Data Mining-Based Performance Evaluation of DC-DC Power Converter Test Bench Using IoT Monitoring

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Abstract: ***This study presents the implementation of data mining techniques in a DC-DC power converter test bench integrated with IoT systems. By using decision trees, the efficiency of the converters under various duty cycles is evaluated in real time. The system utilizes ESP32 and Arduino MEGA boards alongside multiple voltage and current sensors to collect data, which is stored in the THINGSPEAK cloud. RAPIDMINER software is used for mining and visualization. The findings highlight the conditions under which converters perform optimally, making this a promising approach for future control system designs.***

Keywords: DC-DC converters, IoT monitoring, data mining, decision trees, efficiency analysis

1. Introduction

The main characteristic of DC-DC power converters is to maintain a regulated DC voltage through the operation of subprocesses within the DC-DC power converters. The converters analyzed in this project are:

Buck power converter: Its main characteristic is to maintain an output voltage lower than the input voltage, which is regulated against input voltage fluctuations.

Boost power converter: Its main characteristic is to maintain an output voltage higher than the input voltage, which is regulated against input voltage fluctuations [1].

The Internet of Things (IoT) is a system that encompasses a series of devices and technologies that are connected to the internet. This has affected everyday life. It should be noted that the Internet of Things has been evolving over time, with these new technologies being implemented in smart buildings and homes, smart transportation and cities, education, energy, and connectivity [2], [3].

This presents a benefit in the use of information technologies, where IoT systems collect data and store it in databases within clouds configured to utilize remote information [4], [5].

The use of this collected data provides operational efficiency as it not only performs real-time monitoring but also optimizes the operations of the system in which the IoT technology is implemented [6], [7].

The implementation of an IoT system within the test bench helps us monitor the electrical variables of DC-DC power converters. The result of the real-time monitoring will be stored in a database using the THINGSPEAK cloud. Monitoring is performed by configuring voltage and current sensors (input voltage "Vin", diode voltage "VD", and output voltage "Vo") and current sensors (input current "Iin", inductor current "IL", capacitor current "IC", and output current "Io").

Data mining involves the processes of discovering patterns, trends, and meaningful relationships in large sets of collected data.

Data mining is used to extract valuable information that can aid in decision-making, predict behavior, and identify hidden patterns. It involves several stages, including:

- Data collection: Gathers data from various sources, such as databases, files, logs, and more.
- Data cleaning: In most cases, the data contains errors, outliers, or redundant information, and this stage cleans unnecessary data.
- Data exploration: Explores the data to understand its structure and characteristics, including visualizations and descriptive statistics.
- Data preprocessing: This stage transforms the data according to the needs that arise.
- Model and algorithm selection: This stage is responsible for choosing the appropriate mining model or algorithm to achieve the analysis objective.
- Results Evaluation: The effectiveness of the model is evaluated using metrics relevant to the specific problem.
- Interpretation and Presentation of Results: The results of implementing data mining are interpreted and presented in a way that is understandable for decision-making.

The advantages of using data mining are significant in decision-making, identifying patterns and trends, and improving efficiency and productivity, among other benefits. This makes it a viable measure for use in information technology.

When implemented in the DC-DC power converter test bench, data mining will analyze the data stored in the database, applying data mining methodologies to analyze the efficiency of the DC-DC power converters through the use of decision trees. The efficiency obtained through the duty cycle

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used in the power converters will be determined by this data mining application using "RAPIDMINER" software, which assists in the correct implementation of the decision tree methodology.

The purpose of this research is to evaluate the dynamic performance of DC-DC power converters using decision tree-based data mining, facilitated by real-time monitoring through an IoT system.

This study contributes to the field by demonstrating how data-driven approaches can enhance performance analysis and control strategies for DC-DC converters in real-time applications.

2. Methodology

1) Test bench for data acquisition.

The DC-DC power converter test bench presents the configuration that it will have where the project is presented in six stages which are shown through Figure 1.

- Power Stage: The main operation is to supply electrical power to different points of the DC-DC converter test bench. It is divided into three power sources. The main source, powering the converters, consists of a variable transformer connected to an AC-DC rectifier. To clean the output wave, two components are used: a capacitor bank and an isolation diode.
- Process Stage: Test bench stage where the DC-DC power converters are located. The BUCK step-down converter and the BOOST step-up converter have been previously analyzed and configured for use in this test bench.
- Controller Stage: In this stage, we can visualize the controller circuits, which are connected to the DC-DC power converters, controlling them through a PWM signal. Each converter is configured for efficient use through a power driver.
- Output Stage: In this stage, it is possible to observe how the DC-DC power converters are composed of two output loads, each of which is configured for each of the DC-DC power converters. Resistive lights are used to visualize converter operation.
- IoT System Stage: This stage is responsible for monitoring the results of the electrical operation of the DC-DC power converters, uploading this data to a cloud and storing it in a database.
- Datamining Stage: This stage is responsible for analyzing the database to more efficiently analyze the data obtained from the DC-DC power converters.

