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Vienna Rectifier for Electric Vehicle Charging Station

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Abstract:

Vienna Rectifier includes the Input stage AC converter system and it helps to boost the output voltage with reduced ripple. In conventional rectifier it draws a non-sinusoidal current from the grid whereas Vienna rectifier draws sinusoidal current from the grid. The main difference between conventional and Vienna rectifier is the harmonics, power factor and efficiency. Vienna rectifier has no harmonic content at grid side and it has improved power factor with high efficiency. The output voltage control technique is used to get the reduced ripple output for a battery charger. Here, Vienna rectifier is used for Level 3 of EV charging station for the battery load of 30kW.In this rectifier, it separately controls the current at grid side. It also has reduced switching losses and less complexity with a unidirectional flow of power that is it transfer power from grid to battery of EV.

Key words: Switching loss, Sinusoidal, Harmonics, Design, Control and Charging.

INTRODUCTION

Power electronic converter plays a vital role in EV charging station which includes AC-DC, DC-DC and DC-AC categories. EV batteries should be charged up to certain level to have enough energy for vehicle during travel. Various battery chargers for EVs are aiming at fast or slow charging dependent on the power rating and place of charge. The Vienna rectifier topology used here is a 3-phase, 3-level and 3-switch (controllable) rectifier. It has been commonly used for several high-power applications due to its high efficiency, high power density and low THD [1]. The invention of the Vienna rectifier has reduced the number of controllable switches of 3-phase rectifiers into three switches, as opposed to the conventional rectifier, which has six switches.

Several electronic equipment's that are interfaced with the grid has rapid switching of currents in power electronic devices causes harmonic distortion in the mains network. These harmonics may interfere with other electronics devices connected to the same grid. To overcome this issue, Vienna rectifier with PFC topologies is proposed to make these switching behaviors appear as resistive loads with a unity power factor to the mains [2]. The sinusoidal current waveform with low THD, high efficiency, and power density are gained. In order to reduce the input current quality LCL filter is designed and used in the input side of the rectifier.

In this rectifier, the required AC filters are relatively small as compared to conventional rectifiers. The switching losses are minimized while the converter boost ratio is increased in this topology [1][2]. It plays a vital role in suppressing higher order harmonics that generated during the switching process and the dc link capacitor has two identical parameters that Constitute tri-level structure. In this rectifier topology it consists of two fast recovery diodes per bridge arm and it also has three sets of bidirectional power converter switches.

Design of a 30 kW, Three-phase/level Vienna rectifier is implemented which characterizes sinusoidal input current, less than 5% current harmonic distortions at the supply side and unity power factor. The Vienna rectifier topology has design procedure, device selection, control technique, selection of Inductor and battery output is presented.

1. SYSTEMDESCRIPTION

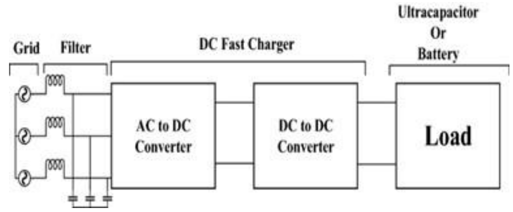

Figure 1: Block Diagram of DC Charging

Figure 1 shows the basic Block diagram of DC charging with Vienna rectifier. According to the power rating, the chargers are classified as Level1, Level2 and Level3 type of chargers. In which Level 1 & Level 2 are designed for home charging with less power consumption of 2kWwith voltage of 120/230V and the public charging stations with 20kW of power whereas Level 3 type of charger are used for commercial charging stations which are directly connected to the medium voltage systems with three phases [3]. EV chargers are separated as on board and off board chargers and by the flow of power the EV batteries can be of unidirectional or bidirectional type. The unidirectional flow of power chargers is used for G2V and bidirectional flow of power are used for both G2V and V2G.The proposed converter is a unidirectional which is only from G2V.

This type of chargers can be controlled to charge battery from grid according to the type of chargers used.Here, Level 3 type of DC charging is selected in which it follows a two basic concepts. The One which converts a three phase AC supply into a Variable DC output which deals with exact DC output voltage when the vehicle is charged. Another concept is to convert the three phase AC supply to fixed DC output voltage [3]. With neither of these two approaches the vehicle is charged and the main objective of this design is to minimize the system size, cooling conditions and which gives high power density.

