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DESIGN AND ANALYSIS OF VOC BASED VIENNA RECTIFIER USING DYNAMIC d-q AND DECOUPLED CONTROL METHODS IMPLEMENTED FOR ELECTRIC VEHICLE CHARGING STATIONS

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ABSTRACT

Front-end converters for many applications, including motor drives, data centers, electric car chargers, and telecommunications, employ AC to DC converters with controlled DC output voltage. Because welding power sources and EV charging stations demand a lot of power, the voltage and current rating at the power converters must be greater than the voltage and current needed for other uses, including motor traction. Vienna rectifiers, often referred to as unidirectional boost rectifiers, are used as front-end converters. This concept proposes a Vienna rectifier for electric car charging that is based on a voltage-oriented controller. Vienna rectifiers are becoming more and more common for converting AC to DC power in a variety of industrial applications, including data centers, aviation systems, communications power sources, welding power supply, and electric car charging stations. Six active semiconductor switches, either MOSFET or IGBT, and six diodes make up the Vienna rectifier scheme. This converter has low total harmonic distortion (THD), excellent efficiency, and high power density. The suggested approach increases the system's stability, boosts grid-side power factor, and lowers harmonics in the input source current. MATLAB/Simulink will be used to validate the behavior and performance outcomes of the suggested voltage-oriented control of the Vienna rectifier using a PI controller (VOC-VR).

1.INTRODUCTION

1.1 GENERAL

Front-end converters for many applications, including motor drives, data centers, electric car chargers, and telecommunications, employ AC to DC converters with controlled DC output voltage. Because welding power sources and EV charging stations demand a lot of power, the voltage and current rating at the power converters must be greater than the voltage and current needed for other uses, including motor traction. Vienna rectifiers, often referred to as unidirectional boost rectifiers, are used as front-end converters.

Compared to traditional three-phase rectifiers, this converter is widely recognized for its topological structural benefits, which include high efficiency, a high power to weight ratio, low total harmonic distortion in the line current, unity power factor at the grid, and a compact filter size. The excellent power to weight ratio, great efficiency, and low voltage stress of the Vienna rectifier make it perfect for high power applications. The controller unit, which has been the focus of much study, is the central component of power electronics systems in recent years. A proportional-integral (PI) controller is the primary controller found in power converters. Accurately creating the linear mathematical model of the system needed for the PI controller is difficult, however. Additionally, the PI controller often finds it difficult to function well in the presence of load disturbances, nonlinearity, and parameter fluctuations. Various control strategies for AC to DC converters used in high power applications, such electric car charging stations and welding power sources, have been documented in the literature.

Power factor correction controllers (PFC), direct power controllers (DPC), voltage-oriented controllers (VOCs), and their combination DPC-SVM are the most often used power controllers for EV charging stations. In active front-end converters, voltage-oriented controllers are often utilized as power controllers for power factor adjustment. shows how, in comparison to using a single controller, combining a traditional controller with an intelligent controller may enhance the system's transient analysis and lower the input current's overall harmonic distortion. Additionally, several converters utilized in the literature may be used to traction and lower power DC applications. This research proposes a unique design for a high power consumption EV charging system that combines a voltage-oriented controller with a Vienna rectifier (VOC-VR). The Vienna rectifier, which is used in EV charging stations, has a voltage-oriented controller and a PI controller as part of the hybrid control structure that is suggested. In order to reduce the input current THD, earlier designs of AC/DC converters for high power applications used a hybrid controller with traditional three-phase regulated rectifiers. This required high rated input and output filters. As a result, the system's efficiency and power density decreased. In order to solve this problem, a unique design for high power applications that integrates a Vienna rectifier with a VOC and PI controller is put forward. Transient stability is increased with the use of Vienna rectifiers, and at an output voltage of 640 V/90 A, the THD is lowered to less than 5%, meeting IEEE 519 requirements. By considerably lowering the input current THD and raising the power density, the suggested innovative design performs better for high power applications than conventional AC/DC power converters.

2.CONVERTERS

2.1AC- DC CONVERTER (RECTIFIER)

A rectifier is an electrical device that performs rectification, or the conversion of alternating current (AC), which alternates direction frequently, to direct current (DC), which only flows in one direction. Rectifiers are used for a variety of purposes, such as radio signal detectors and parts of power supply. Solid state diodes, vacuum tube diodes, mercury arc valves, and other parts may be found in rectifiers.

