Design and implementation bidirectional SEPIC/ZETA converter using Fuzzy Logic Controller in DC microgrid application

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Abstract. The electrical energy has been dependent on fossil fuels, but the availability of fossil energy is running low with increasing electricity demand in society. Therefore a lot of research is done on renewable energy sources, one of which is solar energy. Solar energy can be applied to home scale DC microgrid systems. In the DC microgrid system the independent source of energy for the supply of loads comes from two sources, namely DC bus and 120 volt battery. To combine these two energy sources, a bidirectional converter is needed which will regulate power flow and electricity storage. In this system the battery can become a burden and can be a source of energy in the same series. Bidirectional converters can work in two directions, namely charging mode and discharging mode. The type of converter used in this bidirectional converter is SEPIC/ZETA Converter. The use of this type of converter is expected to reduce the ripple at the output voltage and minimize voltage disturbances during switching. The control method used is a fuzzy logic controller for voltage control which is expected to produce stable output.

1. Introduction
Today, all actions and activities carried out by humans have never escaped the use of electricity. Electricity is one topic that is always feasible and worthy of discussion. The ups and downs of world fuel prices make new innovations so that electricity is no longer fuel oil which is a fossil fuel. Renewable energy systems are being encouraged to reduce the burden of using fossil energy. One of the renewable uses of energy that is quite well known by the public and is in the process of developing a solar energy source. The application being studied is the application of solar energy sources in the form of a home scale DC Microgrid system. Some disadvantages of renewable energy sources are limited power supply and the need for electricity storage. Storage of electrical energy is needed because most renewable energy sources depend on weather conditions. With the energy storage, it can later be used to help supply the load when the energy produced by renewable energy sources no longer works.

The stored energy can also be used to help supply the load to increase the power capacity produced by renewable energy sources. Bidirectional dc-dc converters related to energy storage are promising
choices for many power-related systems, including hybrid vehicles, vehicles using battery sources, renewable energy systems and so on. In this study a bidirectional dc-dc converter can be used to combine two different types of energy sources, namely batteries and dc bus[1-3]. The dc bus source is assumed to come from a renewable energy source that is used to supply the load and charging the battery, while the source that comes from the battery is used to help supply the load. The load power used determines the work of the bidirectional dc-dc converter[4]. The control used is fuzzy logic controller for voltage control which is expected to produce stable output.

2. System Description
The Bidirectional SEPIC / Zeta converter circuit consists of two mosfets which are used as switches S1 and S2, two inductors L1 and L2 (coupled inductor), two capacitors C1 and C2, and two different sources of energy namely DC 400 V bus and battery 120 V. The purpose of this bidirectional converter is to keep the voltage on the dc bus constant at 400 V, so that this converter can work in two directions namely charging and discharging modes. When the voltage on the dc bus is less than 400 V, the converter will work with discharging mode by increasing the voltage from 120 V to 400 V. Conversely when the voltage on the dc bus is more than 400 V, the converter will work charging by decreasing the voltage from 400 V to 150 V.

![Figure 1. Block Diagram System](image)

In Figure 1 shows the system of costs and expenditures on energy storage through the SEPIC / ZETA converter with Fuzzy control which works to make the voltage when the expenditure towards the DC bus becomes fixed and the cost mode can use constant voltage as charging to the storage energy until it reaches full requirements. The filling and emptying conditions are represented by modifying modifier modes, namely SEPIC and ZETA modes.

2.1. PV Module
Photovoltaic consists of several solar cells. Every solar cell is installed in series and parallel. Each solar cell cell works based on the p-n junction principle between semiconductor type p and semiconductor type n.

