DC-DC Converter Design Using Big Data Methodology

by

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ABSTRACT

With the rapid advancement in the technologies related to renewable energies such as solar, wind, fuel cell, and many more, there is a definite need for new power converting methods involving data-driven methodology. Having adequate information is crucial for any innovative ideas to fructify; accordingly, moving away from traditional methodologies is the most practical way of giving birth to new ideas. While working on a DC-DC buck converter, the input voltages considered for running the simulations are varied for research purposes. The critical aspect of the new data-driven methodology is to propose a machine learning algorithm. In this design, solving for inductor value and power switching losses, the parameters can be achieved while keeping the input and output ratio close to the value as necessary. Thus, implementing machine learning algorithms with the traditional design of a non-isolated buck converter determines the optimal outcome for the inductor value and power loss, which is achieved by assimilating a DC-DC converter and data-driven methodology.

The present thesis investigates the different outcomes from machine learning algorithms in comparison with the dynamic equations. Specifically, the DC-DC buck converter will be focused on the thesis. In order to determine the most effective way of keeping the system in a steady-state, different circuit buck converter with different parameters have been performed.

At present, artificial intelligence plays a vital role in power system control and theory. Consequently, in this thesis, the approximation error estimation has been analyzed in a DC-DC buck converter model, with specific consideration of machine learning algorithms tools that can help detect and calculate the difference in terms of error. These tools, called models, are used to analyze the collected data. In the present thesis, a focus on such models as K-nearest neighbors (K-NN), specifically the Weighted-nearest neighbor (WKNN), is utilized for machine learning algorithm

purposes. The machine learning concept introduced in the present thesis lays down the foundation for future research in this area so that to enable further research on efficient ways to improve power electronic devices with reduced power switching losses and optimal inductor values.

ACKNOWLEDGEMENTS

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NOMENCLATURE

KNN	K-nearest neighbor.
$WKNN$	Weighted K-nearest neighbor.
SSM	small signal modeling.
$Buck$	DC-DC buck converter.
$Boost$	DC-DC boost converter.
CUK	DC-DC chook converter.
$Fly-Back$	DC-DC fly-back converter.
$Forward$	DC-DC forward converter.
$Push-pull$	DC-DC push-pull converter.
PCA	Principle component analysis.

1. INTRODUCTION

1.1 DC-DC Converter Overview

1.1.1 What Is DC-DC Converter?

DC-DC converters at a module level can convert each module from a current source into a power source, thus allowing each module to deliver its maximum power to the load despite any mismatches in the system. There are several topologies and algorithms available to achieve this. For the sake of this paper, the most common topologies available will be analyzed to understand each advantage and disadvantage and how it applies to the system. The three most common topologies are buck (step down), boost (step-up), and buck-boost (step down/step-up). In this thesis, the DC-DC buck, boost, and buck-boost converters will be utilized and tested. DC-DC converters are high-frequency power conversion circuits that use high-frequency switching and inductors [1], transformers [2], and capacitors to smooth out switching noise into regulated DC voltages [3]. Closed feedback loops maintain constant voltage output even when changing input voltages and output currents [4]. At 90% efficiency, they are generally much more efficient and smaller than linear regulators [5]. Their disadvantages are noise and complexity.

1.1.2 DC-DC Converter Applications

1. DC-DC converters are developed to maximize the energy harvest for the photovoltaic system, and wind turbines are called power optimizers [6].

2. DC-DC converters applications also include in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from

batteries primarily [7].

3. DC-DC converters optimize the speed controllers for DC motors [8].

4. One of the main application of the DC-DC converter is to step-up, step-down, or both are stepping up an down in high frequency switching devices across distribution grids [9].

5. Battery operated vehicles require DC-DC converter in order to operate without losses for the current and voltage flow [10].

1.1.3 DC-DC Converter Advantages and Disadvantages

1.1.3.1 Advantages

1. Skin effect does not exist in DC. So the size of the conductor in DC transmission is significantly reduced [11].

2. In the case of underground cable, DC transmission is preferred as it requires no charging current and any reactive power [12].

3. Step-up and step-down of voltage is possible with the minimum component count. Other conventional converter require almost double the components [13].

4. Less costly compared to most of the other converters if compromised performance is desired for a low cost [14].

1.1.3.2 Disadvantages

1. DC-DC converter Input current and charging current of the output capacitor is discontinuous resulting in larger filter size [15].

2. The output is inverted, which introduces complexity in the sensing and feedback circuit. The sensed voltage is negative, so an inverting operation amplifier is required for feedback and closed-loop control [16].

3. DC-DC converter is difficult to control. The transfer function of the converter contains a right half plane zero which introduces the control complexity [17].

4. There is no isolation from input to output which is critical in some applications like the power supply of gate driver of semiconductors [18].

1.2   DC-DC Converter Topologies

Some Topologies of DC-DC converters involve switching mode power supplies (SMPS), battery charging, and power supply for main drive motor in electric vehicles. The nature of topology used depends on both the power rating of the converter and input to output voltage conversion ratio. When the output voltage in the converter is less than the input voltage, buck converter topology can be used. When a large voltage conversion ratio of five is required, then boost converters with suitable duty ratio will be the best selection. Nevertheless, when the voltage conversion ratio situated in the range of ten, the conventional method is to use a high-frequency transformer with a proper turns ratio to provide the necessary voltage gain for the converter. Such topologies are termed as isolated topologies as the input and output are electrically isolated because of the use of the transformer. Switched-mode power supplies (SMPS) can be classified according to the circuit topology. The most crucial distinction is between isolated converters and non-isolated converters. Isolation defines the electrical detachment between the input and output of a DC-DC converter.

1.2.1   Isolated DC-DC Converter

An isolated DC-DC converter practices a transformer to eliminate the DC-link between its input and output. In contrast, a non-isolated DC-DC converter has a dc-link between its input and output. The most common isolated DC-DC converters are forward, push-pull (half-bridge), and full-bridge converters, whereas, for non-isolated converters such as Buck, Boost, and Buck-Boost converters. As provided in Fig 1.1, the block diagram for an isolated DC-DC converter is shown with the transformer between the DC/AC inverter and AC/DC rectifier blocks. All isolated methodologies
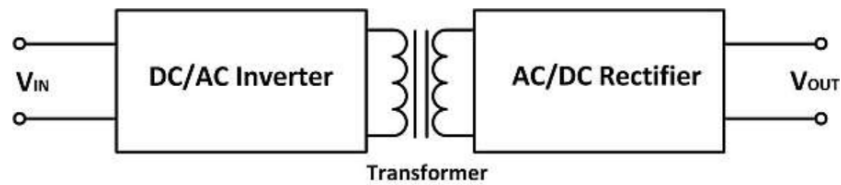
Fig. 1.1. Block Diagram for an Isolated DC-DC Converter

include a transformer, and thus can produce an output of higher or lower voltage than the input by adjusting the turn ratio. For some methods, multiple windings can be placed on the transformer to produce multiple output voltages. Some converters use the transformer for energy storage, while others use a separate inductor. For safety considerations, there must be isolation between an electronic system's AC input and DC output. Isolation requirements cover all systems operating from the AC power line, which can include an isolated front-end AC-DC power supply followed by an isolated DC-DC converter, followed by a non-isolated point-of-load converter. Typical isolation voltages for AC-DC and DC-DC power supplies run from 1500V to 4000V, depending on the application, starting with Fig. 1.2, isolated DC-DC forward converter, it employs a transformer to control the output voltage in terms of increasing or decreasing the output voltage. A typical forward converter consists of a

transformer, which is either a step-up or step-down with a single or multiple secondary windings. The type of transformer also utilized depends on the usable input voltage and the desired output voltage. It additionally provides separation of the load from the input voltage. Moreover, it comprises a transistor such as a MOSFET, which acts as the switching device. Electrical energy is passed directly through the transformer during the transistor's conduction phase. The input voltage determines the output voltage, the transformer turns ratio, and the duty cycle. In the circuit diagram, Vs is the DC input voltage source, S is the controlled switch, D is the diode, L is the filter inductance, C is the filter capacitance, Vo is the output voltage, N are the turn ratios in the forward DC-DC converter.
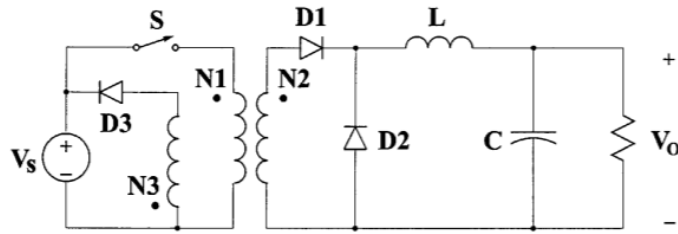
Fig. 1.2. Forward Converter Circuit Block Diagram.

Another isolated DC-DC converter is shown in Fig. 1.3, which is the DC-DC Push-Pull converter. The Push-Pull converter is one of the oldest power switching topologies in isolated DC-DC converters, and it can give multiple outputs with a single input. Push-Pull Converters are defining characteristic pairs of transistors in a symmetrical Push-Pull circuit design, and the transistors systematically reverse the current in the transformers by switching on and off units in the converter. Hence, the current is drawn from the line during both halves of the switching time. Output voltages can be higher or lower than input voltages when changing the winding's turns ratio of the transformer depending on the application of the DC-DC converter. In the circuit diagram, there are two switched $S1$ and $S2$, two diodes $D1$ and $D2$.

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Filter inductance L and filter capacitance C, input voltage Vs and output voltage $V0$. Lastly, N which is the turn ration because of the existence of the transformer and it's a switching DC-DC converter device.
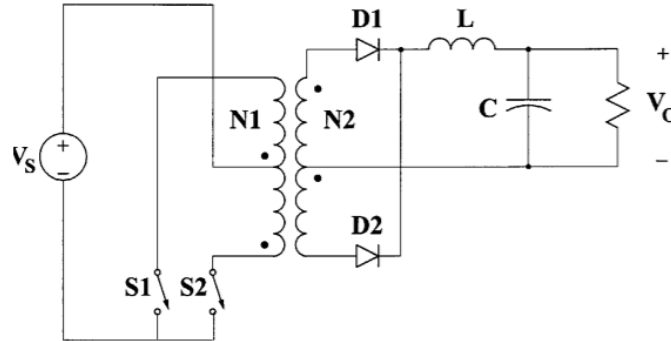
Fig. 1.3. Push-Pull Converter Circuit Block Diagram.

