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New Control Method For Dual Voltage Rectifier

Rai Muhammad OMAR[1], Murtaza FARSADI[2]

Abstract: In this paper, a novel AC-DC converter having dual stage voltage rectifiers and voltage summation architecture is designed. Voltages of the two DC-buses are added together at the output port via down-stream DC-DC transformers (DCXs). The DC output voltage is controlled by regulating the voltage of the adjustable DC-busses of the DV-rectifiers. Therefore, voltage regulation is not required for the DCXs, which can always operate at their highest operation point to guarantee maximum efficiency. As the voltage of the adjustable DC-buses are changeable, multilevel voltages can be obtained with the DV-rectifier, which is benefit for reduction of switching losses and improvement of conversion efficiency. To achieve current regulation of AC input port and voltage regulation of the two DC-buses simultaneously, multi-mode operation and smooth mode transition strategies are proposed for the DV-rectifier. Operation principles, control strategies and characteristics of the DV-rectifier and DCX-based AC-DC converter are analyzed in detail. Feasibility and effectiveness of the proposed solutions are verified with experimental results.

Keywords: *AC-DC converter, dual-voltage-rectifier, dual-dc-bus, sigma structure, multiport converter*

1. Introduction

In today's modern life converters play a pivotal role. Every electronic device uses DC input for working. Digital devices require constant voltages, thus to get those constant voltage levels (DC levels) we need to convert AC into DC using rectifiers. Moreover, AC signals cannot be stored, and DC power or signals can be stored. Thus, to store the electrical energy we need to convert it into DC.

They have been widely used in electric vehicle charger, energy storage, smart-grid and power supplies for datacenter and telecommunications, etc. With the rapid development of electrical vehicles and battery storages, AC-DC converters with wide DC output voltage ranges are necessary to meet the requirements of batteries and dc loads. How to achieve high efficiency and flexible voltage control on both AC input side and DC output side has been an emergent research topic in various AC-DC power systems [2]-[4]. As a result, new topological and control variations and innovations have been continuously emerging.

[1] *Electrical Electronics Engineering, Engineering Faculty, Istanbul Aydin University, Istanbul, Turkey, raiomar@stu.aydin.edu.tr*
[2] *Application and Research Centre for Advanced Studies, Istanbul Aydin University, Istanbul, Turkey, murtazafarsadi@aydin.edu.tr*

This paper is organized as follows:

First it will discuss about our main circuit its configuration and working. Second portion will discuss about control scheme and how it will control our output voltage. In the third portion we shall discuss graphs at different loads and frequencies. And at the end conclusion and future work.

2. Main Circuit:

Basic dual-stage AC-DC converter is shown in fig. 1. In which buck type or boost type or may be both converters are used according to desired requirement. Second stage consist of filter which is used to remove harmonics and fluctuations.

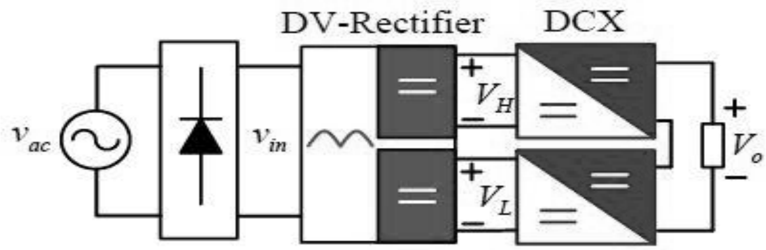

Figure 1: Dual Stage AC-DC Converter

The block diagram of proposed DV-rectifier-based AC-DC converter is shown in Fig. 2. To avoid efficiency reduction of the DC-DC stage due to wide voltage regulation range, the basic idea of the proposed AC-DC converter is based on dual-DC-bus method. Two DC-buses, i.e. a constant voltage DC-bus V_H and an adjustable DC-bus V_L, have been established by the DV-rectifier.

Different types of DV-rectifiers topologies can be made, and their control topology will be changed according to their working. DV-rectifier which we are considering, its working techniques are clearly discussed in [1]. That is not included in our scope. Our control scheme will be only main concern.