2. TOPOLOGYOF VIENNA RECTIFIER

Three phase power is used by equipment operating at high power applications in order to improve the grid side current quality and to reduce the harmonics at input current power factor correction is needed for DC loads [5]. Though there exist many topologies for power factor correction, Vienna rectifier plays a major role due to its reduced harmonics, continuous conduction mode and reduced voltage stress on the devices used. The sine-triangle PWM technique is used to control Vienna rectifier.

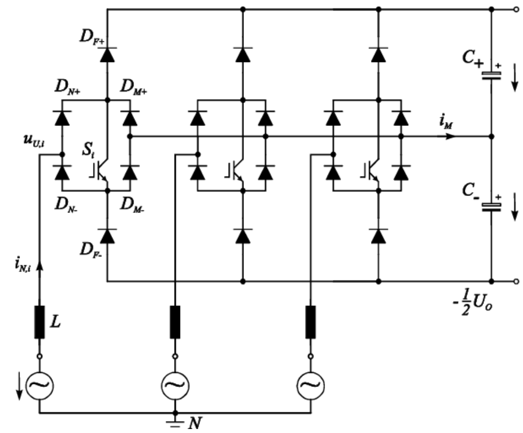

Figure 2: Topology of Vienna Rectifier Circuit with the bidirectional bipolar switch

The proposed converter consists of three phase three switch Vienna rectifier which is commonly used for high power application due to its low THD performance, unity power factor and high efficiency. The designed rectifier has reduced number of switches compared to the conventional rectifier which has six switches. When compared to the conventional rectifier this Vienna rectifier has small filter design to reduce the ripple at output and input side of the converter [5]. The output side DC link capacitor constitutes to trilevel structure with two identical components. It also consists of two fast recovery diodes for each bridge arm and bidirectional switches with three sets are considered for this topology because the phases are independent to each other.

The main aim of this topology is to improve the power factor and should reduce the harmonic content on grid side current of less than 5% [4]. It helps to increase the input current quality and to design the rectifier with reduced ripple for the EV battery. Vienna rectifier designed for boost derived three switch converters with output voltage control technique. The main advantage is without harmonics at input and the operation is even in unbalanced condition. When the Switch is turned ON the inductor gets charged and it drives the current through bidirectional switch[9]. When MOSFET switch gets deactivated the current bypass through the switch and it flows through the freewheeling diode.

3. LCLFILTER FOR VIENNA RECTIFIER

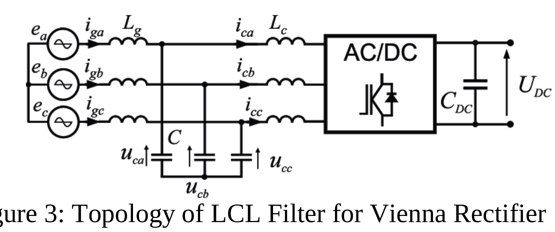

Figure 3: Topology of LCL Filter for Vienna Rectifier Circuit

Simple type of filter that can be used is a series inductor, but its harmonic attenuation is not very pronounced and high voltage drop is produced, hence the size of inductor becomes bulky. The LCL filter is designed for the Vienna rectifier to reduce the harmonic in input side and to interconnect the designed converter to the grid [6][7]. Higher Order LCL Filter is used to replace of conventional L filter for smoothing output current. Higher attenuation is achieved along with cost savings and total weight and size reduction of the components. Good performance can be obtained using small values of inductors and capacitors [10].

4. DESIGN OFVIENNA RECTIFIER

The specifications for the design of 3-phase, 3-level rectifier has been shown in Table 1. Assumptions made are the input current to be a pure sinusoid and the rectifier to be operating at UPF with Efficiency of 98.5 %.

Table 1: Specifications

S.No.	**Parameter**	**Value**
1	RMS Voltage,Vrms	400V
2	Input Voltage, Vin	326V
3	Ripple Voltage, △Vc	20%
4	Output Voltage, Vo	700V
5	Output Power,Po	30kW
6	Efficiency, η	98.5%
7	Switching frequency, Fsw	140kHz

Table 2: DesignCalculations for Vienna Rectifier

Formulas	**Calculated Values**
δ=(Vo-Vin)/Vo	0.534
M= Vo/ (sqrt (3) *Vin)	1.23
Pin=Pout/η	30.45kW
I_N = Pin/(3*Vrms)	25.3A
I_D,avg = I_N/ (2*sqrt (3) *M)	5.95A
I_D,rms = I_N/(sqrt(4/3*sqrt(3)*π*M)	11A
Icout= I_N*sqrt((5/(2*π*M) -(3/ (4*M2)))	10A
I_{PK}= (sqrt (2) *Pin)/ (sqrt (3) *PF*Vin)	62A
L= (Vin* δ)/ (Fsw* I_{PK})	200μH
C= (Icout* δ)/ (Fsw* △Vc)	2800μF