Lastly, for the isolated DC-DC converters, the full-bridge DC-DC converter is presented in Fig. 1.4. A DC-DC Full-Bridge converter is commonly used that offers isolation and also to stepping up or down the input voltage source of the converter. Other vital functions may include reversing the polarity and providing multiple output voltages simultaneously of the converter. The basic circuit design for the DC-DC Full-Bridge converter consists of four active switching devices, such as MOSFETs, IGBTs, Bipolar transistors or thyristors, and their associated circuits. MOSFETs are widely used for the high power bridge converters due to their simple and low power gate drive circuits as compared to the bipolar transistors. The DC input is inverted in the Full-Bridge to a higher frequency AC by the four bridge-connected switching devices. The resulting AC connection is applied to the primary winding of the transformer, which steps the DC-DC converter either up or down as required. On the secondary side winding, it is rectified back to DC connected to the DC-DC converter. From the circuit block diagram, there are four switched from $S1$ to $S4$, DC input voltage source denote as Vs, two diodes and they are $D1$ and $D2$, inductore filter L, capacitor filter

C, load resistor R and output voltage of the load Vo.
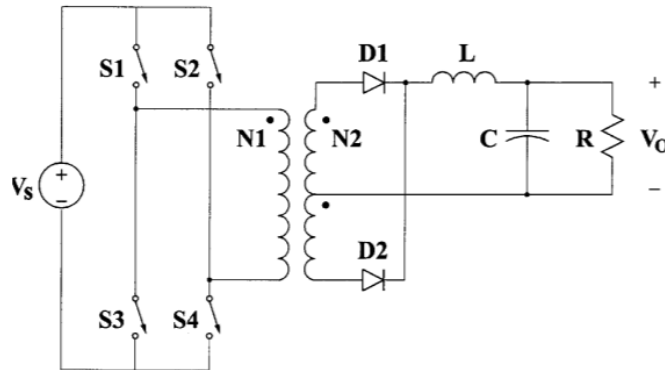
Fig. 1.4. Full-Bridge Converter Circuit Block Diagram.

1.2.2 Non-Isolated DC-DC Converter

As mentioned before, typical non-isolated DC-DC converters are buck (step-down), Boost (step-up), and buck/boost (step-up and step-down) converters. Moreover, for the typically isolated converters such as forward, push-pull (half-bridge), and full-bridge DC-DC converters. For a typical non-isolated DC-DC converter, there is a DC link between the input and output parameters. Meaningly it has a single circuit that has the current flow between the input and the output with a common grounding so that the current can flow, which means there is no barrier such as a transformer between its input and output electrical components in the DC-DC converter device. Below in the figures, are the schematics of each converter for the non-isolated DC-DC converters to see an overview of how the circuit block diagram is. Starting from non-isolated DC-DC converters such as DC-DC Buck converter shown in Fig. 1.5 below. A Buck converter or step down converter is a non-isolated type DC-DC converter that steps down the voltage while stepping up the current, where the DC output voltage is lower than the DC input voltage. The popularity of switched-mode regulators such as DC-DC Buck converter is due to their compact size and efficiency. DC-DC Buck
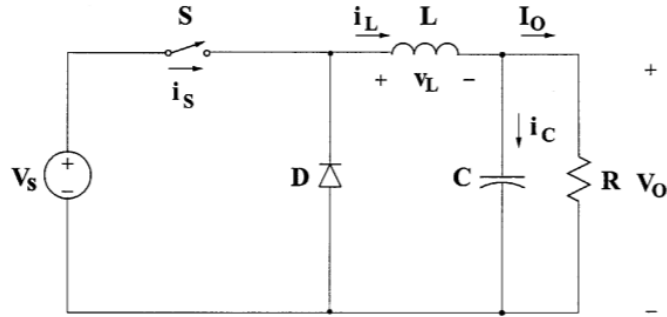
Fig. 1.5. Buck Converter Block Diagram.

converter typically contains at least two semiconductors in the converter, a diode, and a transistor. Also, it contains an energy storage component such as a capacitor or an inductor in the DC-DC Buck converter device. One of the basic operations in the DC-DC Buck converter is that the current is in the conductor is controlled by a switch since it is a switched-mode power supply (SMPS) device. From the block diagram in Fig. 1.5, Vs is the DC input voltage of the converter, S is the switching device that turns on-state and off-state between each switching cycle, D is the diode where it controls the direction of the current in the converter, L is the filter inductor component, C is the filter capacitor component, R is the load resistance component of the Buck converter and Vo is the DC output voltage load of the Buck converter.

Another non-isolated DC-DC converter, which is a DC-DC Boost (step-up) converter, is illustrated in Fig. 1.6. DC-DC Boost converter from the name of the Boost converter, which requires it boosts the output voltage while stepping down the current. In other means, the output voltage is higher than the input voltage. It is considered one of the classes of switched-mode power supplies (SMPS), which contains two semi-conductors such as a diode and a MOSFET or any other types of transistors. And it contains energy storage elements such as the capacitor and an inductor. The boost converter can be available in terms of any power DC source such as batteries, DC generators, solar panels, and fuel cells. As presented in Fig 1.6, the

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DC input voltage source is Vs, the inductor filter is denoted with L, the switching device is S, a diode D, filter capacitance C, load resistance R and output voltage of the load Vo.
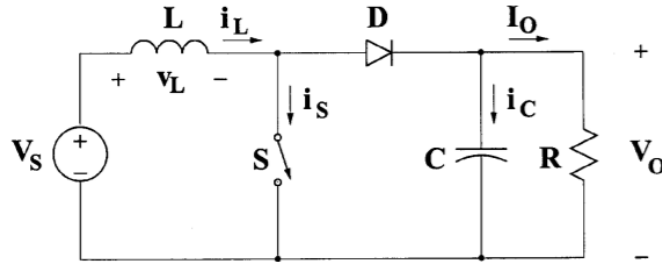
Fig. 1.6. Boost Converter Block Diagram.

Lastly, the non-isolated DC-DC Buck/Boost converter circuit diagram is shown in Fig. 1.7. The DC-DC Buck/Boost converter has an output voltage magnitude that is either greater or lesser than the input DC source voltage. The output voltage magnitude depends on the duty cycle. The DC-DC Buck/Boost converter is also known as the step-up and step down transformer. The DC-DC Buck/Boost converter consists of filter components such as capacitance and inductance, a switching device, a MOSFET, or any other switch transistor devices, a resistor to resist the output load. The DC input voltage link is Vs, the controlled switch S, filter inductor L, filter capacitance C, load resistance R and output voltage denoted as Vo.
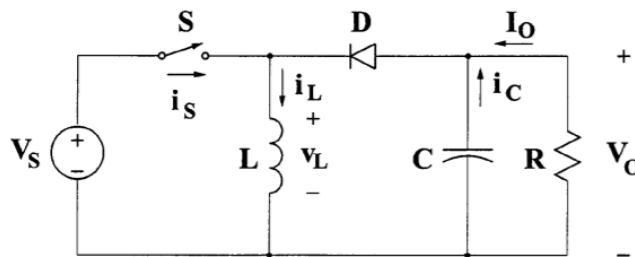
Fig. 1.7. Buck/Boost Converter Block Diagram.

All the circuits mentioned are the non-isolated types of DC-DC converters with their circuit block diagrams.

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1.3 Motivation

The motivation of the thesis is to merge big data methodology to power electronics devices. Machine learning algorithms have played a vital role in understanding and training the data. It applies the use of artificial intelligence that offers systems the capacity and the capability to advance without being overly programmed. Machine learning shifts the focus on the advancement of computer programs that can collect an entire set of data and apply these data in a self-reliant way. Hence, the merging of all sciences, which are power systems engineering, power electronics engineering, and machine learning, is the primary motivation to create such a new methodology in the research, as shown in Fig. 1.8.
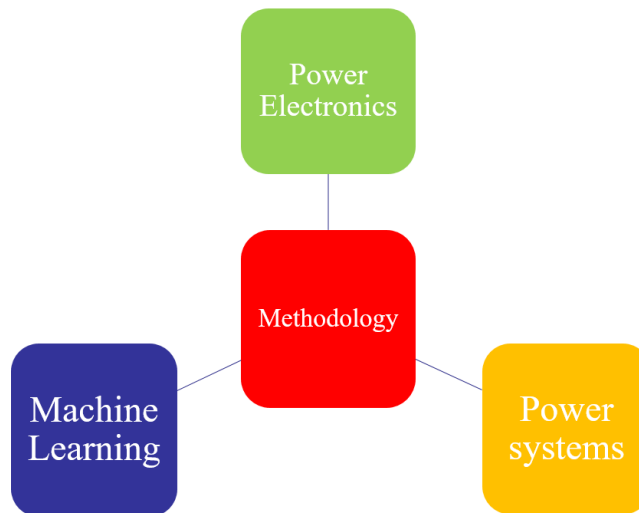
Fig. 1.8. Motivation Block Diagram.

1.4 Organization of Thesis

The remainder of the present thesis is structured as follows. Chapter 2 illustrates the operational concepts between the isolated DC-DC converters such as buck converter, boost converter, and buck/boost converter. Furthermore, the main design

concepts and circuit analysis for each DC-DC non-isolated converter are further discussed. Chapter 3 describes the leading software presented for the research and the research design of the experiment performed in the present thesis. To this end, we start by introducing the simulation software used for studying the DC-DC buck converter. The software set-up is followed by a detailed presentation of the experimental design of the power electronic device system and the assumptions needed. Chapter 4 provides an additional part of the simulation done, such as small-signal modeling (SSM) with the comparison of K-Nearest Neighbor. Furthermore, it focuses on the concept of artificial intelligence and machine learning. We start by interjecting machine learning and discuss its functionality. Also, propose a machine-learning algorithm to solve the DC-DC buck converter design model. Finally, we summarize the results, evaluate them in terms of the approximation error, inductor value, switching power losses, and discuss other findings to highlight the importance of machine learning in the power electronic devices.