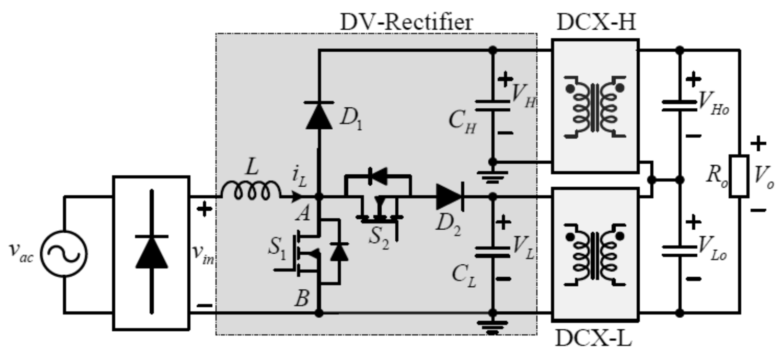

Figure 2: Proposed Dual Voltage Rectifier

3. Control Scheme:

Scope is to compare Pulse Width Modulation (PWM) efficiency with Fuzzy Logic Control scheme. We will see the voltages, power and current graphs of both control schemes and then conclude which one is best and beneficent for us. First, we shall consider PWM control scheme.

3.1 PWM Control Circuit:

Fig. 3 shows the control block diagram of the proposed AC-DC converter. The front-end DV-rectifier is responsible for input current regulation and the two DC-link bus voltage control, while the down-stream DCX is used to regulate the load voltage, current or power control. As shown in Fig. 3, a voltage control loop and a current control loop are employed for the DCX, so that constant voltage and constant current output can be achieved.

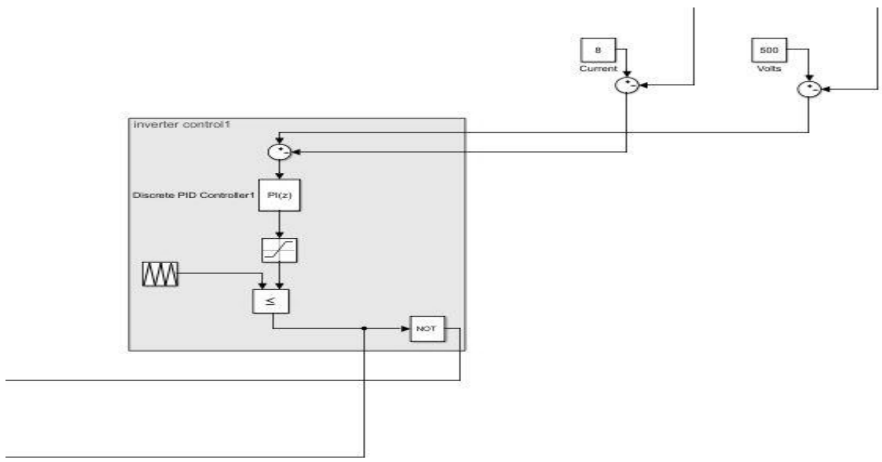

Figure 3: Voltage & Current Loop for the DCXs

The operation frequency of the two DCXs, i.e. f_{DCX}, is always the same. Therefore, only one controller and one pulse frequency modulator (PFM) are needed for the two DCXs, which can simplify the implementation of control. It should be noted that, when the switching frequency of the two DCXs is the same, the low frequency ripples on V_H and V_L will affect the output voltage ripple of each DCX, but the total output voltage *Vo* can still be regulated to suppress the low frequency voltage ripple by slightly changing the gain *GDCX* of the two DCXs simultaneously.

The relationship between the control signal V_{ctrl} and the average value of v_{AB} is as follows:

$$\bar{v}_{AB} = V_{Hi}\left(1 - d_{1_{VHi}-SM}\right) = V_{Hi}(2 - v_{ctrl})$$

When the rectifier operates in the *VL*-SOM, the terminal-3 of the SPTT is disabled and the switch pole is connected to terminal-1 and terminal-2 alternatively. In this case, the relationship between the control signal $V_{c1}$and the average value of v_{AB} is as follows:

$$\bar{v}_{AB} = V_{Low}\left(1 - d_{1_{VLow}-SM}\right) = V_{Low}(2 - v_{C1})$$

When the rectifier operates in the DOM, the terminal-1 of the SPTT is disabled and the switch pole is connected to terminal-2 and terminal-3 alternatively. In this case, the relationship between the control signal V_{c2} and the average value of v_{AB} is as follows:

$$\bar{v}_{AB} = V_{Low} d_{2\_DM} + V_{Hi}\left(1 - d_{2_{DM}}\right) = V_{Low} v_{c2} + V_{Hi}(1 - v_{C1})$$

where d_2_DOM is the duty cycle of S_2 in the DOM.
PWM control strategy and graphs of output voltage, output power and total harmonic distortions are shown in fig. 4, 5, 6 and 7 respectively.