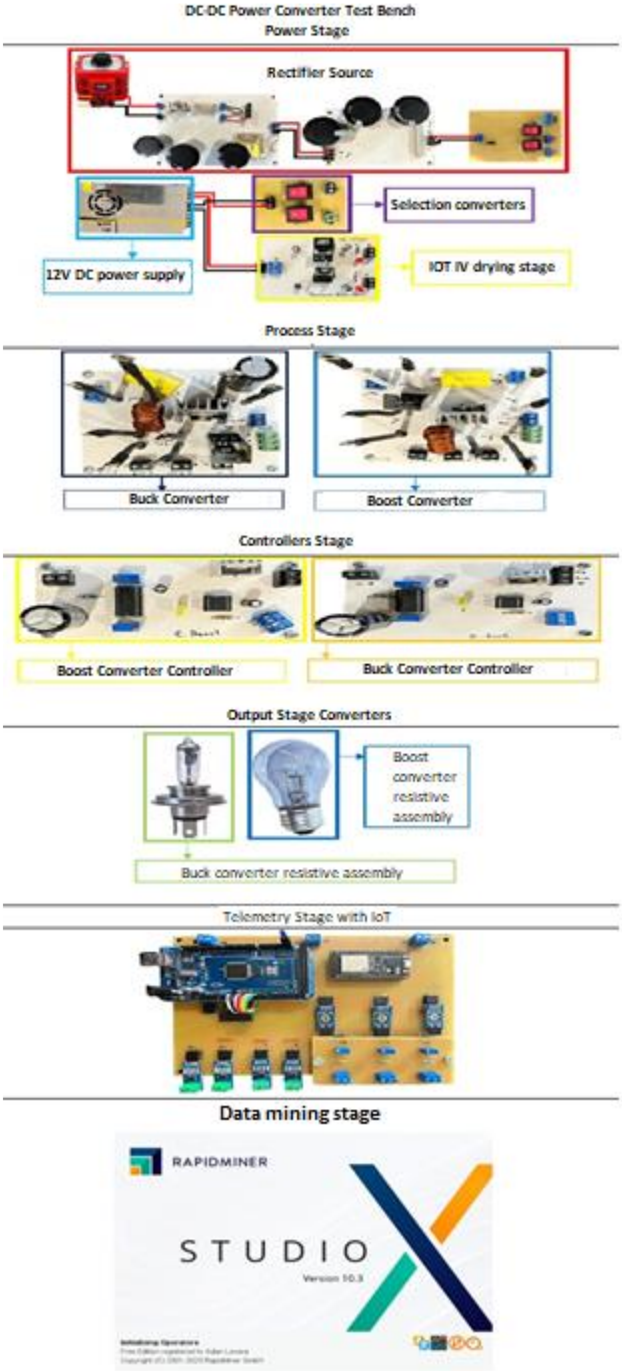

Figure 1: DC-DC converter test bench stages
Source: Own

2) Design of DC-DC Power Converters

The test bench design is carried out through four of the six stages included in this project. From these stages, the power stage is designed and built, whose main task is to power the DC-DC converter test bench.

The driver stage is specifically designed for the test bench, and its main function is to implement a pulse-width modulation (PWM) signal. This signal will function as a variable switch within the DC-DC power converters.

The signal implemented in the power converters will be reflected through the output stage, which represents the output load of the DC-DC power converters. To evaluate this output load, a configuration with resistive spotlights will be used, whose illumination will indicate the correct operation of the converters.

The DC-DC power converters implemented in the test bench are the BUCK buck converter and the BOOST boost converter. The design of these converters is carried out through mathematical calculations specific to each type.

1) IoT System Design

The IoT system analyzes the electrical performance of DC-DC power converters in real time, storing them in a cloud (THINSPEAK), which is compatible with Microsoft Excel. This system consists of two development boards: an ESP32 and an Arduino MEGA. These boards are connected through an I2C connection. The master board uploads the analyzed converter data to the cloud, while the slave board processes it via voltage and current sensors, the analyzed data from the converters to the cloud, is responsible for uploading the analyzed data from the converters to the cloud. The slave board, which is responsible for analyzing the data from the power converters through the use of voltage and current sensors, taking into account the electrical variables mentioned above in the introduction.