![Figure 2. Equivalent circuit of solar cell PV](image)
This semiconductor consists of atomic bonds in which there are electrons as a basic constituent. Large power of photovoltaic is expressed in Watt peak (Wp). The equivalent circuit of photovoltaic can be shown in Figure 2. The mathematical equation of the PV module can be expressed as:[5]

\[ I_{pv} = N_s I_{pp} - N_s I_o \left( \exp \left( \frac{V_{pv} + R_s I_{pv}}{A K T} \right) - 1 \right) - N_s \left( \frac{V_{pv} + R_s I_{pv}}{N_s R_{SH}} \right) \] (1)

where:
- \( I_{pv} \) = output power pv module (A)
- \( V_{pv} \) = output voltage PV (V)
- \( I_{pp} \) = generated current (A)
- \( I_o \) = current reverse diode (A)
- \( R_s \) = resistance series solar cell (ohm)
- \( R_{SH} \) = resistance shunt solar cell (ohm)
- \( N_p \) = number of parallel solar cell
- \( N_s \) = number of series solar cell
- \( Q \) = electron charge \((1.6 \times 10^{-19} \text{ C})\)
- \( K \) = constant boltman \((1.38 \times 10^{-23} \text{ J/K})\)

2.2. SEPIC/ZETA Converter

Bidirectional dc-dc converter transfers energy from two different sources. Bidirectional SEPIC / Zeta converters are used as a standard photovoltaic (PV) system, wind, fuel cell, and UPS (Uninterruptable Power Supplies). An example of a non-isolated bidirectional DC-DC Converter is conventional buck / boost, multilevel, SEPIC / Zeta, and switched capacitor type converters. In conventional bidirectional boosts, comparison comparisons are significantly reduced by disturbing components, making them unsuitable for non-isolated applications. Multilevel Converter requires more switching components that make the control circuit more complicated. Although the switched capacitor can produce a high step-up voltage or a much lower step-down, the configuration of the circuit is very complex.

SEPIC / Zeta Converter is an efficient non-inverting dc-dc converter which can be operated in SEPIC or Zeta mode with a simpler design than a small number of components[6-7]. However, the ripple value of the output voltage and voltage disturbance on the active component is very large, so a snubber circuit is needed to overcome the problem. The block diagram depicting the energy storage system in renewable energy systems is shown in the following figure 3.

![Figure 3. Block diagram Bidirectional System](image-url)
The system consists of sources, loads and ESS (Energy Storage System). This system can work in two operating modes. In the first condition, if the renewable energy source output is sufficient to absorb the current directional converter work in the charging mode (SEPIC Mode) [8-11] and energy flows from the dc bus to the battery. The second condition is if the voltage source output is less than the set range, then the bidirectional converter will work by discharging (ZETA Mode) and the generator will be blocked from the battery[12-13]. The bidirectional ZEPIC / Zeta converter circuit is like Figure 4.

![Figure 4. Membership function Error](image1)

In the bidirectional system SEPIC / ZETA is used Fuzzy Logic Controller with the 5x5 membership function for input Error as shown in Figure 5 so that the data produced is quite accurate with relatively small error results[14-15].

![Figure 5. Membership function Delta Error](image2)

| Table 1. Rule Base |
|-------------------|
| DEE | NB | N | Z | P | PB |
| DNB | H  | H | H | MH| M |
| DNB | H  | H | MH| MH| LM| |
| DZ  | H  | MH| MH| LM| LM| |
| DP  | MH | MH| LM| LM| L | |
| DPB | M  | LM| L | L | L | |
In the bidirectional system SEPIC / ZETA is used Fuzzy Logic Controller with the 5x5 membership function for input Error as shown in Figure 5 so that the data produced is quite accurate with relatively small error results. Fuzzy Logic Controller have a rule base as shown in table 1 so that the data produced is quite accurate with relatively small error results.

![Figure 5](image)

**Figure 6.** Surface Viewer

The error and delta error values on the surface viewer shown in Figure 5 and the surface viewer for the fuzzy logic controller are totally shown in Figure 6. In Figure 6 it can be seen that the results of the fuzzy logic controller rule shown in table 1 produce a good surface viewer resulting in data accurate output.

### 3. Experiment and Discussion

Experiment is done by simulating the bidirectional SEPIC / ZETA converter system in SEPIC mode and ZETA mode using fuzzy logic control so that the charging process towards energy storage and discharging process towards DC bus can run well and accurately.

![Figure 7](image)

**Figure 7.** Simulation Result When SEPIC mode
After being simulated, the results shown as shown in Figure 7 and Figure 8 show that the signal generated shows that when the SEPIC and ZETA modes can operate properly using the fuzzy logic controller method.