2.1.1 HALF-WAVE RECTIFICATION

Either the positive or negative half of the AC wave is passed while the other half is blocked in half wave rectification. It is particularly inefficient for power transmission since only half of the input waveform reaches the output. One diode in a one-phase supply or three diodes in a three-phase supply may be used to accomplish half-wave rectification.

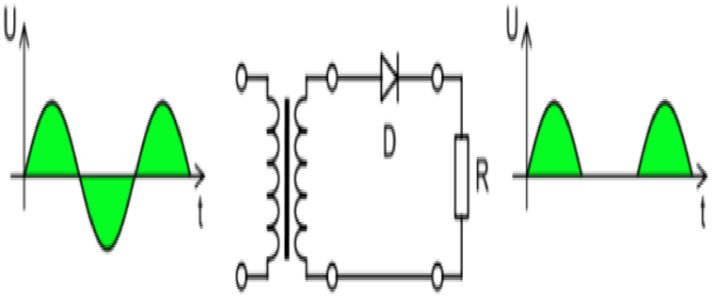

Fig.2.1 Half wave rectification

The two following perfect equations may be used to get the output DC voltage of a half wave rectifier:

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$$V_{rms} = \frac{V_{peak}}{2}$$

$$V_{dc} = \frac{V_{peak}}{\pi}$$

3. PROPOSED CONFIGURATION

3.1 VIENNA RECTIFIER

Six active semiconductor switches, either MOSFET or IGBT, and six diodes make up the Vienna rectifier scheme. Fig. 3.1 illustrates the Vienna rectifier architecture with three phases and three levels. Every diode and semiconductor switch is subjected to a voltage stress of Vdc/2. Two capacitors are linked in parallel on the DC side and three inductors are connected on the input AC side. The grid's neutral point and the DC link's neutral point are connected. Figure 3.2

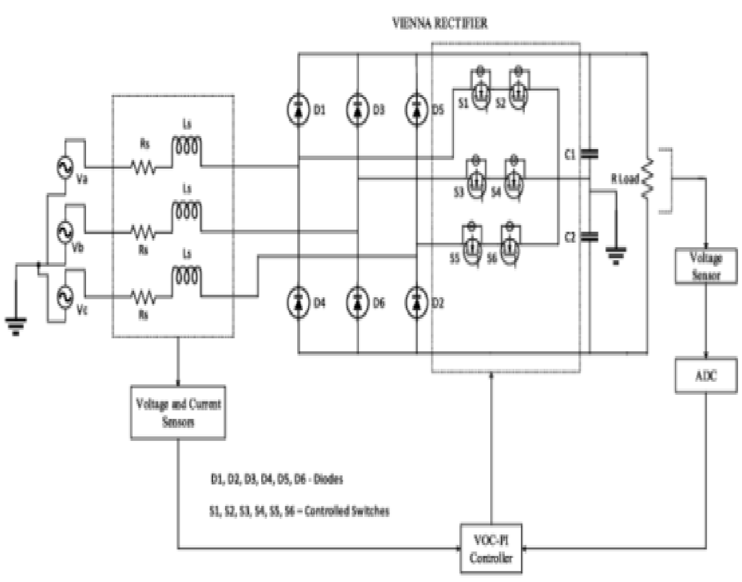

Fig.3.1 The proposed electric vehicle charger is based on Vienna rectifier with a VOC controller (VOC-VR) system.

demonstrates how the three-level Vienna rectifier works for a single leg's current route in each mode. The remaining two legs use a 120◦ phase difference to carry out the same function. When a reference voltage in mode 1 is regulated and positive half cycle