These sensors are responsible for analyzing the electrical performance of the converters. Therefore, for proper operation, they are configured according to the characteristics of the converters.

Current and voltage sensors are used. The main characteristic of the current sensors is a maximum tolerance of 20 amperes, while the maximum tolerance of the voltage sensors is a maximum of 25 volts.

To accommodate low-tolerance voltage sensors, a voltage divider circuit is implemented so that the sensors can be used within the test bench, since it has values that exceed the maximum tolerance.

The database design is primarily based on the electrical variables monitored by the DC-DC power converters. Therefore, this database also includes variables such as the time at which the converters are monitored.

DC-DC power converters are monitored based on the duty cycle applied to the converters. Therefore, three duty cycle percentages are implemented for each converter: 25%, 50%, and 75% for the Buck converter, and 25%, 50%, and 66% for the Boost converter.

The latter operates at 66% due to the converter's unique characteristics, which is that it cannot raise its voltage three times its rated value. Therefore, to avoid accidents, this approach is chosen, so the database generates a data sheet for each monitoring, with six data sheets stored.

2) Data Mining Implementation

The data mining system is based on the analysis of the database, which is performed through IoT system monitoring.

The analysis will allow us to observe the efficiency of DC-DC power converters when used at different duty cycles. By implementing data mining methodologies such as decision trees, we can observe which duty cycle assigned to the power converters provides the greatest efficiency and the time it takes to perform this task. RAPIDMINER software is used for this implementation.

RAPIDMINER enables effective implementation of decision trees using configurable operators, which use these operators to configure the necessary settings to observe the results.

3. Results and discussion

The result of the physical operation of the power converters shows how they operate by switching on the output load based on the resistive lamps. This load is affected according to the duty cycle implemented in the DC-DC power converters. The duty cycle is shown in a BUCK step-down converter with percentages of 25%, 50%, and 75%, and the physical operation of the BOOST step-up converter with percentages of 25%, 50%, and 66%, as can be seen in Figure 2.

Based on this operation, the IoT system designed and built is implemented to create the database.

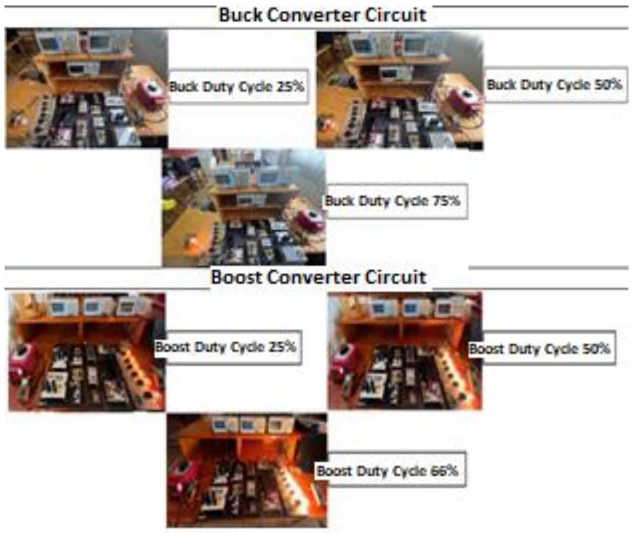

Figure 2: Physical operation of DC-DC power converters. Source: Own.

The intensity increase of the resistive sources is shown in each of the power converter's duty cycles.

The behavior of the electrical variables of the converters implemented in the test bench is monitored in real time by seven sensors: three voltage sensors and four current sensors.

These sensors operate for two minutes, taking a total of 665 samples. 95 samples are recorded for each sensor. From these samples, the database created by the THINSPEAK cloud is compatible with Microsoft Excel, and stores data on the behavior of the electrical variables of the DC-DC power converters (see Figure 3).

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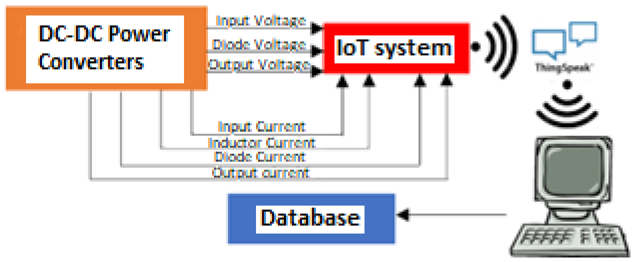

Figure 3: IoT system operation. Source: Own.