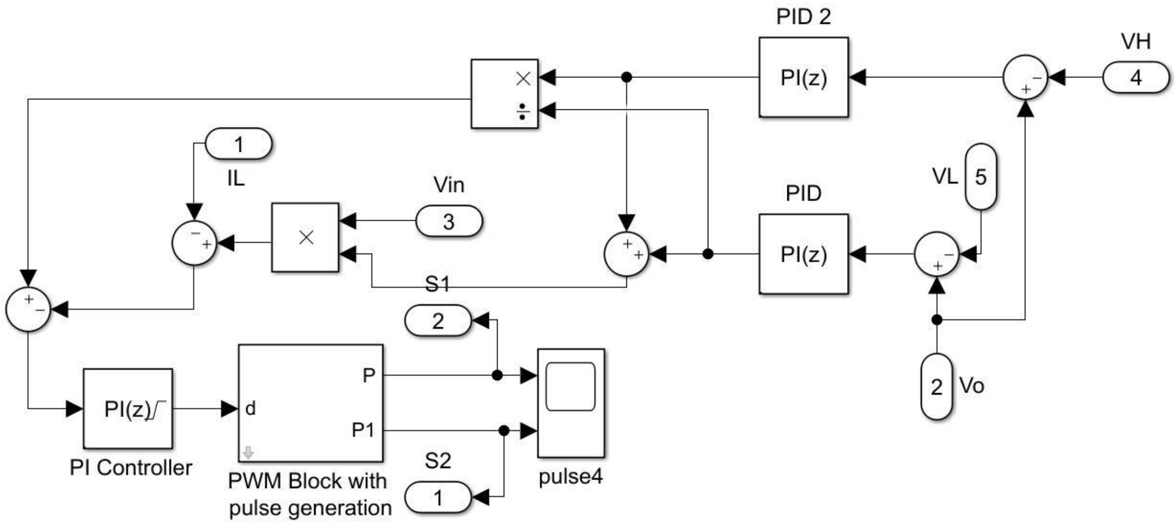

Figure 4: PWM Control Circuit for DV-Rectifier

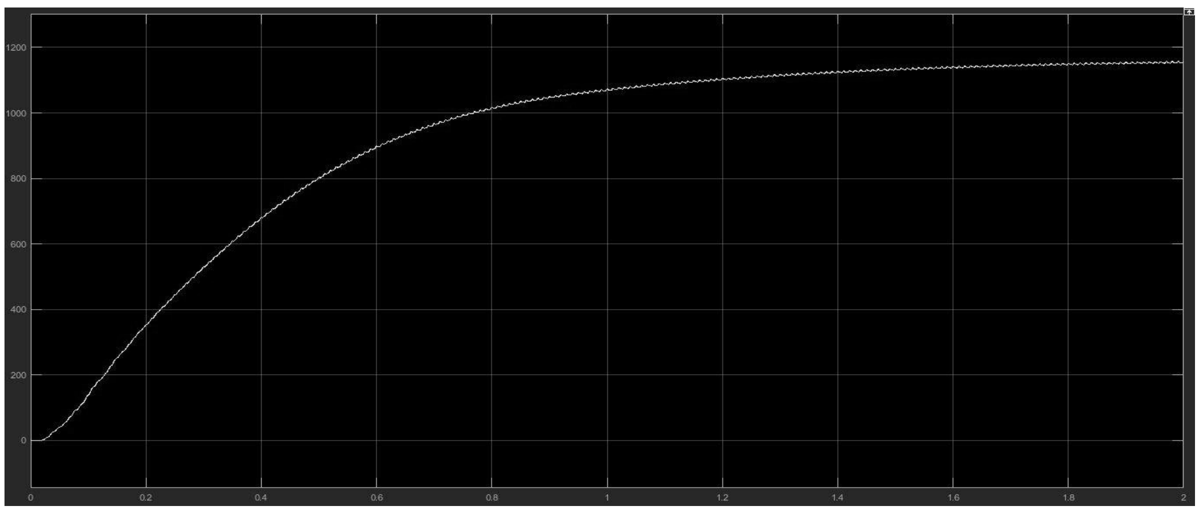

Figure 5: Output Power Graph of DV-Rectifier Using PWM

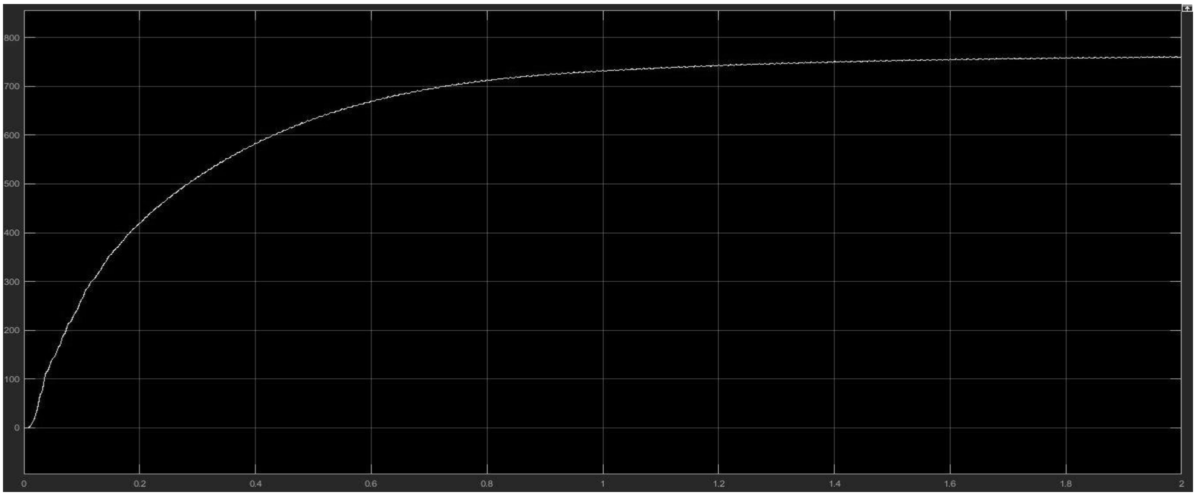