Table 3: DesignCalculations for LCL Filter

Formulas	**Calculated Values**
Fres=Fsw/10	14kHz
C=(0.05*P0)/(V2*2*π*f)	45 μF
Lmax=(0.2*Vg)/ (2* π*f*I)	2.2mH
L1=L2=Lmax/2	1.1mH

5.1 Control Technique

In DQ-axis control, the time-dependent, three-phase currents are transformed into a time-invariant, two-coordinate vector using projections [2]. These transformations are the Clarke Transformation, the Park Transformation, and their respective inverse transformations.These transformations are implemented as blocks within the Measurements subsystem. To maintain a power factor, close to 1, the reactive power being drawn from the grid should be close to zero. Therefore, commanding a zero Q-axis current from the controller allows the power factor to be close to 1

In the model, the controllers have the following gains:

- Both DQ-axis current PI controllers: P = 5 and I = 500
- Voltage neutral P controller: P = 0.001

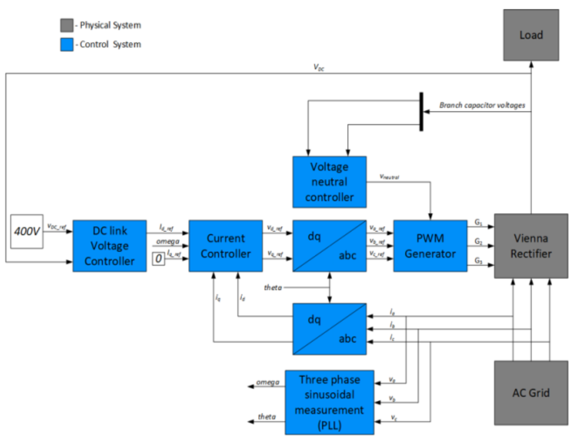

Figure 4: DQ control for Vienna rectifier

The controller gains are stored in a Data Store Memory block and provided externally to each PID block [8]. When the tuning process for a controller is complete, the new tuned gains are written to the Data Store Memory block. This configuration allows you to update your controller gains in real-time during the simulation.

5. SIMULATION MODEL

The simulation model of 3-Phase, 3-Level Vienna rectifier with required specifications with DQ transformation control technique is implemented in MATLAB/SIMULINK is shown in Figure 5.

Figure 5 shows the Three-phase Vienna rectifier is simulated with bidirectional diodes consists of six diodes with single MOSFET switch. Then the output from diode fed to the DC link Capacitor which is connected to the battery load of 30kW. The closed loop circuit is done with PI controller with Clarke and park transform. The Battery connected load is of lithium ion with nominal voltage of 700V.The LCL filter is designed to reduce input THD [11].

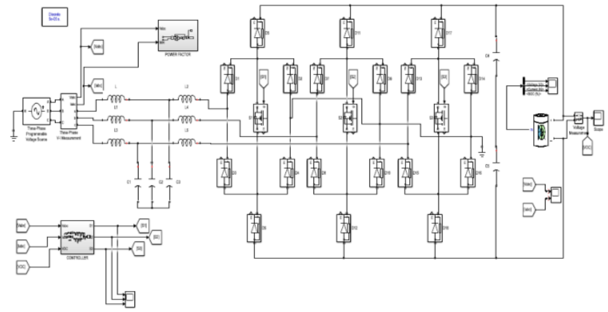

Figure 5: Vienna rectifier with DQ control

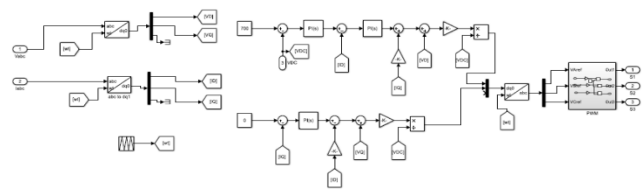

Figure 6: DQ controller subsystem

The Controller subsystem of Vienna rectifier is shown in Figure 6. The three-phase input voltage and current are converted to two component that is Vabc and Iabc is converted to Vd, Vq, Id and Iq in comparison with the repeating sequence. Then, to maintain the output voltage at 700V it is compared with the reference value and the signal is fed to the PI controllers to control the output voltage at DC link capacitor.