2. DC-DC CONVERTER OPERATION

2.1   Introduction

In the past chapter, isolated and non-isolated DC-DC converters were introduced, and all the components needed for the DC-DC converters to operate were defined. In this chapter, the focus will be shifted to understanding the operation of the non-isolated DC-DC converters such as Buck converter, Boost converter, and Buck/Boost converters. Since voltage changes with minimum loss in the non-isolated DC-DC converters, power switching is needed [19]. The switching is continuous between the on-state and the off-state for all the non-isolated DC-DC converters. Hence, the operational switching between the on-state and off-state will be discussed for non-isolated Buck, Boost, and Buck/Boost converters.

2.1.1   Buck Converter

A buck converter (step-down converter) is considered one of the switched-mode power supplies devices that decreases the voltage as an output [20]. The buck converter contains passive filter components such as a filter inductor and a filter capacitor, also contained two semiconductor switches such as a diode and switched gate such as MOSFET. In addition, a load resistor that is connected to the output side of the DC-DC buck converter. Since the buck converter contain a power switching mechanism, that means it operates under on-state and off-state. As a recall from the previous explanations of the buck converter, the switches $S1$ and $S2$ can be replaced with a switching device and a diode as shown in Fig. 2.1. During the on-state, the controller switch turns on and connects the input voltage V_{in} to positive components which are L and C filters. Driving the inductor's current.
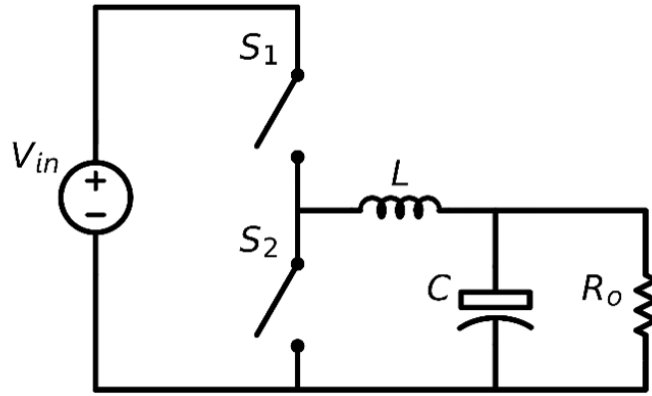
Fig. 2.1. Buck Converter Circuit.

This is maintained during a curtain amount of time called the on-time which is also denotes as T_{on}, hence the control signal is changed to a low-state as shown in the signal waveform. Furthermore, in the following Fig. 2.3, it shows the circuit

Fig. 2.2. On-state Signal.

schematic of the buck converter during the on-state.

For the off-state signal, after which the control signal has changed, it will cost the controllable switch to turn off, and the current is driving through the diode throughout the circuit [21]. As illustrated in Fig. 2.3, this signal is maintained during a period of time, which is called T_{off}, and it is shown as a signal from the waveform in Fig. 2.5. The red box indicates the control signal, and it shows how the signal behavior according to its state during the off-state.

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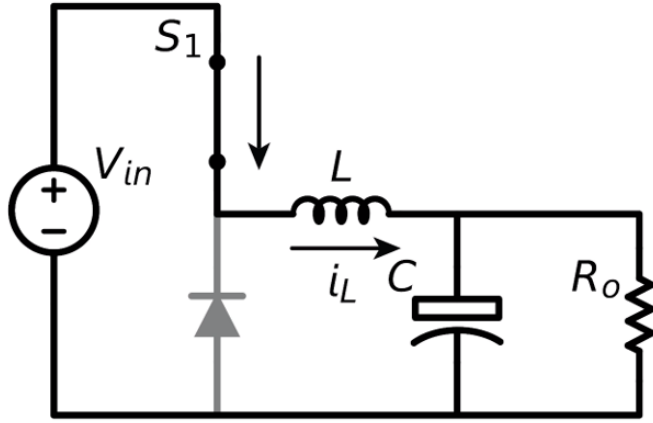
Fig. 2.3. Buck Converter During On-state Signal.
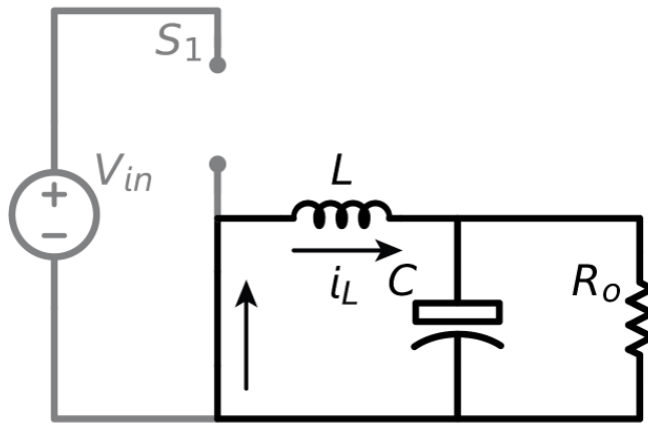
Fig. 2.4. Buck Converter During Off-state Signal.

2.1.2 Boost Converter

A boost converter (step-up converter) is a power converter with an output DC voltage more significant than its input DC voltage as illustrated in Fig. 2.6. It is a class of switching mode power supply (SMPS) containing at least two semiconductors switches (a diode and a transistor) and at least one energy storage element [22]. Filters made of capacitors (sometimes in combination with inductors) are typically added to the output of the converter to reduce output voltage ripple [23]. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since
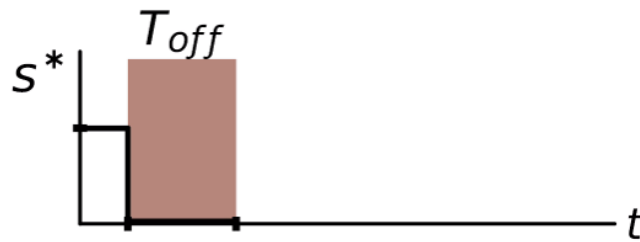
Fig. 2.5. Off-state Signal.

power $(P = VI)$ must be conserved, the output current is lower than the source current. The boost converter has the same components as the buck converter, but this converter produces an output voltage higher than the source. Boost converters start their voltage conversion with a current flowing through the inductor (switch is closed). Then they close the switch leaving the current no other path to go than through a diode (functions as a one-way valve) The current then wants to slow-fast, and the only way it can do this is by increasing its voltage. At the end that connects to the diode and switch. If the voltage is high enough, it opens the diode, and one through the diode, the current can't flow back. This is the fundamental concept of a boost converter [24].
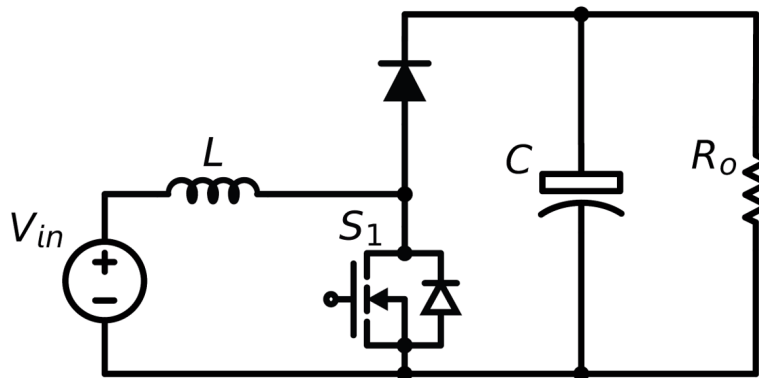
Fig. 2.6. Boost Converter.

Analysis of the boost converter begins by making these assumptions:

1. The circuit is operating in a steady-state.

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2. The inductor current is continuous (always positive).

3. The capacitor is large, and the output voltage is held constant at voltage V_o. This restriction will be relaxed later to show the effects of finite capacitance.

4. The switching period is T, the switch is closed for time DT and open for time $(1 - D)T$.

5. The components are ideal.

The fundamental principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged, it acts as a load and absorbs energy (somewhat like a resistor); when being discharged, it acts as an energy source (somewhat like a battery) [25]. The voltage it produces during the discharge phase is related to the rate of change of current, and not to the first charging voltage, thus allowing different input and output voltages.

The basic operation principle of a Boost converter consists of 2 distinct states (Figures 2.7 and 2.8):

1. In the On-state, the switch $S1$ (see Fig 2.8) is closed, increasing the inductor current.

2. In the Off-state, the switch is open (see Fig 2.7), and the only path offered to inductor current is through the diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor.

3. The input current is the same as the inductor current, so it is not discontinuous as in the buck circuit, and the requirements on the input filter are simpler modified compared to a buck converter.
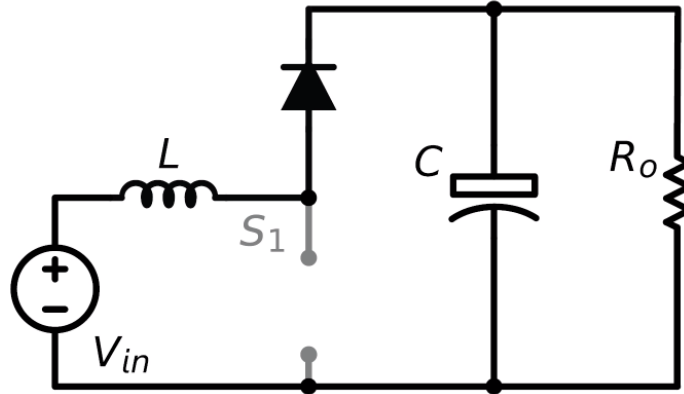
Fig. 2.7. Boost Converter During Off-signal.
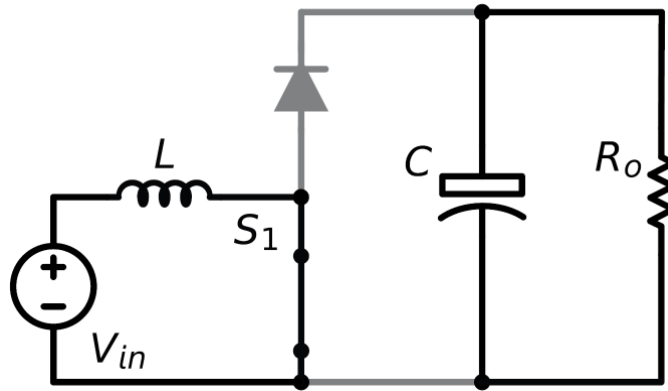
Fig. 2.8. Boost Converter During On-signal.