Figure 6: Output Voltage Graph of DV-Rectifier Using PWM

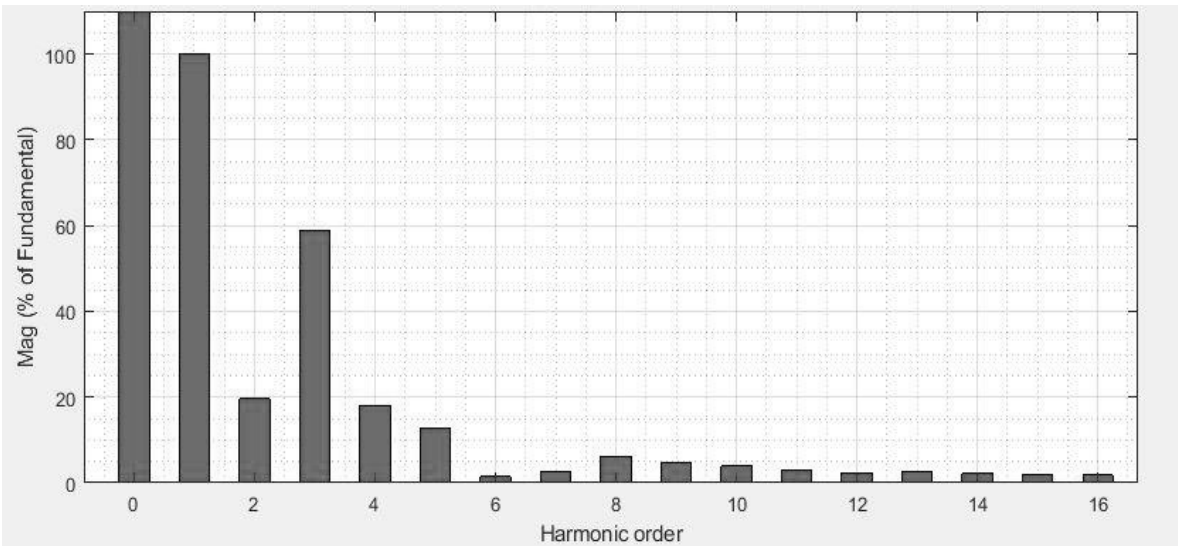

Figure 7: Total Harmonic Distortion (THD)

3.2 Fuzzy Logic Controller:

Why are we relying on Fuzzy Logic controller?