The orange box shows the circuitry for physical operation. It also shows how data is sent to the IoT system, comprised of the two ESP32 and Arduino MEGA development boards. This is done through the seven sensors included in these development boards. The information collected by the sensors is sent to a database via the THINGSPEAK cloud. Using the THINGSPEAK cloud allows us to create the database through compatibility with Microsoft Excel.

Figure 4 shows how the IoT system works through a flowchart.

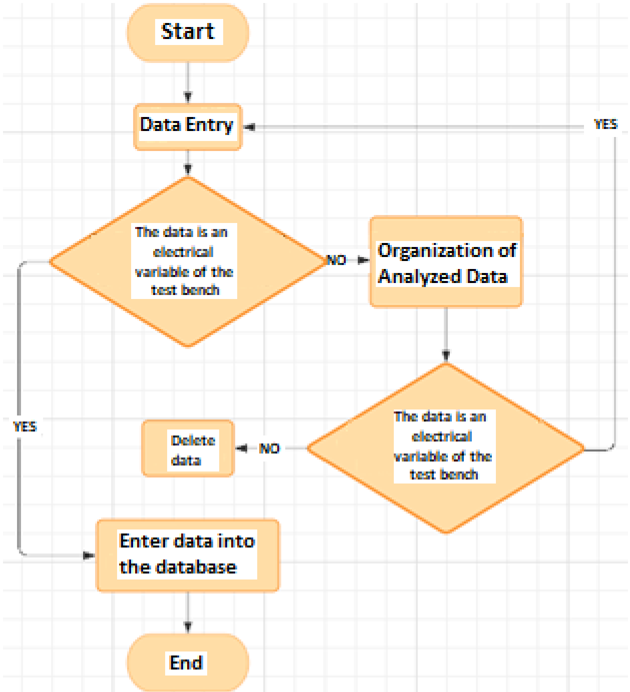

Figure 4: IoT system operation. Source: Own.

Its function is:
1) **Start:** The process begins with data entry.
2) **Data entry:** Data is received for processing.
3) **Electrical variable verification**: It is verified whether the data corresponds to an electrical variable from the test bench.
   a) Yes: The data is reorganized, grouping the analyzed data.
   b) No: It is verified whether it is data from the test bench.
4) **Deletion or entry into the database:** If the data is not from the test bench, it is deleted; if the data is from the test bench, it is entered into the database.
5) **End:** The process concludes.

Therefore, by using the two DC-DC power converters, the function is the same in the operation of the implemented IoT system. This database is also the step toward implementing the data mining methodology, which will be carried out using the RAPIDMINER software.

The application of data mining in the database created by the IoT system stage is shown in Figure 5.

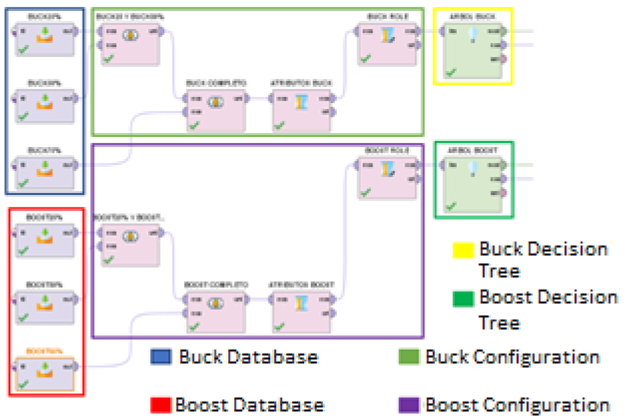

Figure 5. Data mining application
Source: Own

The application uses RAPIDMINER software, whose operation is divided into colored blocks. The blue and red blocks represent the databases containing the data previously analyzed by the sensors in the IoT system. These blocks are transferred to the light green and purple blocks. In this section, the most important data attributes are configured to visualize the data, taking into account the time the data was collected and its efficiency. Finally, the decision tree is configured using the flag green and yellow blocks.

The data mining application is implemented through the steps followed within the decision tree methodology.

A collection of data is obtained from the database of the operation of electrical variables provided by the IoT system. Within this database, the data is cleaned, searching for possible data not included in the data for the analysis of the efficiency of DC-DC power converters.

Data exploration allows us to identify the information needed to analyze the efficiency of DC-DC power converters. Using RAPIDMINER software, this is shown in Figure 6.

With the efficiency visualized by the DC-DC power converters, we select the decision tree to use. This will reveal the time at which the data showed the best efficiency, as shown in Figure 7.