2.1.3 Buck/Boost Converter

Another basic switched-mode converter is the buck-boost converter. The output of the buck-boost converter can be either higher or lower than the input voltage. The assumption made about the operation of this circuit is the same as it was for the previous converter circuits. As provided in the following schematic, in Fig 2.9, it shows the buck/boost converter circuit diagram.

The two operating states of a buck–boost converter are Fig 2.10 and 2.11 respectively. When the switch is turned-on, the input voltage source supplies current to the inductor, and the capacitor supplies current to the resistor (output load).When the switch is opened, the inductor supplies current to the load via the diode D. The

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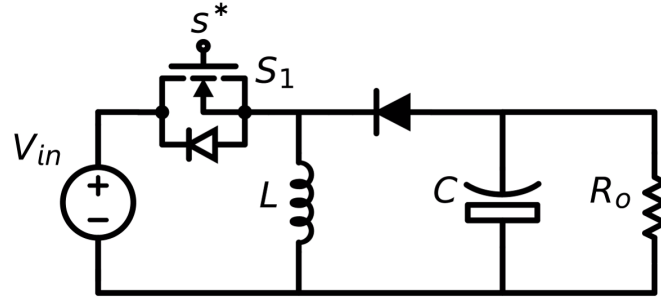
Fig. 2.9. Buck/Boost Converter
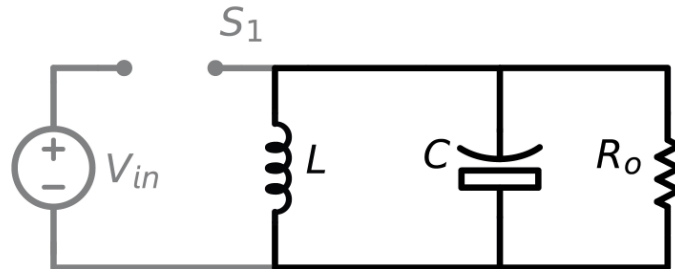
Fig. 2.10. Buck/Boost converter Off-signal Circuit

basic principle of the buck–boost converter is fairly simple:

1. while in the On-state, the input voltage source is directly connected to the inductor L. This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load.

2. while in the Off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.

3. polarity of the output voltage is opposite to that of the input.

4. the output voltage can vary continuously from zero to negative infinity (for an ideal converter). The output voltage ranges for a buck and a boost converter are respectively from zero to positive infinity.The circuit has two main mode of operations which are continuous conduction mode and discontinuous conduction mode.
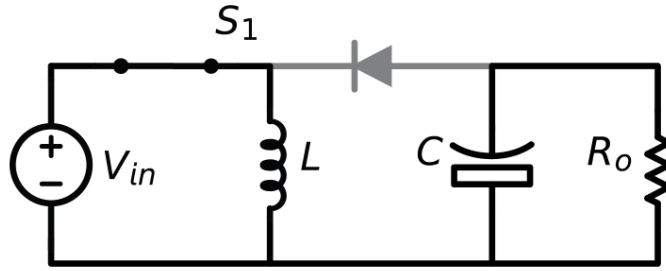
Fig. 2.11. Buck/Boost Converter On-signal Circuit

2.2 Summary

In summary, the operational principles of the non-isolated DC-DC converters have been discussed. from the DC-DC buck converter, boost converter and buck/boost converter have been addressed. Understanding mainly how switched-mode power supply devices operate during the on-state and off-state mechanisms for all the non-isolated DC-DC converters in buck, boost, and buck/boost converters.

3. EXPERIMENTAL MODELING

Research conducted in the present thesis is based on simulation. The experimental set-up was simulated better to visualize the behavior of the power electronics systems. Further details on the DC-DC buck converter system set-up is provided in the following chapter in terms of set-up and data collection.

3.1 Simulation Software

In the simulation software section, we explain the software programs used in the present thesis. Sections 3.1.1 provides further detail on the software, clarify the reasons for choosing them, and specify our research purposes for using them in the current research.

3.1.1 MATLAB

MATLAB is a high-performance language software that offers high technical computing features. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation [24]. Typical uses include:

1. Math and computation.

2. Algorithm development.

3. Modeling, simulation, and prototyping.

4. Data analysis, exploration, and visualization.

5. Scientific and engineering graphics.

6. Application development, including Graphical User Interface building.

The software enables the user to determine many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would need to write a program in a scalar non-interactive language such as C or Fortran. The name MATLAB stands for matrix laboratory. MATLAB was initially written to provide easy access to matrix laboratories software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation [25]. MATLAB has evolved over the years with input from many users. In university conditions, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and examination.

3.1.2   MATLAB Set-up

After providing the necessary reasons for utilizing the software MATLAB for research purposes, a proper set-up for the DC-DC buck converter is essential to get the initial results. Demonstrated in Fig. 3.1 is the DC-DC buck converter set-up that has utilized in MATLAB and built. Provided in the figure, is the DC-DC buck converter.
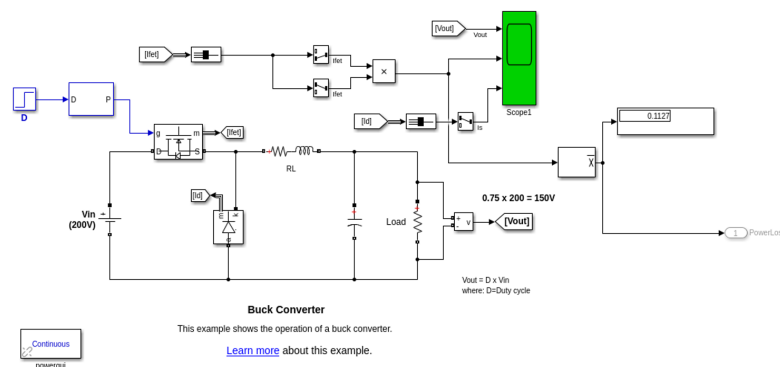

Fig. 3.1. Buck Converter Set-up in MATLAB.

The set-up clearly shows all the components needed to build the buck converter. By applying exhaustive search in terms of different parameters with different values for each component, data sets are being created and saved.

4. MACHINE LEARNING ALGORITHMS & RESULTS

In this chapter, deriving from the importance of determining the approximation error estimation, in this chapter, we illustrate an artificial intelligence method to analyze and solve the problem. Recent studies have demonstrated the effectiveness of artificial intelligence in many fields, including but not limited to, marketing, banking, power system, health care, and much more. Among the well-known methods in artificial intelligence is machine learning.

4.1 What is Machine Learning?

Machine learning applies to the use of artificial intelligence that offers systems the capacity to acquire and advance from experience without being overly programmed robotically. More specifically, machine learning focuses on the advancement of computer programs that can collect data and use these data to learn in a self-reliant way [26]. Machine learning aims to understand the construction of the data and use them to construct models that can be perceived and used by humans. Since machine learning is a subdivision of computer science, it differs from conventional computational strategies. In traditional computing, a programmer arranges specific algorithms of clearly programmed instructions used by computers to solve a particular problem. Instead, machine learning has algorithms that authorize processors to learn from data inputs and to use statistical analysis to provide values in a specific range [27]. For that purpose, machine learning enables computers to improve models from sample data and to make determinations based on the obtained data.

In the present-day world, machine learning has many and various practical purposes. For instance, machine learning is applied in facial recognition technology to help users in tagging themselves. Furthermore, machine learning technology is also

used in the navigation of self-driving automobiles to navigate on the roads. Due to the changes that require higher efficiency in manufacturing, the design execution of algorithms is mostly needed for production systems. Industry corporations are continually looking for systems that are more durable, more dependable, and require less effort to operate. Using machine learning tools helps businesses achieve higher revenue [28]. Importantly, performing algorithms help to enhance the skills necessary to find these solutions.

The machine learning technology is also used in electrical power systems, more specifically, in power transmission, production, and preservation. Among other applications, machine learning models and practices are used to convert historical data from the electrical data into predictive data type models. Furthermore, machine learning can be used to generate transformer rankings, feeder failure rankings, as well as to compute the mean time between failure estimations. Machine learning is also beneficial in the maintenance operations of power companies. Interestingly, it assists in fixing a problem before an error occurs.

A significant requirement for a machine learning algorithm is information analysis. Data analysis is the prerequisite for creating a machine learning algorithm. Data analysis is a process of data collection, refining, aggregating, envisioning, and searching. All these processes help in making appropriate predictions [29] and acquiring data from flat-files, spreadsheets, and databases, conducting exploratory data analysis (EDA), and data are reshaping. The building of models also includes visualization of the results, development of model diagnostics, and residual diagnostics. Machine learning algorithms can use the model's data performance to predict the future. Machine learning algorithms also require an understanding of Python codes and R codes and how to operate them correctly. At this stage, the selection of the algorithm is implemented. A researcher should be specific in the collection of type and class of

algorithm, as well as in the information of the system to execute.

4.2   Proposed Solution

From the definition of machine learning, it can be seen that the central part of machine learning is preparing data so that learning from data can be productive. Due to the availability of data nowadays, machine learning has become an attractive opportunity for many large companies, such as Amazon, Google, Apple, among others. In the present thesis, the approximation error problem was chosen for machine learning tools to be performed. The first step was to collect data on the system. Using MATLAB software, we extracted all the data collected from the network and analyze it in MATLAB.