Fuzzy logic controllers (FLC's) have the following advantages over the conventional controllers: they are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms. A self-organizing fuzzy controller can automatically refine a starting approximate set of fuzzy rules. PI-type fuzzy controller applications can increase the quality factor.

3.3 Mamdani Fuzzy Logic Controller:

Mamdani fuzzy inference system was applied as a decision-making model to classify aqua sites based on water, soil, support, infrastructure, input, and risk factor related information. Mamdani fuzzy inference system was used to develop the fuzzy rule-based model. It consists of five operating mechanisms named as fuzzification, calculation of weight factor, implication, aggregation and defuzzification.

Design of fuzzy controllers is based on expert knowledge of the system to be controlled instead of accurate mathematical model. There are two inputs in the fuzzy controller. The first is the error e(k) between the output voltage V[k] and the reference value Vref and the second is the difference between successive errors i.e. change of error ce(k) and are given by [6]

$e(k) = Vref - V(k)$
$ce(k) = e(k) - e(k-1)$

FLC control strategy and graphs of output voltage, output power and total harmonic distortions are shown in fig. 8, 11, 12 and 13 respectively.

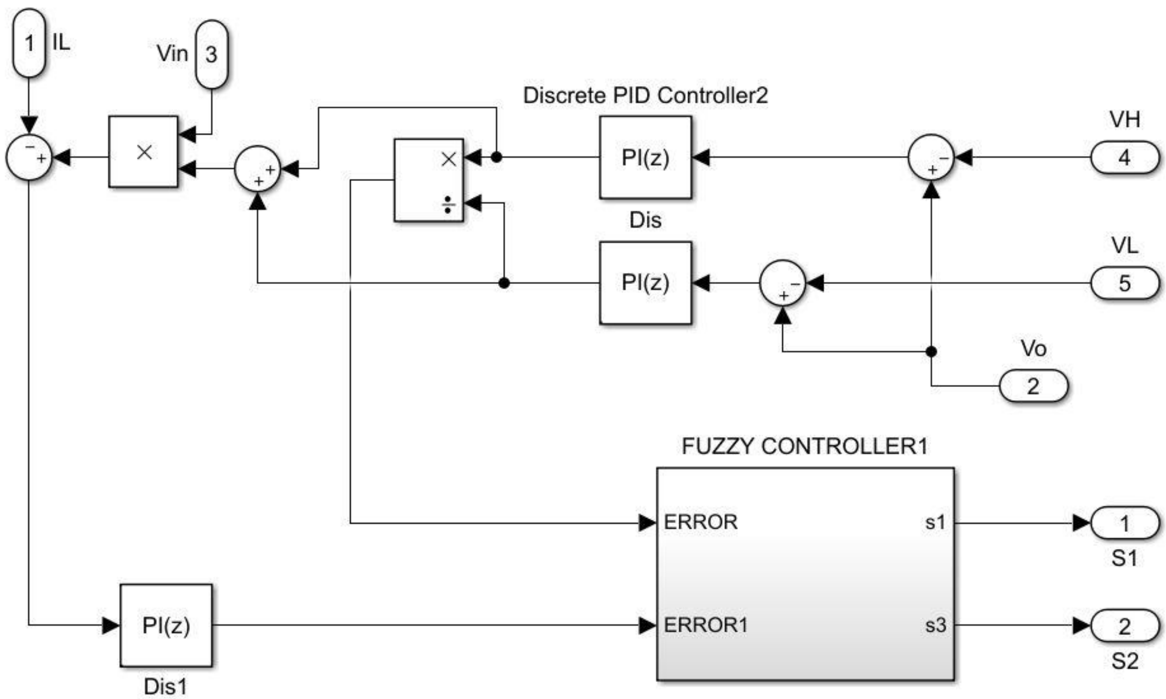

Figure 8: Fuzzy Logic Controller for DV-Rectifier

Fuzzification is the process of converting input data into suitable linguistic values. The first step in the design of a fuzzy logic controller is to define membership functions for the inputs. Five fuzzy levels are chosen and defined by the following fuzzy-set values for the error e and change in error ce:
NB negative big; NS negative small; ZE zero; PS positive small; PB positive big.