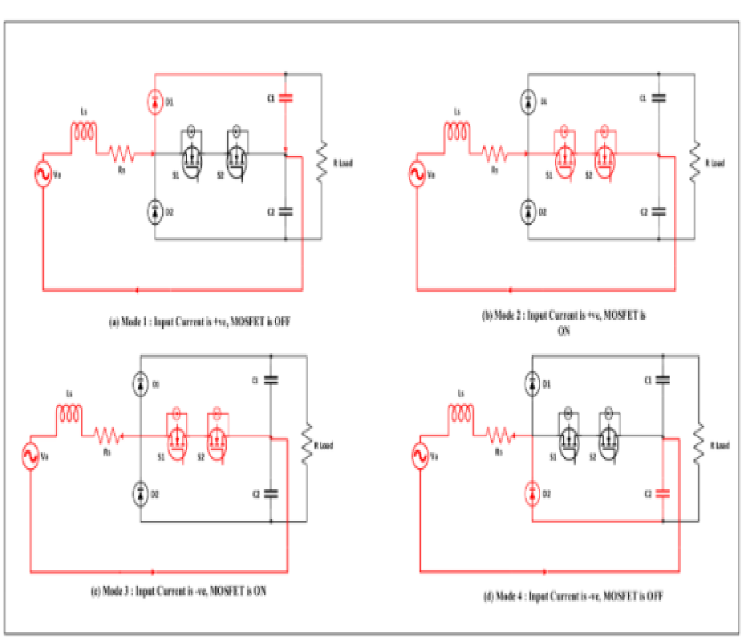

Fig.3.2 Four modes of operation of Vienna rectifier topology

suitable for high power uses, including power sources for communications, wind energy conversion systems, electric car charging stations, and welding. Vienna Rectifier has used a variety of power controllers, including vector, SVPWM, predictive, and dead-beat controllers, for high power applications.

3.2 VOLTAGE ORIENTED CONTROLLER

The control structure that is put in place has a significant impact on how AC to DC power converters operate. Dual vector current controllers (DVCC) are the foundation for a voltage-oriented controller's functionality. Voltage-oriented control is used to address the following issue:

• Ripples in output DC voltage

• Total harmonic distortion of the input current; • Grid-side input power factor A voltage controller and a current controller make up the voltage-oriented controller.

$$v_{d,ref} = K_p\left(i_{Sd,ref} - i_{Sd}\right) + K_i(i_{Sd,ref} - i_{Sd})dt$$
$$v_{q,ref} = K_p\left(i_{Sq,ref} - i_{Sq}\right) + K_i(i_{Sq,ref} - i_{Sq})dt$$

METHODOLOGY

The proposed Vienna rectifier with VOC controller (VOC-VR) is a three-phase three-level rectifier, which is controlled by the voltage-oriented controller algorithm. The proposed system includes a three-phase AC system, a Vienna rectifier controlled by a VOC algorithm, and a DC link capacitor. Feedback voltage from the EV's load-side battery is generated using current and voltage controllers for the closed-loop operations. The VOC controller performs two main functions: (1) DC output voltage regulation to a predetermined value, and (2) the regulation of the total input harmonic distortion and maintaining in phase with the voltage to provide unity power factor. The proposed VOC-VR system is shown in Fig. 5. The de-coupler controller is the key feature of the proposed VOC control algorithm. Three PI controllers were used in the proposed control circuit. The first PI controller is a current controller that controls the internal loop of id current component. This controller is used to estimate the reference voltage signal vd_ref by minimizing the error between id with id_ref . Second PI controller is also called a PI current controller, which reduces iq current component to 0 by managing the inner loop of iq a current component which is used to estimate the voltage reference voltage signal vq_ref . Third PI controller is a voltage controller, which is used to manage the output loop of DC-link voltage Vdc. This controller is used to estimate reference current signal id_ref by comparing measured Vdc with its pre-determined reference voltage vd_ref . The voltage-oriented controller must transform input from three-phase current and decouple into active id and reactive iq components, respectively. Regulating the decoupled active and the reactive components minimizes errors between required reference and calculated values of the active and reactive components. The DC link voltage control method controls the active current component id which aims to achieve an active power flow balance in the systems while the reactive current component iq is controlled to 0 to provide a unity power factor at the input side. The characteristics of two PI current controllers and PI voltage controllers are given in equation (6)-equation (8) [13]

$$v_{d\_ref} = v_d + 2\pi f L_s i_q - (K_{p1}\left(i_{d_{ref}} - i_d\right) + K_{i1}\int\left(i_{d_{ref}} - i_d\right)dt) \quad (6)$$

$$v_{q\_ref} = v_q - 2\pi f L_s i_d - (K_{p2}\left(0 - i_q\right) + K_{i2}\int\left(0 - i_q\right)dt) \quad (7)$$

$$i_{d\_ref} = K_{p3}\left(V_{dc_{ref}} - V_{dc}\right) + K_{i3}\int\left(V_{dc\_ref} - V_{dc}\right)dt \quad (8)$$