The problem at stake solved using machine learning, where the model was trained using existing data sets to predict the parameters needed for the DC-DC buck converter. The proposed solution is that the model would be trained using supervised learning, which is a branch of machine learning that deals with pre-training the model using inputs with known output, thereby enabling the model to compute a mathematical function that can gradually learn to generalize on future unknown problems from further training on more data.

4.3   Data Analysis

Data analysis is the first stage of machine learning before building a model. Feature reduction or, as it is frequently called, "data cleaning" is an essential part of the entire machine learning concept. The reason behind its importance is that this action studies all parameters and features of the dataset (device components, in our case) Moreover, it will take the most practical features to determine the label to be considered in building the model. To find out the correlation between different ele-

ments, PCA (Principal Component Analysis) is generally used. Principal Component Analysis is basically "a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated features into a set of values of linearly uncorrelated features called principal components" [30]. However, in the present thesis, a different angle of data reduction is being seen.

4.3.1 *Data Analysis Build*

The data cleaning, processing, and analysis phase provide an insight into the ways to approach the problem at stake. At this point, all features were included in the next stage for redundant purposes in determining the target. This would conclude the data analysis platform that helps the training stage and makes the model more accurate.

4.4 Machine Learning Methods

The proposed solution for the problem of supervised learning in machine learning Overall, there are several learning algorithms of this type, such as classification and regression. In the present thesis, the following two methods were applied to the prepared data: K-nearest neighbors (KNN) and support vector machine (SVM).

4.4.1 *K-Nearest Neighbor*

K-nearest neighbors (K-NN) is one of the simplest and fastest classifications and regression algorithms; however, in our case, it was used only for grouping. More specifically, K-NN has three advantages that make it one of the first choices before considering any sophisticated machine learning algorithms for a classification problem:

1. Ease of interpretation of the output data parameters

2. High speed of training

3. fast predictive power

As suggested by its name, K-NN applies by taking a vote from K-nearest neighbors of a data instance for which the model is trying to find its actual class. It makes a circle that covers all K points from which a majority is needed. To compare with the nearest neighbors, K-NN uses a relatively simple formula of distance. Some of the most commonly used equations are shown below (see Eq. (5.1)-(5.2)):

- Euclidian Distance

$$d(x_i, x_j) = \sqrt{\sum_{k=1}^{k}(x_i(k) - x_j(k))^2}. \tag{4.1}$$

- Manhattan Distance

$$d(x_i, x_j) = \sum_{k=1}^{k} | (x_i(k) - y_j(k) | . \tag{4.2}$$

To observe both Eq. (5.1) and (5.2) with the problem case, the initial data analysis stage revealed that, for each particular data point, the instance values were in a specific area and showed a diverse behavior, making some cluster; therefore, the simplest way to predict a test data instance would be by obtaining its neighbors using one of the distance formulas shown in Eq.(5.1) and Eq. (5.2).

Furthermore, the value of K has to be decided. For the value consideration, two things have to be considered:

(a) Validation error rate.

(b) training error rate.

The validation error rate is the primary reason why data scientists do not perpetually go with the value of K = 1. It is because it shows a different course; specifically, it decreases in the beginning, and, on reaching a minimum duration, its error rate begins to rise as well.

4.4.2 Weighted K-Nearest Neighbor

The Weighted K-Nearest Neighbor (WKNN), is a modified version of the K-Nearest Neighbor. One of the many issues that affect the performance of the K-NN algorithm is the choice of hyper-parameters selection. The intuition behind Weighted K-nearest Neighbor is to give more weight to the data points that are nearby the test data and less weight to the locations which are further away. This means the further the distance from the data point, and the less weight is given to the corresponding data. The closer the distance from the data point, the more weight is given to the data point. According to this algorithm, it has applied across the entire data-set and choose accordingly based on the distance of the data points.

4.4.3 Support Vector Machine

Support vector machine (SVM) is the fastest machine learning algorithm for multiclass classification problems, like the one addressed in the present study. SVM is particularly valuable for large data sets, as it produces a model which scales linearly with the extent of the instruction data set. linear SVM was the perfect choice for its ability to deal with large data sets with a linear increase in computation power required. Finally, at this point, the problem setup is using less than ten features to predict the target class. However, in the future, predictions for data analysis would need to be based on a more significant number of features, and linear SVM can work

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with higher dimensional data.

SVM operates by seeking and drawing a margin line between class instances. Similarly to K-Nearest Neighbor, the current data set was divided into groups of smaller data; therefore, what SVM would do is draw lines to separate these classes/groups from each other as precisely as possible.

Support Vector Machine works by trying to minimize the error function given in Eq. (5.3).

$$\frac{1}{2}w^T w + C \sum_{i=1}^{N} \xi_i.$$

<div align="right">(4.3)</div>

mathmatical equations are subjected to the following constraint:

$$y_i(w^T \emptyset(x_i) + b) \geq 1 - \xi_i \ and \ \xi_i \geq 0, \ i = 1, 2, ..., N.$$

<div align="right">(4.4)</div>

In the following, C is the capacity constant, w is the vector of coefficients, b is a constant, and ξ_i represents parameters for controlling non-separable data. The index i identifies the N training cases. Note that "$y \in \pm 1$" represents the class labels and x_i represents the independent features. The kernel $\emptyset$ is used to transform data from the input (independent) to the feature space in the model.

4.5   Experimental Results and Analysis

4.5.1   *Current State-of-Art Method in Power Electronics & Resulting Power Loss*

The non-isolated DC-DC converter buck converter is widely used topology in low-voltage and high current applications and demands. Low power loss and high-efficiency DC-DC buck converters are needed hugely among commercial, industrial,

and the future of industries. Strong knowledge of power losses in a non-isolated DC-DC buck converter is crucial for improving the DC-DC buck converter performance. Furthermore, it is also essential for the further design of DC-DC converter optimizations. Power loss in the DC-DC buck converter includes several parts such as switching loss, conduction loss, and inductor losses. Among these losses, switching losses are considered essential since the DC-DC buck converter is a switched-mode power device, and every switching cycle counts in terms of performance and efficiency. Some vital concepts are involved in the DC-DC converter before solving the power loss equations. Also, Defining metrics to quantify the performance of the DC-DC buck converter has been earmarked as one of the crucial concepts to attain the needed parameters to solve switching power losses.

In a DC-DC buck converter with an assigned input voltage, the average output voltage is controlled by controlling the switch during the on-state and off-state duration t_{on}, t_{off} and the switching period T_s. One of the methods for controlling the output voltage employs switching at a constant frequency. Hence, the constant switching period can be given as:

$$T_s = t_{\text{on}} + t_{\text{off}}. \tag{4.5}$$

Adjusting the t_{on} duration and t_{off} duration of the switch to control the average output voltage is called PWM (Pulse Width Modulation) switching. The switching duty ratio D, which is defined as the ratio of the on duration to the switching time period, is varied. The mathematical representation for duty ratio is given as:

$$D = \frac{t_{on}}{T_s}. \tag{4.6}$$

The output voltage can be calculated as in terms of the switching duty ratio as given below:

$$V_o = \frac{t_{on}}{T_s} \times V_{in} = D \times V_{in}. \tag{4.7}$$

From equation (5.7), re-arranging the output voltage and input voltage relationship to solve for the duty ratio will result in:

$$D = \frac{V_o}{V_{in}}.$$ (4.8)

Now, to calculate the current across the load that is passing during the switching time will be:

$$I_{Load} = \frac{V_o}{R}.$$ (4.9)

One of the first steps to solve the switching power loss is to calculate the inductor value because the inductor has a reverse relationship with the switching power loss in the DC-DC buck converter, which means the bigger inductor value, the less power loss is going to occur in the DC-DC buck converter and vice versa. The first step to solve the inductor component in the DC-DC buck converter is to solve the differential equation that relates the derivative of the inductor current with the voltage applied in the inductor component in the DC-DC converter as shown in the following:

$$V_{in} - V_o = L\frac{di_L}{d_t}.$$ (4.10)

Solving from equation (5.10) for the inductor current ripple in which induces the following mathematical formula:

$$di_L = \frac{(V_{in} - D \cdot V_{in})D \cdot T_s}{L}.$$ (4.11)

di_L is the inductor current ripple, it undergoes a constraint according to the design of the DC-DC buck converter which is:

$$di_L = 5\% \cdot I_{Load}.$$ (4.12)

The reason that the inductor current ripple is limited to 5% in the design it is because the more significant value of the inductor current ripple, the bigger amplitude of

harmonic that is going to affect the DC-DC buck converter. Lastly, since the inductor current ripple is dependent on the inductor value on the DC-DC buck converter, and it is limited to 5%, by rearranging equation (5.11) to calculate the inductor:

$$L = \frac{(V_{in} - D \cdot V_{in})D \cdot T_s}{di_L}.$$
(4.13)

Since the inductor current ripple is limited, the current peak load is also going to be limited according to the device modification and can be calculated as:

$$I_{peak} = I_{Load} + \frac{di_L}{2}.$$
(4.14)

Considering the inductive current ripple di_L is dependent on the inductor value L, so it is also considered as a function of the inductor value $F(L)$. Ultimately, the current peak load will be:

$$I_{peak} = \frac{V_o}{R} + \frac{f(L)}{2} = F(L).$$
(4.15)

Finally, the essential phase on the dynamic equations to calculate the power loss during the switching of the DC-DC buck converter is represented in the following formula:

$$P_{sw} = \frac{I_{peak} \cdot V_{in}}{V_{ref} \cdot I_{ref}}(E_{on} + E_{off}) \cdot f_{sw}.$$
(4.16)

Where P_{sw} is the switching power loss, V_{ref} and I_{ref} are the voltage reference and the current reference values, respectively. Turn on energy loss denoted with E_{on} and turn off energy loss is E_{off} during the switching periods. Moreover, f_{sw} is the switching frequency on the device. For calculating the voltage reference and current reference according to the switching power loss formula are in the following:

$$V_{ref} = 1.5 \cdot V_{inmax}$$
(4.17)

And for the current reference calculation:

$$I_{ref} = 1.5 \cdot I_{Loadmax}$$
(4.18)

Where V_{inmax} and $I_{Loadmax}$ are maximum input voltage and maximum current load applied to the DC-DC converter. From equation (5.15), the end conclusion to calculate the switching power loss as a function of the inductor can be found by:

$$P_{sw} = \frac{F(L) \cdot V_{in}}{V_{ref} \cdot I_{ref}}(E_{on} + E_{off}) \cdot f_{sw}. \tag{4.19}$$

Example: Calculation of Switching Power Loss

For understanding purposes of the dynamic equations explained above, a practical example should be tested and solved using the dynamic equations and get inductor value first then, calculate the switching power loss with the function of the inductor value. For example, the parameters that have chosen to solve the practical problem include V_{in} to be $70V$, V_o to be $6V$, switching frequency $100kHz$, and limit inductor ripple to be 5% of the load. From acquiring the dynamic equations as explained above, the inductor value is found to be $L = 2.7 * 10^{-4} Henry$. Moreover, according to the switching power loss equation in equation (5.19), the switching power loss P_{sw} resulted in $7.2 * 10^{-4} Watts$.