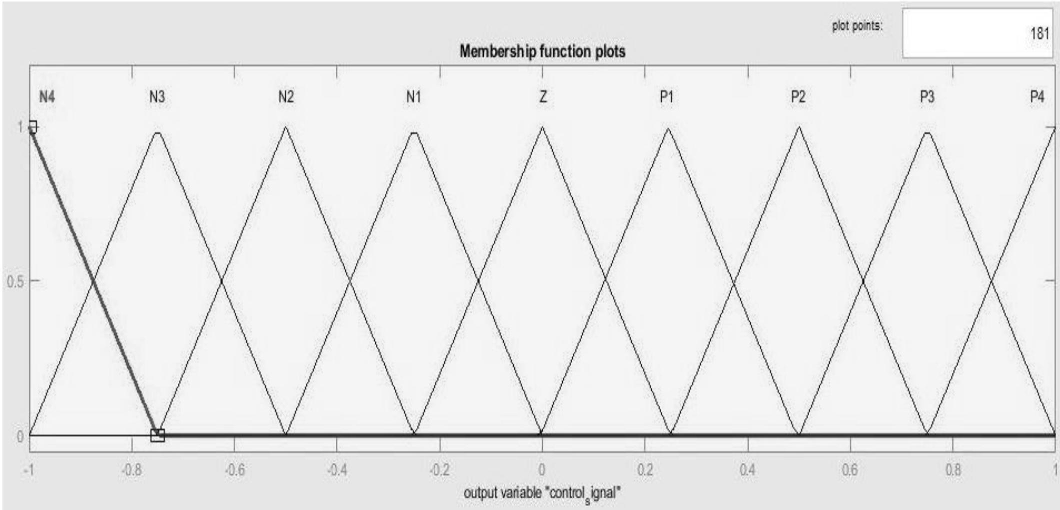

Figure 9: Control Signal Membership Function Plot

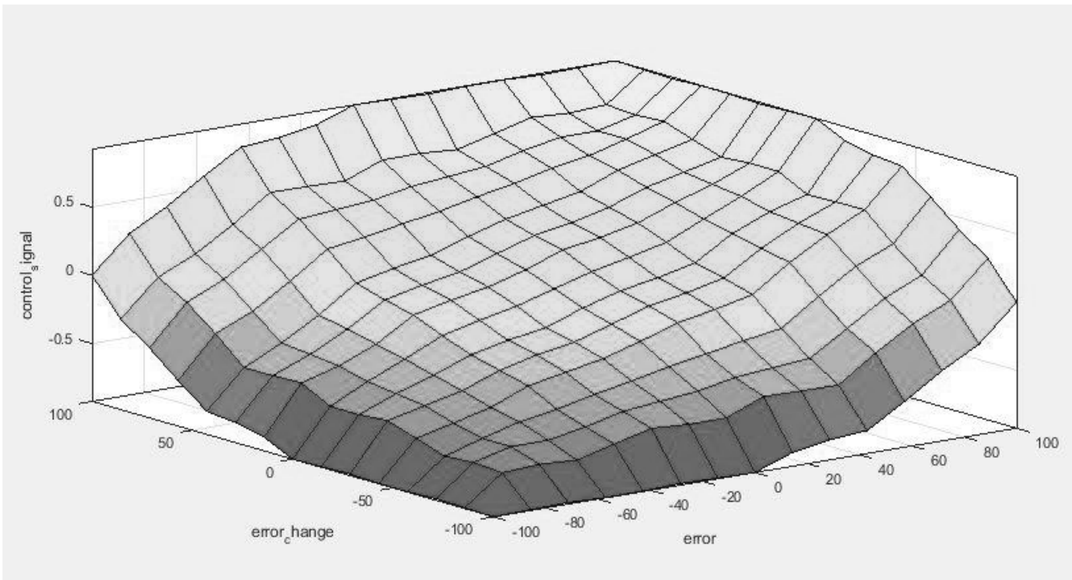

Figure 10: Control Surface Plot for Fuzzy Logic Controller

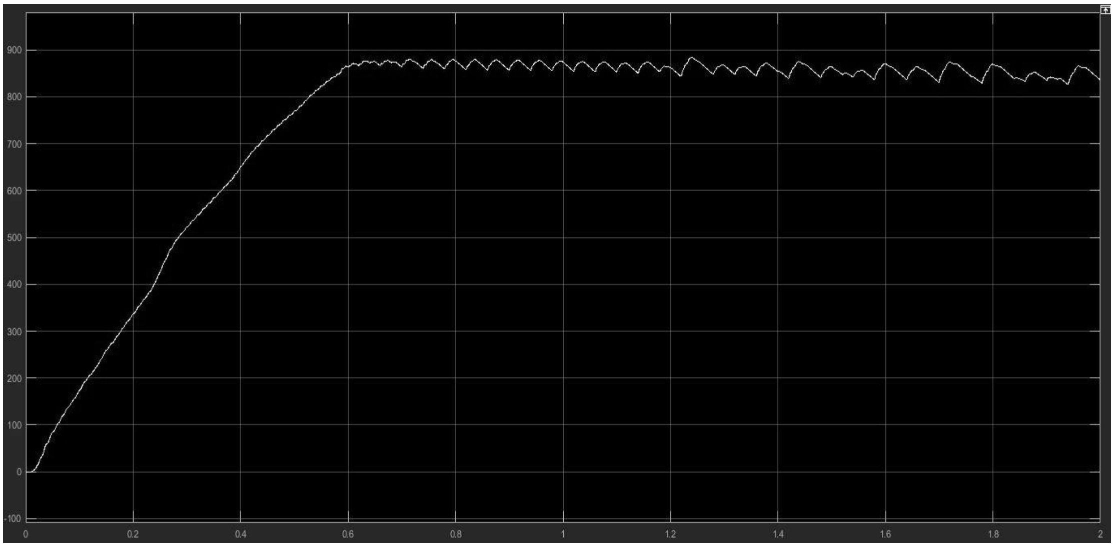

Figure 11: Output Voltage Graph of DV-Rectifier Using FLC

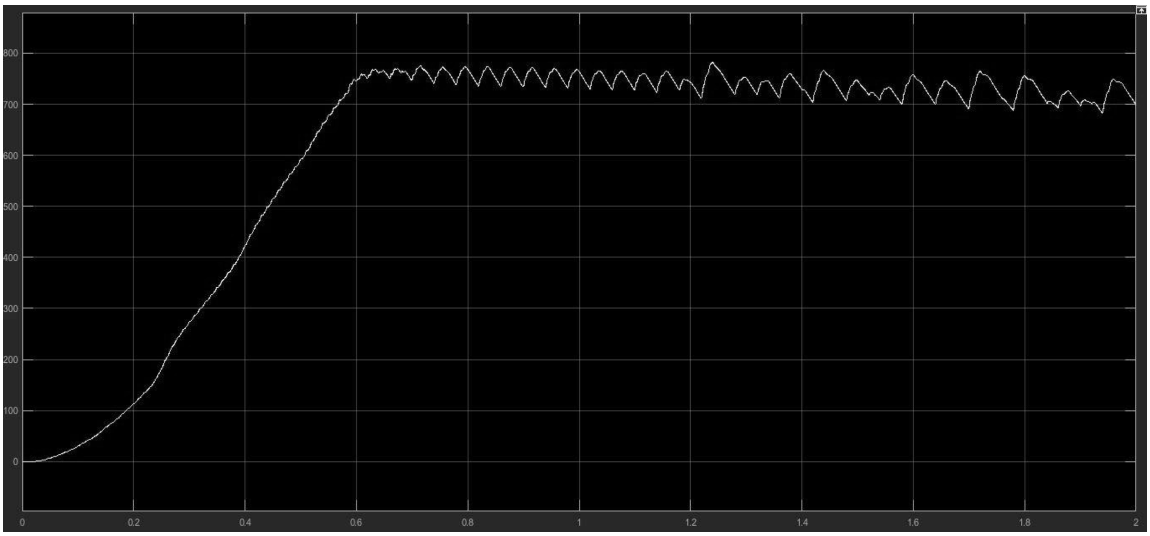

Figure 12: Output Power Graph of DV-Rectifier Using Fuzzy Logic Controller

4. Conclusion:

We have seen in our upper given graphs related to power and output voltages at same conditions of input voltages and frequencies, we have concluded that fuzzy logic controller is better than the PWM logic controller as the output of FLC circuit reaches its desired output faster than the other one. Although FLC is faster than PWM controller we have noticed that we got more harmonics in circuit controlled by FLC instead of PWM controlled circuit.

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