Improving the Security of Power Grids using Fuzzy Logic and Hidden Markov Models

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Abstract

In the United States the use of smart grid technology allows for bi-directional flow of electricity so that users can generate and sell energy back to the electric power grid. This advancing technology presents increased security vulnerabilities and risks. Various levels of vulnerability could be identified that are related to their causes and effects on the normal functioning of the power grid. Moreover, the unsupervised machine learning approach could be integrated into an evolutionary algorithm such as a genetic algorithm, to evaluate how the control system could change its responses over time. In order to improve the security of the power grids, fuzzy logic controllers were applied to circuits with different types of power converters. Hidden Markov analysis also proved helpful in increasing security. The results were analyzed and applied to smart grid technology models.

Introduction

Fuzzy logic allows for complex systems to be modeled using simple logic rules [2]. Fuzzy logic was implemented using Simulink and Matlab to analyze how a circuit's output voltage would change based on the rules given to the fuzzy logic controller. The types of power converters that were analyzed were a low-dropout linear voltage regulator, a buck-boost converter, and a boost converter. A low-dropout linear voltage regulator is a power converter that can maintain a constant voltage when there is a small difference between the input and output voltages making them power efficient [1]. A buck-boost converter can take an input voltage and produce an output voltage that is either lower or higher than the input voltage [3]. A boost converter can produce an output voltage that is higher than the input voltage [4].

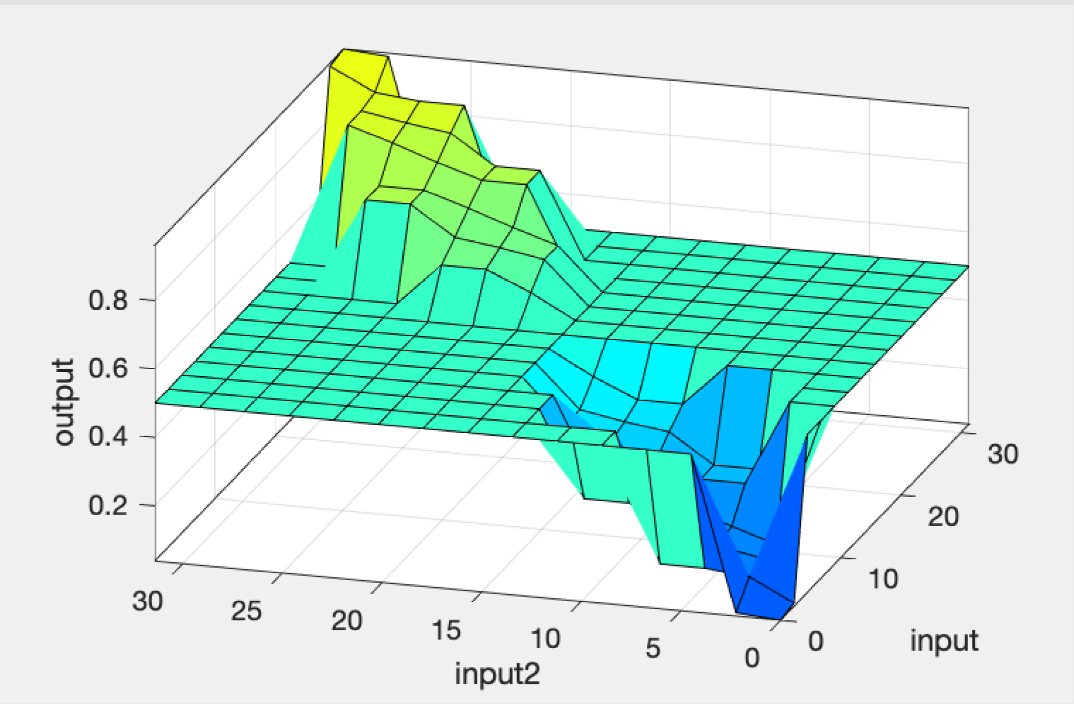

Figure 1. Buck-boost converter fuzzy logic rules surface

Methodology

Low-Dropout Linear Voltage Regulator:

The original circuit, designed by Dr. Venkatesh Kumar is a PI-Controller Based Voltage Regulation of Three Phase Inverter. A signal builder was added to input a sine wave. In the circuit the error, derivative of error, and integral of error were taken of the input and the line to line output voltage. These three values were inputs for the fuzzy logic controller and the three outputs controlled the PID controller. Figure 5 shows that both inputs to the circuit with and without fuzzy logic were the same. Figure 6 shows that the fuzzy logic controller lowered the output voltage of the circuit. This means that it had an impact on the values and it is effective in altering voltage.