4.5.2 Machine Learning-based Visualization and Resulting Power Loss

With the dynamics equations approach discussed in the previous section, there is a drawback according to the results obtained from the given parameters to solve for the inductor value L and the switching power loss P_{sw}. As discussed from before, according to the result from the dynamics equation, the switching power loss is high according to the value of $7.2 * 10^{-4} Watts$. The need for big data methodology to reduce the power switching losses of the DC-DC buck converter is crucial and simpler then dynamics equations calculation. In this section, the machine learning algorithm has successfully applied to the data generation, and the current visualization for understanding purposes has been reviewed in the following for output parameters

that have been generated in the data-set. All visualization plots are shown in Fig. 5.1 to Fig. 5.11. weighted K-Nearest Neighbours (WKNN) algorithm has been used in the creation of the data and analyzed. Two neighbors have been used around the equation values, which are represented in the red dot color in the plot. On the other hand, WKNN values have also been analyzed and compared with the equation values. Three different test points have been used and correspond to their nearest neighbors. To have better visualization, plots are demonstrated accordingly.
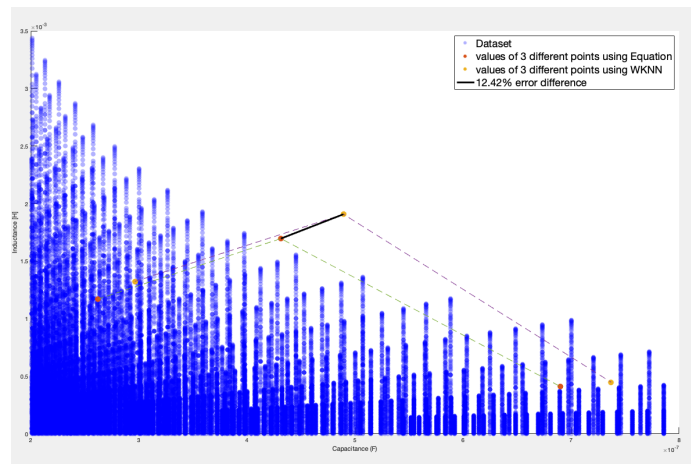
Fig. 4.1. Overview of Data.
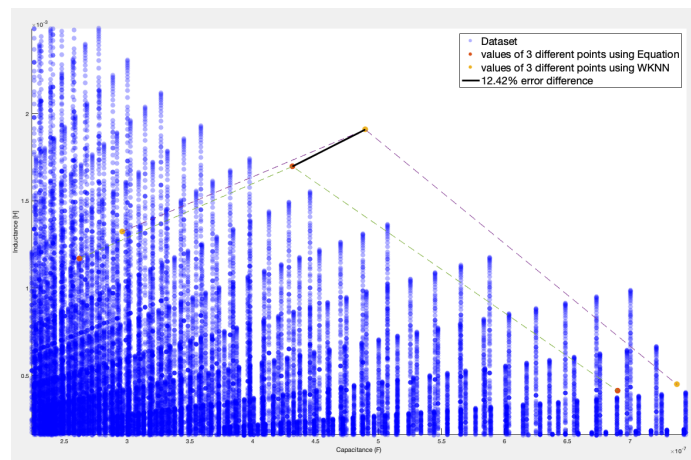
Fig. 4.2. Zoomed Into Data.
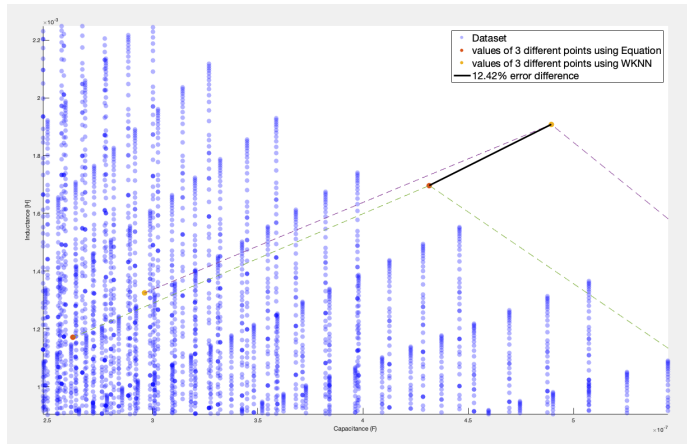
Fig. 4.3. Data Overview Zoomed Further.
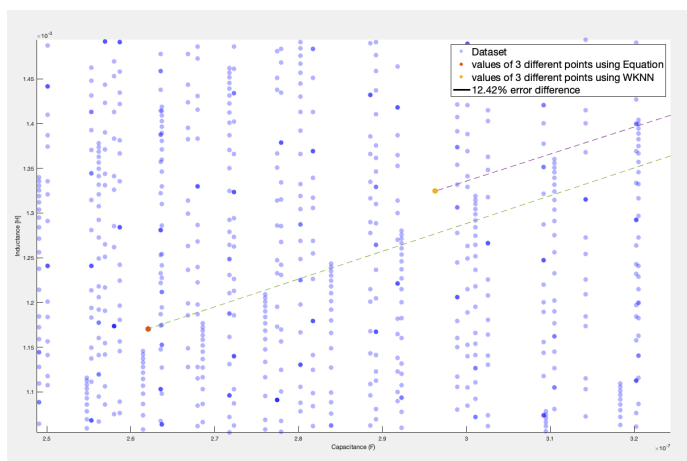
Fig. 4.4. Visualization Plot Zoomed.
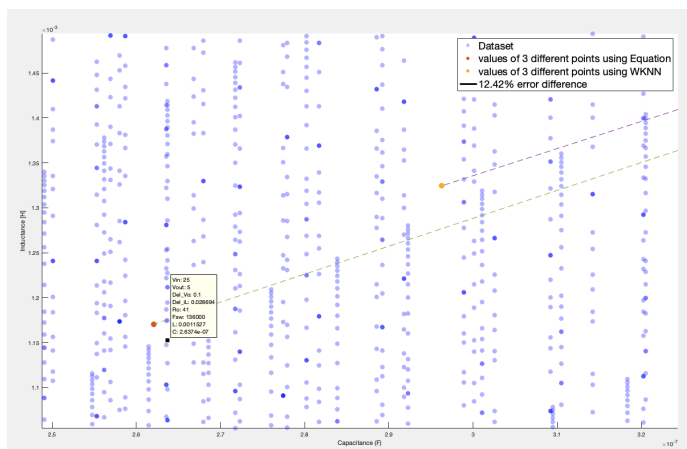
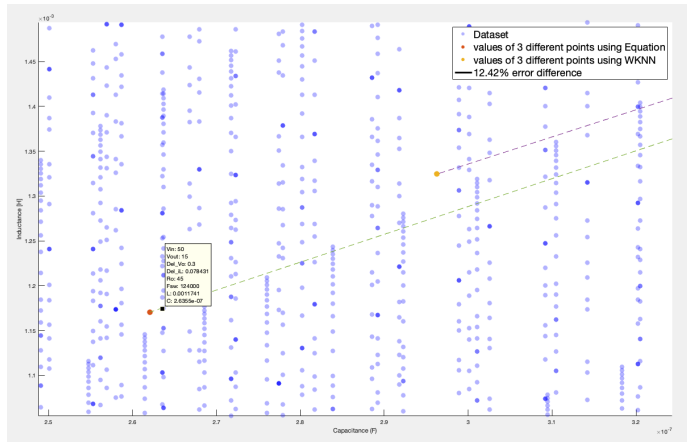Fig. 4.5. Equation Value Plot.

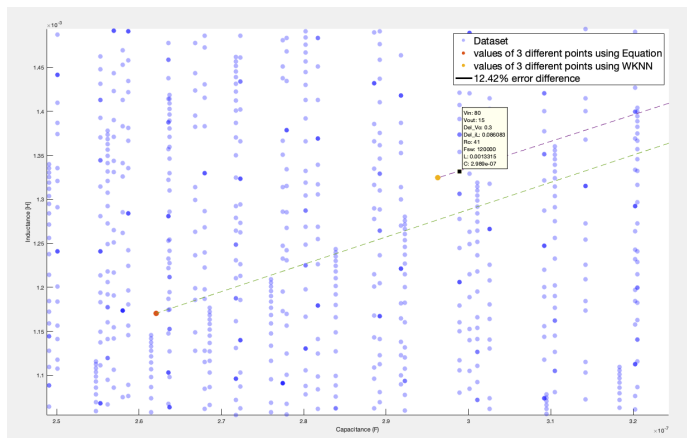35

Fig. 4.6. Equation Value Neighbor's Plot.