4. Conclusions

Bidirectional SEPIC / ZETA Converter is proven to operate well in SEPIC and ZETA mode, The Fuzzy Logic Controller shows good performance when energy is transferred to storage energy and when energy storage is transferred to the load.

References

[1] Ayush A., Shubam G., Aakash K., Vivek S., “Analysis of Energy storage system for wind power generation with application of bidirectional converter”, in International conference on computational intelegence & communication Technology”, 2016.

[2] T. Aharon, A. Kuperman, and D. Shmilovitz, "Analysis of Bidirectional Buck-Boost Converter for Energy Storage Applications," in Proceedings of IEEE IECON Conference, Vienna, pp. 858-863, August 2013.

[3] H. Lee, T. Liang and J. Chen, "Design and Implementation of a Bidirectional SEPIC-Zeta DC-DC Converter," in Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS), Melbourne, June 2014.

[4] Dr. Ray Ridley.2000.Analyzing the Sepic Converter.IngririsRidley Engineering.

[5] Application Note 1484 Designing A SEPIC Converter. TEXAS INSTRUMENT.

[6] M. L. Septya, I. Sudiharto, N S. Dwitya, O. A. Qudsi, E. Sunarno, “ Design And Implementation Soft-switching MPPT SEPIC Converter Using P&O Algorithm”, E3S Web of Conferences, 2018.

[7] M. A. Mughis, I. Sudiharto, I. Ferdiansyah, D. S. Yananatri, “ Design and Implementation of Partial M-Type Zero Voltage Resonant Circuit Interleaved Bidirectional DC-DC Converter (Energy Storage and Load Sharing)” International Electronics Symposium on Engineering Technology and Applications (IES-ETA), 2018.

[8] Soedibyo, Murdianto F.D, Suyanto, A. Mochamad, P. Ontoseno,” Modeling and simulation of
mppt SEPIC combined bidirectional control invers KY converter using ANFIS in microgrid system,” Indonesian Journal of Electrical Engineering and Computer Science, vol. 1, pp. 264-272, February 2016.

[9] M. Z. Efendi, F.D. Murdianto and R. E. Setiawan, “Modeling and Simulation of MPPT Sepic Converter using Modified PSO to Overcome Partial Shading Impact on DC Microgrid System,” International Electronics Symposium on Engineering Technology and Applications (IES-ETA), 2017

[10] F. D. Murdianto, A. R. Nansur, and A. S.. L. Hermawan, “Modeling and Simulation of MPPT Coupled Inductor Sepic Converter using Flower Pollination Algorithm (FPA) Method in DC Microgrid,” International Electronics Symposium on Engineering Technology and Applications (IES-ETA), 2017

[11] F.D. Murdianto, M. Z. Efendi, R. E. Setiawan and A. S.. L. Hermawan, “Comparison method of MPSO, FPA, and GWO algorithm in MPPT SEPIC converter under dynamic partial shading condition”, International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), 2017

[12] F.D. Murdianto, A. S.. L. Hermawan, A. R. Nansur and R. E. Setiawan, “Comparison method of flower pollination algorithm, modified particle swarm optimization and perturb & observe in MPPT coupled inductor SEPIC converter on DC microgrid isolated system”, International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), 2017

[13] A. R. Nansur, F. D. Murdianto, A. S. L. Hermawan,“ Improving the Performance of MPPT Coupled Inductor SEPIC Converter using Flower Pollination Algorithm (FPA) Under Partial Shading Condition” (IES-ETA) International Electronics Symposium on Engineering Technology and Applications, Surabaya, 2018.

[14] F. D. Murdianto, M. Z. Efendi, R. E. Setiawan, E. Purwanto, G. Prabowo,” Modeling and simulation of MPPT SEPIC–BOOST using modified Particle Swarm Optimization (MPSO-FLC) under partial shading condition” (iEECON) International Electrical Engineering Congress, Krabi, 2018.

[15] F. D. Murdianto, A. S. L. Hermawan, A. Jaya, A. R. Nansur, E. Purwanto, M. M. Rifadil,” Modeling and simulation of MPPT SEPIC–BUCK converter series using flower pollination algorithm (FPA–PI) controller in C microgrid isolated system” (iEECON) International Electrical Engineering Congress, Krabi, 2018.