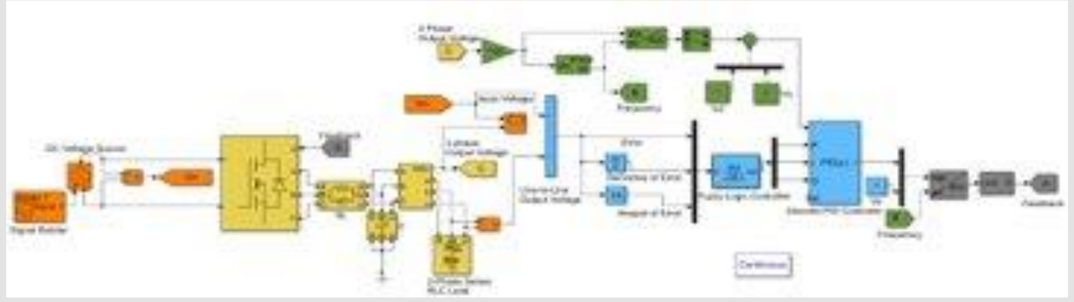

Figure 2. LDO circuit with fuzzy logic controller used for analysis

Overcurrent in Boost Converters:

The analysis of the boost converter included the testing of overcurrent within the circuit. Figure 7 shows the result of the current with voltage remaining constant. Testing the overcurrent showed where in the circuit the current was fluctuating with other parts of the circuit still intact such as voltage, resistance, amplitude, period, and capacitance.

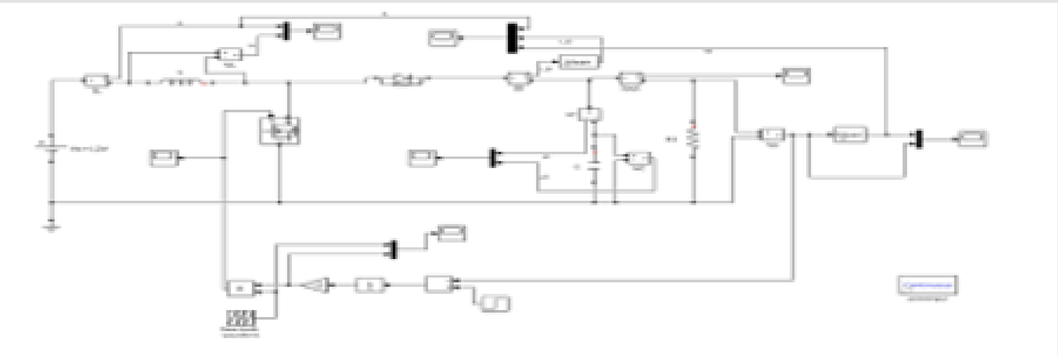

Figure 3. Boost converter circuit diagram

Buck-Boost Converter Modeled with Fuzzy Control and Hidden Markov Models:

Both Markov models and fuzzy control are useful in controlling a buck-boost converter, a power converter that both decreases and increases output voltage depending on the range of inputs. With the rules of fuzzy control, pictured in figure 1, we can assign certain outputs based on the input. For example, if the input to the fuzzy control is a high threshold, and we want the converter to function as a buck converter, we can make a rule to assign a lower value to the output. Using Markov models we can refine our output using a feedback loop. The purpose of Markov models are to characterize unknown states based on given outputs. When these states are characterized, we can manipulate them to refine our input and output [5]. Figure 4 shows the implementation of both models in a buck-boost converter.

