds and operates at this quantity.
5.2.1. Working steps for the converter

Status 1 \([t_0-t_1]\): In this status, energy is supplied to load through the transformer by photocell panels and batteries. This operation is governed by the following equation:

\[
U_{Lm} = U_{SA} - U_{SB} \tag{9}
\]

\[
U_{L_f} = n(U_{SA} - U_{SB}) - U_O \tag{10}
\]

\[
\frac{dQ_{Lm}}{d_t} = \frac{U_{SA} - U_{SB}}{L_m} \tag{11}
\]

\[
\frac{dQ_{L_f}}{d_t} = \frac{n(U_{SA} - U_{SB}) - U_O}{L_f} \tag{12}
\]

\[
Q_{co} = Q_{L_f} - \frac{U_O}{R} \tag{13}
\]

\[
Q_p = Q_{Lm} + nQ_{L_f} \tag{14}
\]

Where \(Q_p\) is the current at the first side of the transformer.

Status 2 \([t_1-t_2]\): In this status photocell panel is isolated from the converter and the battery supplies the energy to the load. Equations for this status as are follows:

\[
U_{Lm} = -U_{SB} \tag{15}
\]

\[
U_{L_f} = -nU_{SB} - U_O \tag{16}
\]
\[ \frac{dQ_{m}}{dt} = -\frac{U_{SB}}{L_{m}} \]  \hspace{1cm} (17)

\[ \frac{dQ_{f}}{dt} = -n \frac{U_{SB} - U_{o}}{L_{f}} \]  \hspace{1cm} (18)

\[ Q_{co} = Q_{lf} - \frac{U_{o}}{R} \]  \hspace{1cm} (19)

Status 3 [12-13]: In this period, photocell panels and batteries are disconnected from the load. \( U_{Lm}, U_{Lf} \) and \( Q_{co} \) are as given as:

\[ U_{Lm} = 0, \ U_{Lf} = 0, \frac{dQ_{co}}{dt} = 0, \frac{dQ_{m}}{dt} = 0, Q_{co} = -\frac{U_{o}}{R} \]  \hspace{1cm} (20)

5.3. Model 3: Photocell energy is same to load energy

In this model, photocell energy becomes equal to the load demand. Output voltage reaches its peak value of 25 V within 0.15 seconds. The Results are shown in Figure 14, 15, and 16.

![Figure 14. Output V_o in model 3.](image1)

![Figure 15. Pulse switches in model 3.](image2)

![Figure 16. Voltage in primary side in model 3.](image3)

5.3.1. Working steps for the converter

Status 1 [10-11]: In this status, connection between battery and solar panel is established through SB1. \( U_{Lm}, U_{Lf} \) and \( Q_{co} \) are calculated as follows:

\[ U_{Lm} = U_{SA} - U_{SB} \]  \hspace{1cm} (21)
\[ U_{lf} = n(U_{SA} - U_{SB}) - U_o \]  
(22)

\[ \frac{dQ_{lm}}{dt} = \frac{U_{SA} - U_{SB}}{L_m} \]  
(23)

\[ \frac{dQ_{lf}}{dt} = \frac{-nU_{SB} - U_o}{L_f} \]  
(24)

\[ Q_{co} = Q_{lf} - \frac{U_o}{R} \]  
(25)

Qp is the current at the first side of the transformer, which is defined as:

\[ Q_p = Q_{lm} + nQ_{lf} \]  
(26)

Status 2 [11-12]: In this period, load gets energy from the photocell panel and battery gets disconnected from the circuit. Equations are given as:

\[ U_{lm} = U_{SA} \cdot U_{lf} = nU_{SA}, \quad \frac{dQ_{lm}}{dt} = \frac{U_{SA}}{L_m}, \quad \frac{dQ_{lf}}{dt} = \frac{nU_{SA}}{L_f}, \quad Q_{co} = Q_{lf} - \frac{U_o}{R} \]  
(27)

Status 3 [12-13]: In this status both PV panels and batteries get disconnected from the load. \( U_{lm}, U_{lf} \) and \( Q_{co} \) equations are given as:

\[ U_{lm} = 0, \quad U_{lf} = 0, \quad \frac{dQ_{lm}}{dt} = 0, \quad \frac{dQ_{lf}}{dt} = 0, \quad Q_{co} = \frac{U_o}{R} \]  
(28)

6. Transition between each two modes

![Figure 17. The transmission between mode 1 & mode 2.](image-url)
7. Conclusion

On this paper, a 3-port converter is designed using a fuzzy logic controller. The fuzzy logic controller is integrated with a full-bridge converter to derive the load using solar panels and batteries. This controller works best in scenarios where solar panels are not generating sufficient power and we need to shift to some alternative sources like batteries without breaking the connection.

All rules and membership functions are developed for the fuzzy logic controller. The converter operates in 3 different modes. The fuzzy logic controller takes a decision established on load demand and PV panel production and then controls four switches by generating different waveforms. Maximum power point tracking is used along with a boost converter to optimize the PV power. The model is developed and testing using Matlab/Simulink. Equations are generated for each mode; output voltage waveforms are analyzed and results are confirmed by the volt-second balance equation.
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