(8) Kp1, Ki1Kp2, Ki2Kp3, Ki3 = gain values PI current controller Ls = source inductance. The switching frequency for the current control loop will be larger than the bandwidth αi

$$\alpha_i < 2\pi \frac{f_s}{10} \quad (9)$$

$$K_{p1} = K_{p2} = \alpha_i L_s \text{ and } K_{i1} = K_{i2} = \alpha_i R_s \quad (10)$$

(10) where, αi (rad/s) = current controller bandwidth. For the voltage control loop, the PI controller is tuned by using a DC link capacitor as the following [34], [35]:

Kp3 ≥ Cdc1ξω and Ki3 ≥ Cdc1ξω/2 (11)

where damping factor ξ is equal to 0.707 and ω is angular frequency. Using initial values, tuning and modifications are made, which strengthens the proposed charging tech

4.PULSE WIDTH MODULATION

4.1 WHAT IS PWM

The best way to switch the power devices of the solar system controller and ensure consistent voltage battery charging is to use pulse width modulation, or PWM. When using PWM regulation, the solar array's current tapers based on the state of the battery and the necessity for recharging. Take a look at a waveform like this one, which shows a voltage transitioning between 0 and 12 volts. It should be very evident that a "suitable device" attached to its output would observe the average voltage and believe it is being fed 6v, or precisely half of 12v, as the voltage is at 12v for exactly the same amount of time as it is at 0v. Therefore, we may adjust the 'average' voltage by changing the positive pulse's width.

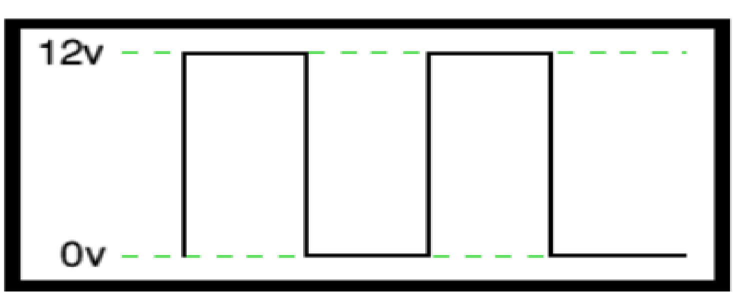

Fig.4.1 Average voltage exactly half of 12v

Similarly, as fig. 4.2 below illustrates, the average voltage will be 3/4 of 12 volts, or 9 volts, if the switches maintain the voltage at 12 for three times as long as at 0 volts.

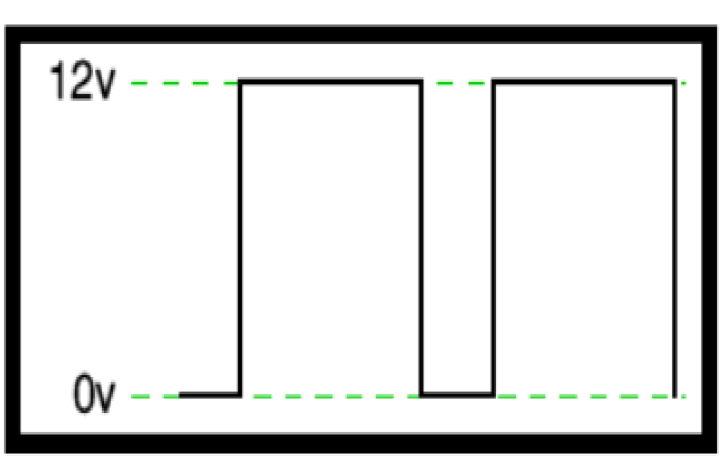

Fig.4.2 Average voltage will be 3/4 of 12v

PWM OPERATION

At the rising edge of the PWM Load signal, the sub-module SVPWM_Tm begins its computations upon receiving the modulation index instructions (UAlpha and UBeta). The SVPWM _Tm module includes an algorithm that determines the suitable time duration (within one PWM cycle) for each active vector and chooses which active space vectors (V1 to V6) to employ based on sector determination. Additionally, the appropriated zero vectors are being chosen. In normal circumstances, the SVPWM _Tm module uses 11 clock cycles; in worst-case scenarios, it uses 35 clock cycles (Tr).