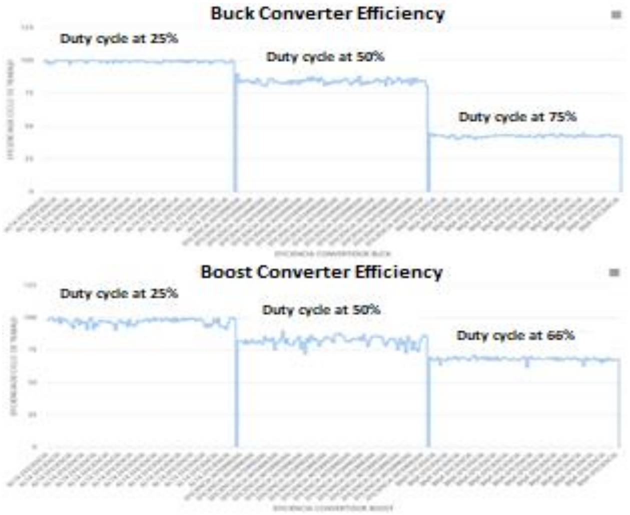

Figure 6. Visualization of DC-DC power converter efficiencies. Source: Own

Efficiency is divided into four categories: high, intermediate, low, and zero, based on the behavior of the converters' electrical variables. Furthermore, it is noted how efficiency decreases as the duty cycle implemented in the converters changes.

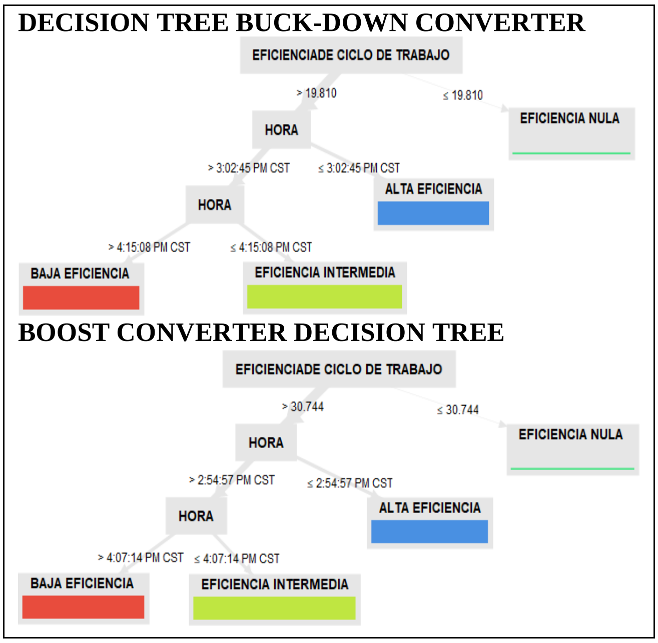

Figure 7. Buck converter decision tree and BOOST converter decision tree. Source: Own.

The decision tree for the BUCK converter is shown above, with the following interpretation:

1) If the duty cycle efficiency is greater than 19.810:
- If the time is after 3:02:45 PM CST and also after 4:15:08 PM CST, the classification is "LOW EFFICIENCY."
- If the time is before or equal to 4:15:08 PM CST, the classification is "INTERMEDIATE EFFICIENCY."
- If the time is before or equal to 3:02:45 PM CST, the classification is "HIGH EFFICIENCY."

2) If the duty cycle efficiency is less than or equal to 19.810:
- The classification is "ZERO EFFICIENCY."

Below is the BOOST converter decision tree, which is interpreted as follows:

3) If the duty cycle efficiency is greater than 19.810:
- If the time is after 3:02:45 PM CST and also after 4:15:08 PM CST, the classification is "LOW EFFICIENCY."
- If the time is before or equal to 4:15:08 PM CST, the classification is "INTERMEDIATE EFFICIENCY."
- If the time is before or equal to 3:02:45 PM CST, the classification is "HIGH EFFICIENCY."

4) If the duty cycle efficiency is less than or equal to 19.810:
- The classification is "ZERO EFFICIENCY."

4. Conclusions

The initial objective of the project was to implement data mining using decision tree methodologies in a DC-DC converter test bench monitored in real time through an IoT system. By implementing this data mining, it was possible to observe how the efficiency at the time of monitoring was analyzed using the data and its time stamp.

The data mining implementation model is highly efficient for this project. Thanks to this implementation, we were able to observe high efficiency times in the analyzed data and thus be able to conduct further tests in the future, taking into account the efficiencies that can be obtained, thus better evaluating the performance of DC-DC power converters through the implementation of a control system.

This framework sets the stage for broader deployment of intelligent monitoring systems in power electronics applications.

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