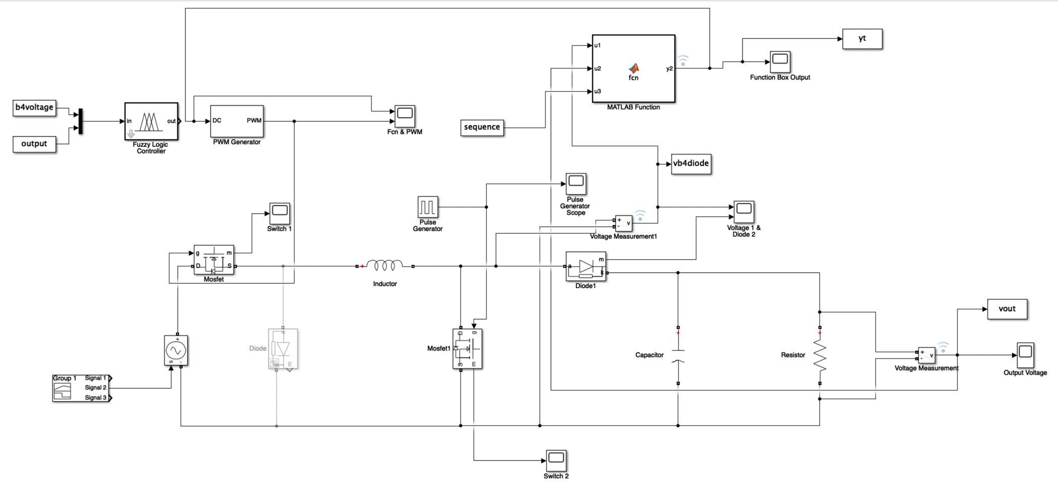

Figure 4. Buck-boost converter diagram implementing fuzzy logic and Markov feedback analysis

Results

Results from Low-Dropout Linear Voltage Regulator:

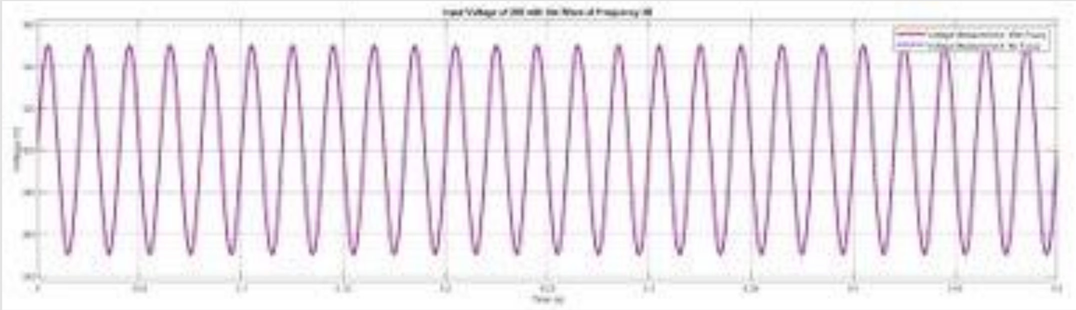

Figure 5. Input signal is 50 Hz Sine Wave
Input of 350 V

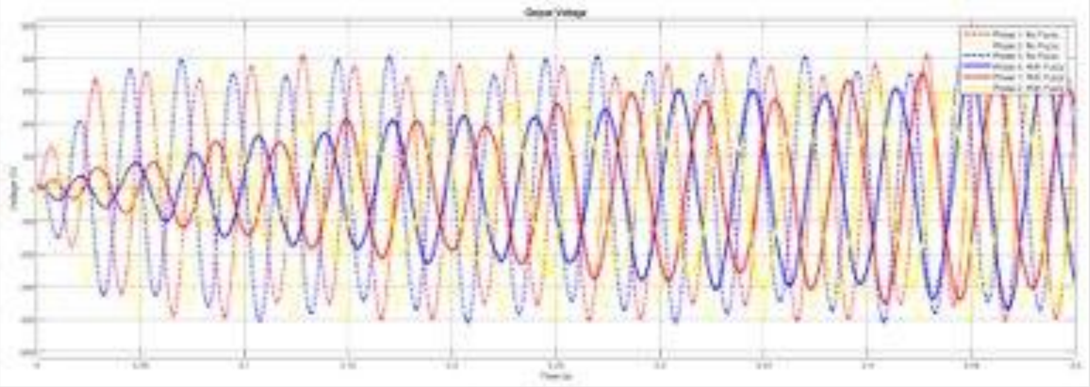

Figure 6. Output voltage of circuits with and without fuzzy logic

Results from Overcurrent in Boost Converters:

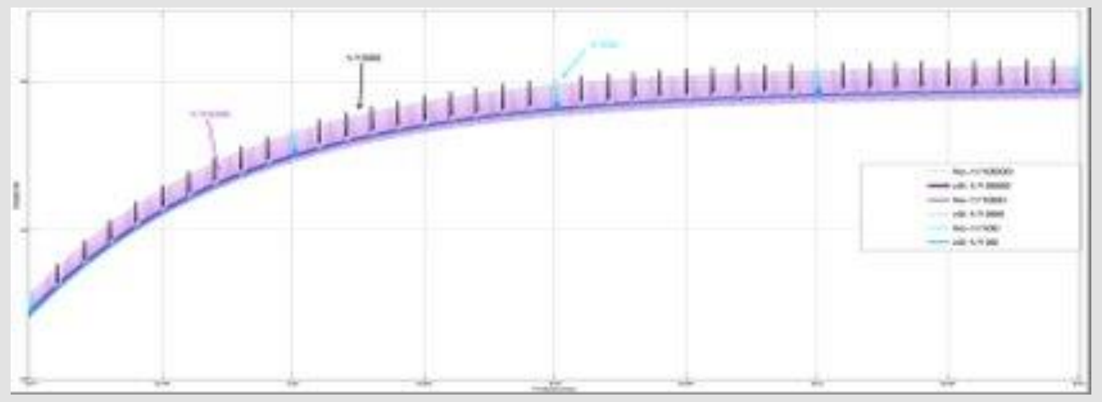

Figure 7. Output of overcurrent
Input of 50V

Results from Buck-Boost Converter Model:

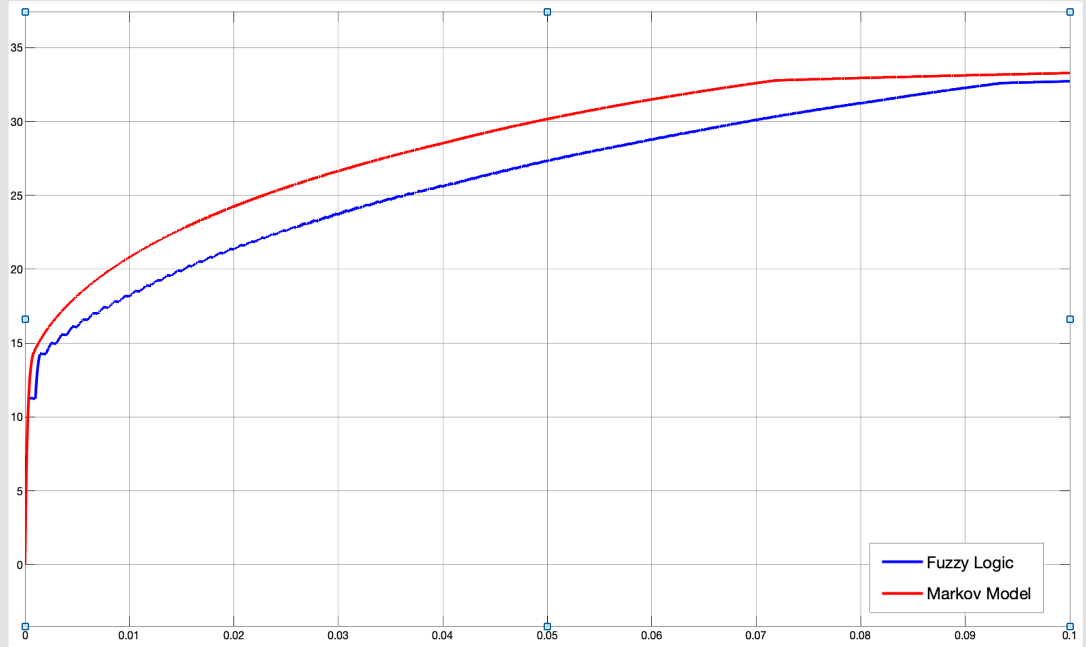

Figure 8. Output of buck-boost converter modeled using fuzzy and Markov control
Input of 20 V

Both the fuzzy logic controller and the Markov feedback controller proved effective in stabilizing the output voltage, as shown in figure 8. In this figure, the circuit model was in boost mode, meaning it increased the input voltage of 20 V to about 33 V. A more stable output means a more secure output, which means a more secure system.

Conclusion and Recommendations

Analyzing different types of power converters allowed us to see on a smaller scale how a smart grid functions. Adding a fuzzy logic controller to a low-drop out voltage regular changes the output voltage of a circuit. This means that depending on the rules that program the fuzzy logic controller, the output voltage can be regulated based on specific needs. It can also be used to correct any faults that occur because the fuzzy logic controller can be programmed to adjust for abnormalities in voltage. The analysis of boost converters shows how the different parts of the circuit and the sensors work together to create efficient circuit flow. The overcurrent and overvoltage sensors produced different results throughout, depending on the placement in the circuit. For the buck-boost model, fuzzy logic and Markov control stabilized and secured the system, making both control systems an attractive addition to smart power grid security.

Figure 9. Buck-boost converter

References

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