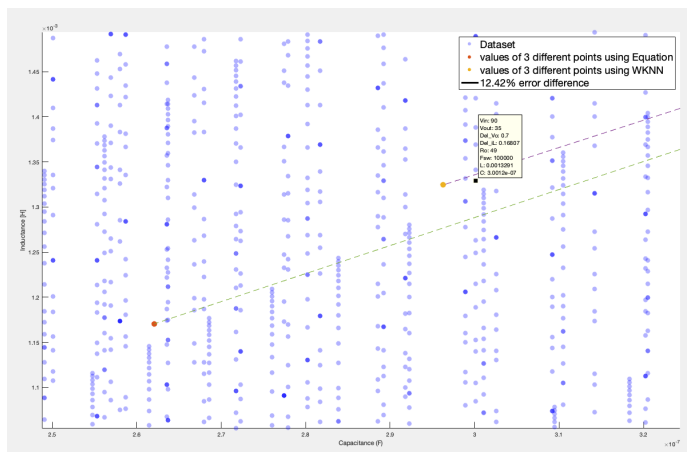Fig. 4.7. WKNN Data Neighbor's Plot.

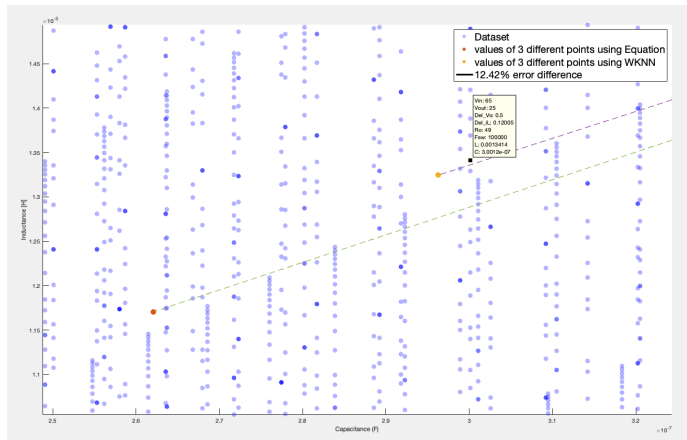
Fig. 4.8. WKNN Data Second Neighbor's Plot .

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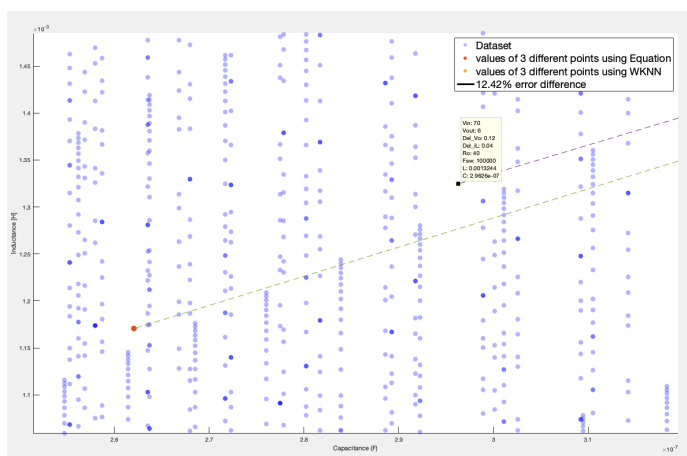Fig. 4.9. WKNN Data Third Neighbor's Plot.
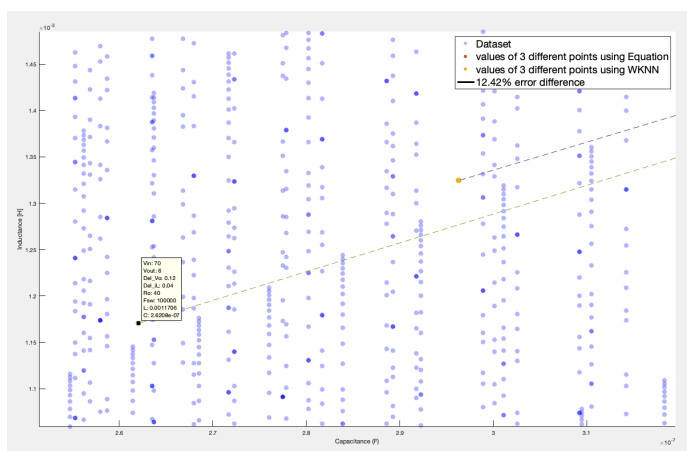

Fig. 4.10. WKNN Data Plot.

Fig. 4.11. Equation Data Plot.

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Example: Calculation of Switching Power Loss

For the machine learning algorithm, the inductor L and the switching power loss P_{sw} have been calculated and compared to the dynamics equations. the inductor value L according to (WKNN) algorithm with k = 10 is resulted with $1.8 * 10^{-3} Henry$ and for the switching power loss P_{sw} is $4.8 * 10^{-4} Watts$. The main advantage of applying machine learning algorithms and obtained the results is that the inductor value L is much lower than the dynamic equation results, in which it will result in a lower switching power losses to the DC-DC buck converter device. Hence, such algorithms can achieve better performance and lesser losses in the future of power electronics applications.

4.5.3   K-NN vs SSM Visualization

In this chapter, we report the results of several experiments performed after a series of modifications of the DC-DC converter. In the first comparison experiment, KNN, in comparison with SSM, was studied for the buck converter model. In the second comparison experiment, SVM, in contrast with KNN, was also studied. After building the model using the MATLAB features, the instantaneous error voltage across the DC-DC buck converter was measured. Different circuits with different parameters were considered in the study process. The primary aim of this experiment was to investigate the performance of machine learning algorithms in terms of detecting approximation error and how much accuracy it is producing in comparison with SSM.

Table 4.1 in the following document shows explicitly, the data points generated with the given duty ratio and a result of the output voltage with output current. The following simulation are based on data creation that was created by applying nested for loops, it is important to see the visualizing to get a deep better understanding of the behavior of the buck converter.
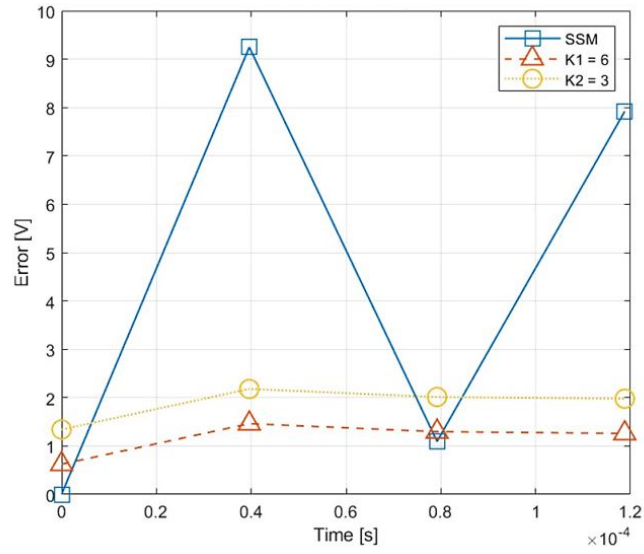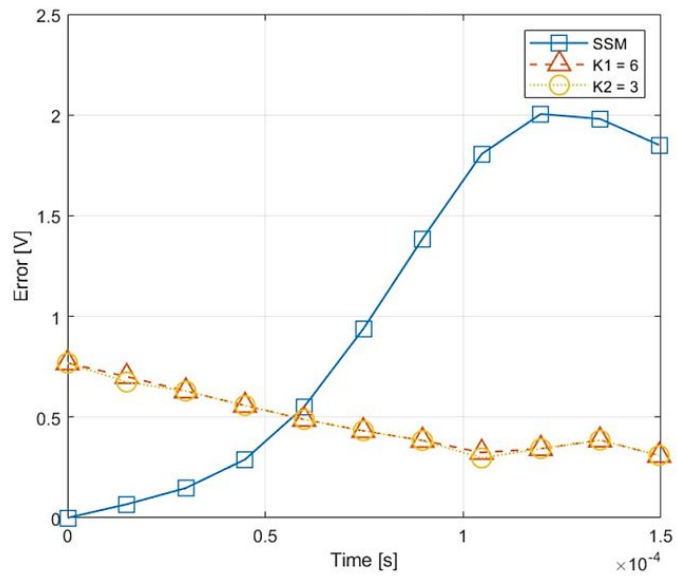
Fig. 4.12. Circuit 1 Error Analysis.

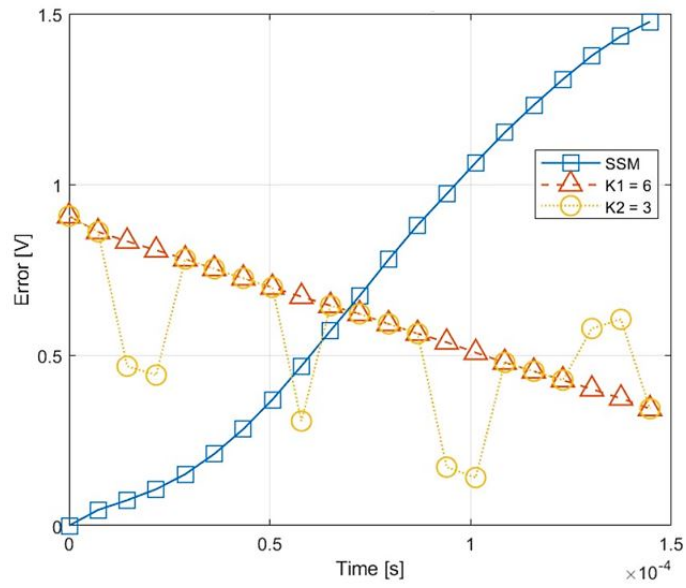Fig. 4.13. Circuit 2 Error Analysis.