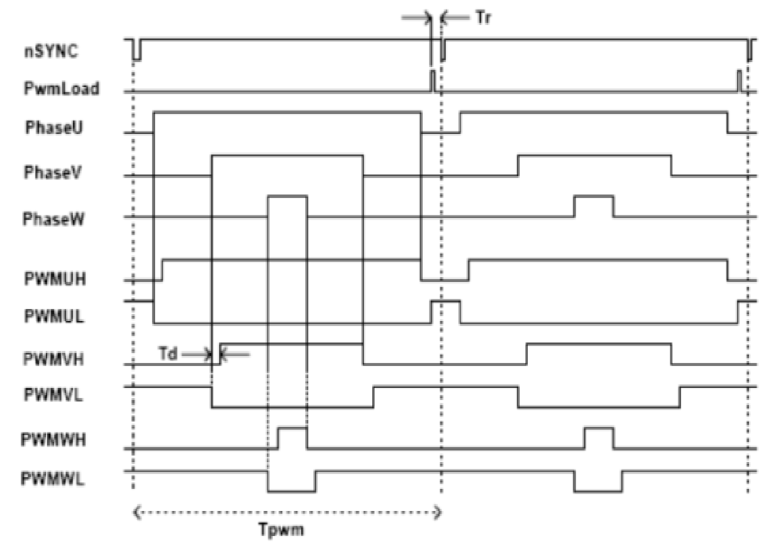

Fig.4.11 3-phase Space Vector PWM

5.PI CONTROLLER

As PI control, only employ the integral and proportional terms. Even more so than complete PID controllers, the PI controller is the most often used version. The modified variable input that is provided into the system is the value of the controller output, u(t).

u(t)=ubias+Kce(t)+KcτI∫t0e(t)dt

e(t)=SP−PV

5.1 DISCRETE PI CONTROLLER

Discrete sampling periods are used in the implementation of digital controllers, and the integral of the error must be approximated using a discrete variant of the PI equation. In this version, Δt is used as the time interval between sampling instances, and nt is the number of sampling instances. The continuous form of the integral is replaced with a summation of the error.

u(t)=ubias+Kce(t)+KcτInt∑i=1ei(t)Δt

5.2 ADVANTAGES AND DISADVANTAGES

In contrast to proportional-only control in general, the integral term in a PI controller causes the steady-state error to drop to zero. In the event of noisy data, the absence of derivative action could help the system remain more stable in the steady state. The reason for this is because higher-frequency variables in the inputs have a greater effect on derivative behavior. A PI-controlled system will be longer to achieve its set point and react to disturbances than a well-tuned PID system if derivative action is absent. This is because a PI-controlled system is less sensitive to actual (non-noise) and relatively quick changes in state.

MATLAB & SIMULATION RESULTS

6.1 SIMULATION CIRCUITS

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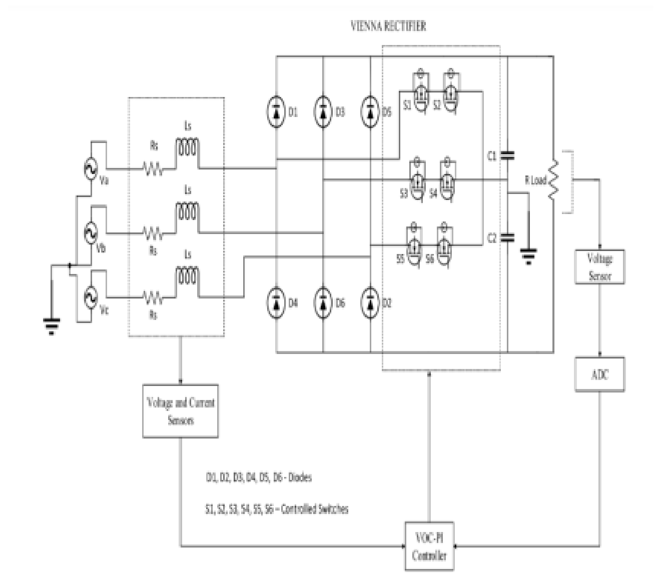

Fig.6.1 The proposed electric vehicle charger is based on Vienna rectifier with a VOC controller (VOC-VR) system.