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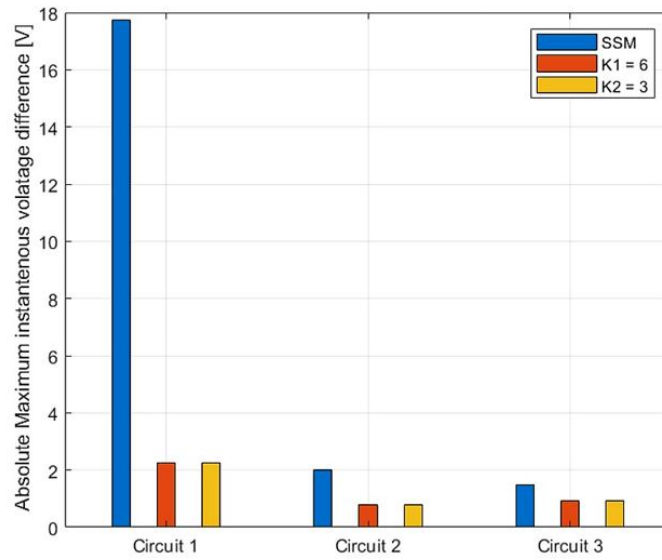Fig. 4.14. Circuit 3 Error Analysis.

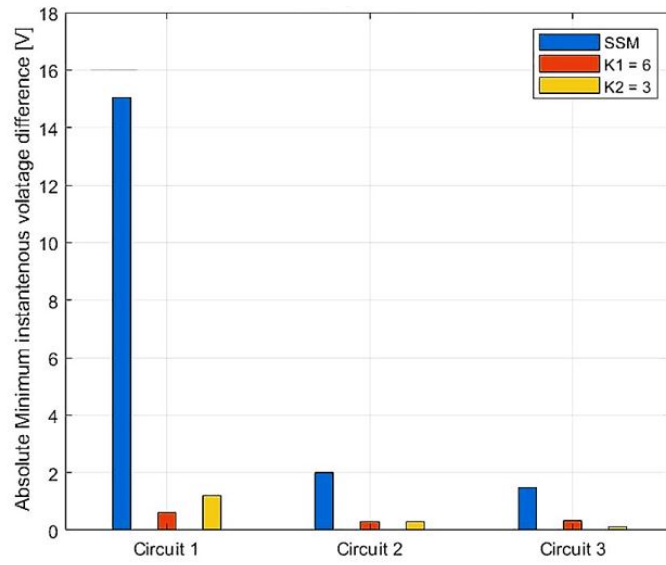Fig. 4.15. T-bar Error Analysis for Circuit 1.

Fig. 4.16. T-bar Error Analysis for Circuit 2.
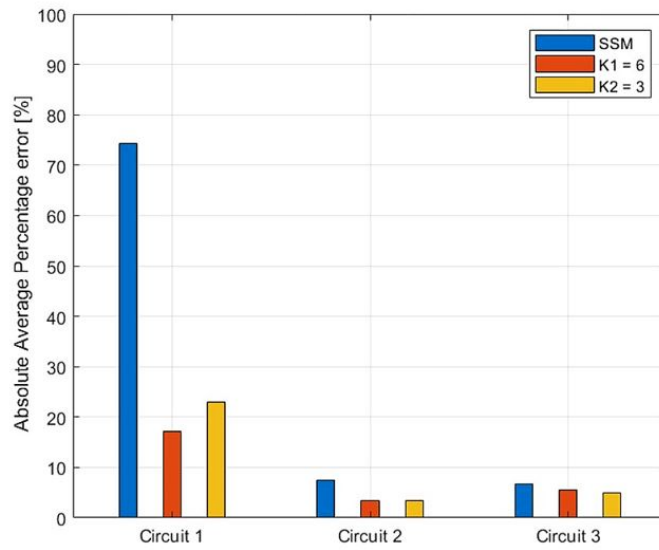
Fig. 4.17. T-bar Error Analysis for Circuit 3.
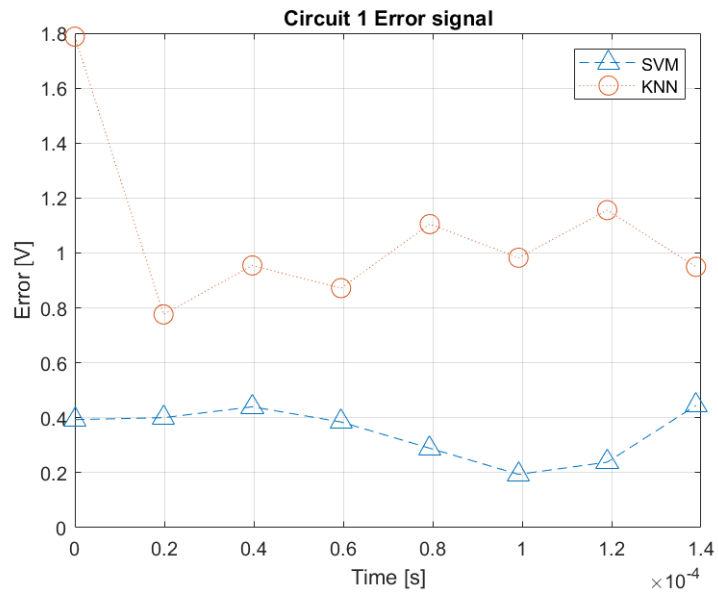
Fig. 4.18. Circuit 1 Error Analysis
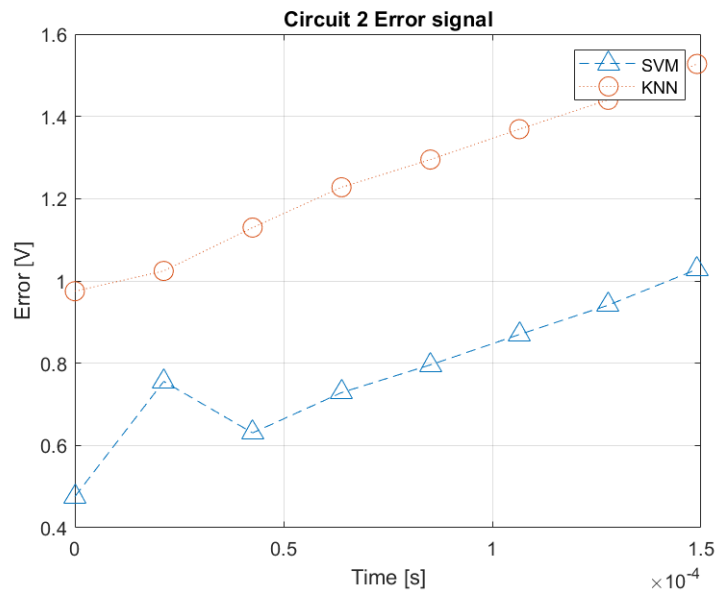
Fig. 4.19. Circuit 2 Error Analysis
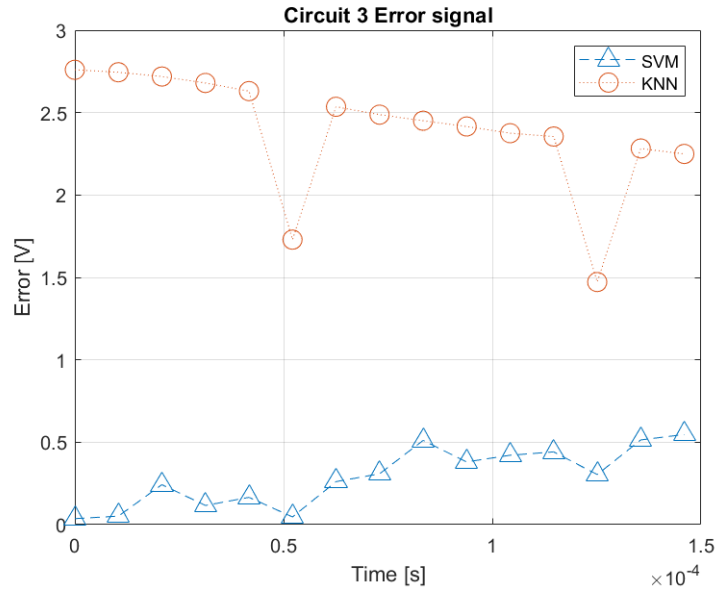
Fig. 4.20. Circuit 3 Error Analysis

Table 4.1. Sample of Data-set

V_{in}	K_c	V_o	Ratio	I_o
40	100	22.369	0.1	0.5592
40	100	22.8038	0.1	0.5701
40	100	22.0804	0.1	0.5520
45	125	24.9405	0.1	0.5542
45	125	24.7668	0.1	0.5504
45	125	24.6588	0.1	0.5480
50	150	23.6206	0.1	0.4724
50	150	23.6605	0.1	0.4732
50	150	23.6321	0.1	0.4726

4.6　Summary

In summary, in this chapter, We used three classifiers to obtain results. The results showed that not all classifiers performed well on the problem, as each classifier has its way of training on the data and subsequent testing. Furthermore, inductor value results from the dynamic equations have been compared with the machine learning algorithms. Also, the switching power losses from the dynamic equations are compared to the values of machine learning algorithms. All in all, machine learning algorithms achieved better results in terms of obtaining less switching power losses and obtained higher inductor value to achieve better performance in the DC-DC buck converter.

5. CONCLUSION

In this research, a non-isolated DC-DC converter is introduced and analyzed. Buck Converter is simulated under various voltage inputs. Different inductance, capacitance, and input voltage values are applied in the DC-DC converter. Machine learning algorithms are proposed for the data process in Matlab. The database is created for a test study to implement machine learning algorithms and to provide error approximations, calculate inductor values, and power switching losses. There are numerous reasons for switching transformers to DC-DC converters, and the most critical reason is that data-driven methodology does not define any errors through its process and calculates the optimal value based on created data-sets. All in all, machine learning algorithms are a primary method to capture better inductor values and lower power switching losses that are not accounted for in the traditional method in which dynamics equations are utilized.

In the present thesis, we aimed to propose the best Machine Learning algorithms for the DC-DC converter project. The applied machine learning algorithms using dc-dc converter aims to produce a constant voltage output power of efficient, regarding the voltage level. Also applying several machine learning algorithms to the code gave us an insight on how the data learns on how to predict, map the data and also memorize the positions of each individual data. Using a DC-DC buck converter for big data methodology will prepare a very attractive values in the future because the power of computer solutions based on the results we have obtained. Furthermore, machine learning can be used in various application other than power system such as in the medical, educational and transportational systems to solve various difficult problems with ease.

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