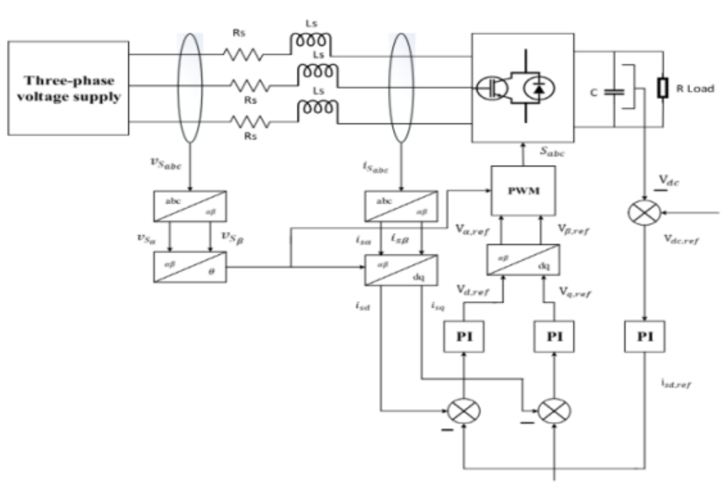

Fig.6.2 The control structure of voltage-oriented controller with PWM technique

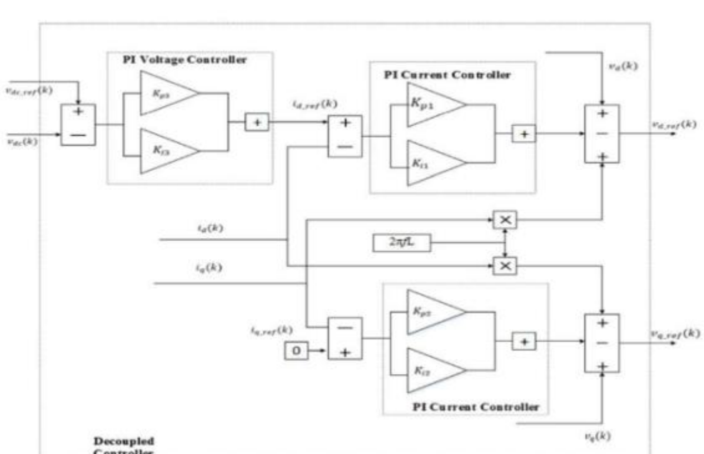

Fig.6.3 The control circuit of the decoupled controller for the voc technique

6.2 SIMULATION RESULTS

6.2.1 VOC WITH PWM TECHNIQUE

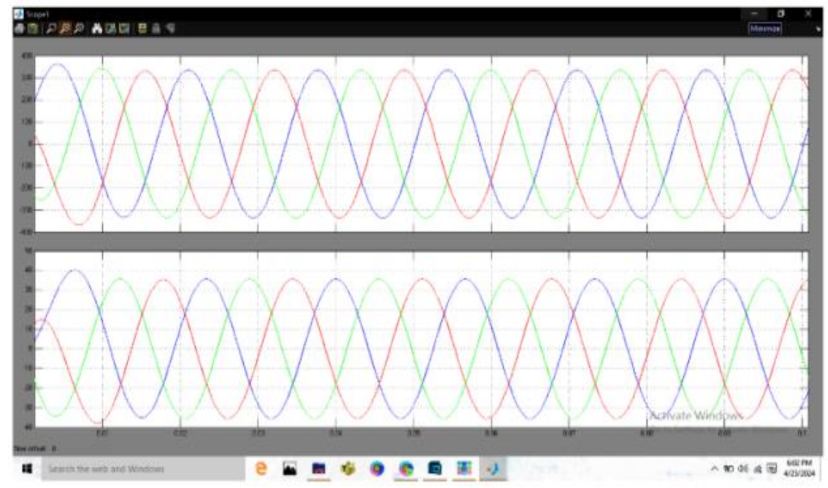

Fig.6.4 Input Waveform for VOC with PWM Technique for Fast Charging Stations

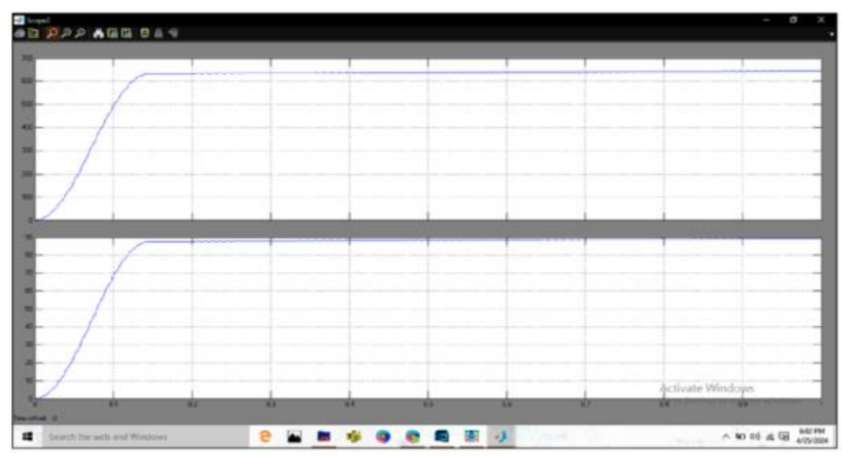

Fig.6.5 Output Waveform for VOC with PWM Technique for Fast Charging Stations

6.3 THD VERIFICATION

6.3.1THD VERIFICATION-VOC CONTROLLER

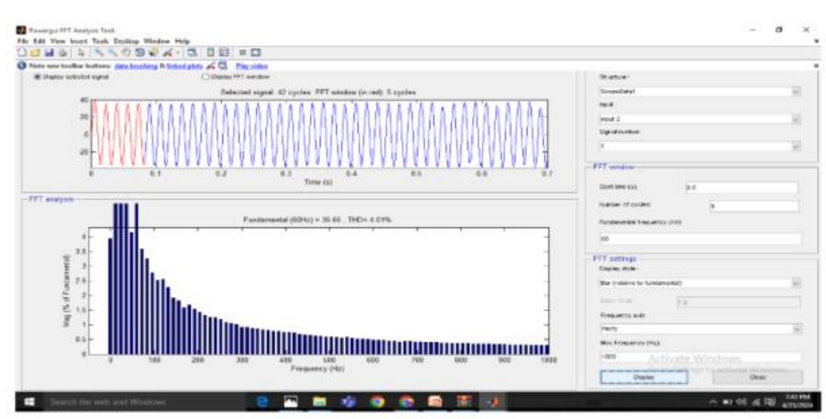

Fig.6.6 THD for Voltage Oriented Controller with PWM Technique

6.3.2 THD VERIFICATION- DECOUPLED CONTROLLER

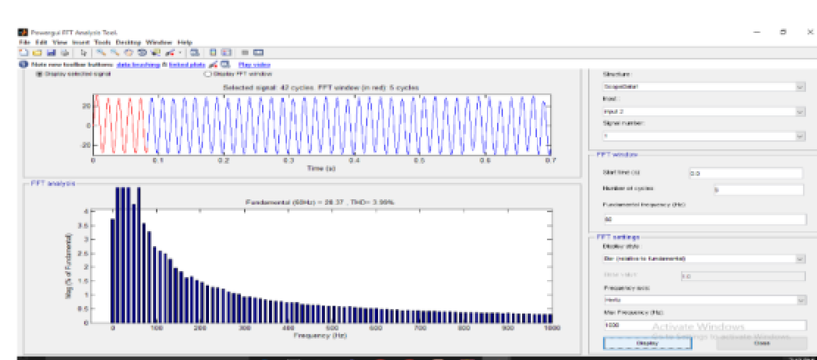

Fig.6.7 THD for Decoupled Controller Method

7. CONCLUSION

The voltage-oriented controller (VOC-VR) has served as the foundation for the design and simulation testing of a three-level Vienna rectifier in this study. With MATLAB Simulink software, the suggested system has been simulated with an eye on high-power applications like DC-fast chargers for electric vehicle. The Vienna rectifier's suggested controller focused on integrating voltage-oriented controls with the PWM technique. The input and output filters, as well as the Voltage Oriented Controller (VOC) and Vienna rectifier, counterbalance the reactive and unstable active currents in the proposed system. A sinusoidal current with the fewest ripples and distortions is also guaranteed by the suggested design at the input side. The input current's total harmonic distortion is kept at 5%, in compliance with IEEE-519 standards, and the system's power factor remains at unity. Simulations data has shown how advantageous the suggested controller is over the traditional PFC controller. The voltage-oriented controller-based Vienna rectifier is a great option for electric car charging stations because of its low THD, strong power factor, and less need for filtering.

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