PI controller is used for the control. Two PI Controllers have been used in which one of the controllers is used for current control and the other is used for voltage control. Then dq axis is transformed to three phase abc to generate PWM pulses

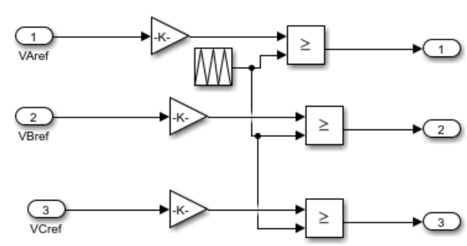

Figure 7: Subsystem of PWM pulse generation

Figure 7 shows thePWM generation for Switching Sequence. This subsystem shows the pulse generated by comparing the reference value of the input voltage with the carrier signal. Then the output pulse is fed to the three MOSFET switches of the Vienna rectifier.

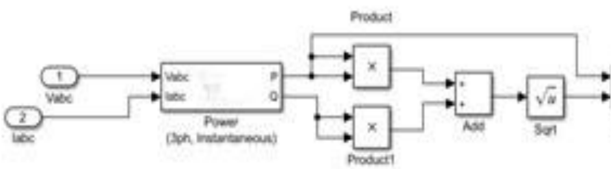

Figure 8: Subsystem for Power Factor

Figure 8 shows the Power factor is determined by using the formula and it is simulated in MATLAB simulation.

6. RESULTS ANDDISCUSSION

Figure 9, Figure 10, Figure 11 and Figure 12 shows the input voltage waveform of Vienna rectifier with 330V with sinusoidal voltage which phase shifted of 120. The Input current of Vienna rectifier with good input current quality at the peak current of 12A the Input Current THD performance of the Vienna rectifier in order to get improve input current quality. The Input current harmonics in Vienna rectifier should be less than 5% and it shows the THD of 3% for the fundamental frequency of 3.09Hz This Waveform shows the battery voltage, current and state of charge percentage. It shows the output voltage reaches 700V while charging and the current gets zero at that state of charge reaches 50% when the rated capacity is reached.

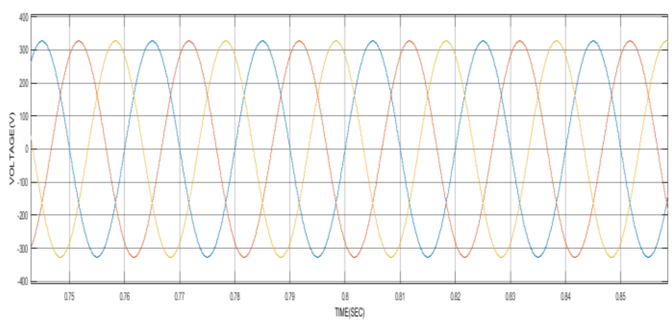

Figure 9: Input Voltage Waveform

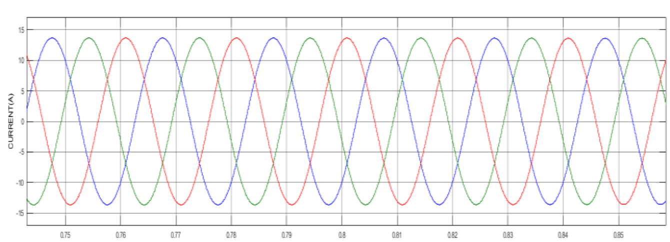

Figure 10: Input Current Waveform

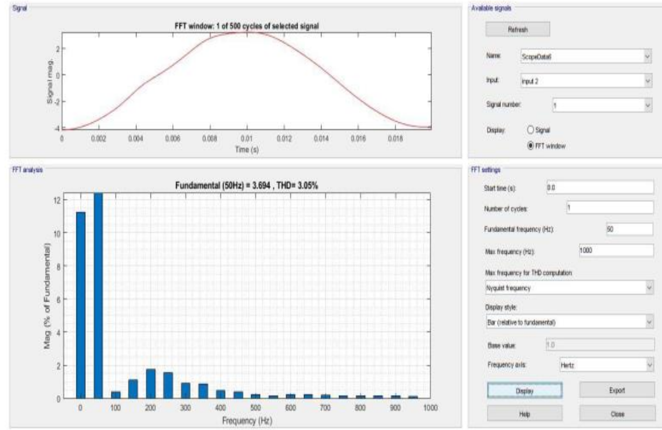

Figure 11: THD Analysis

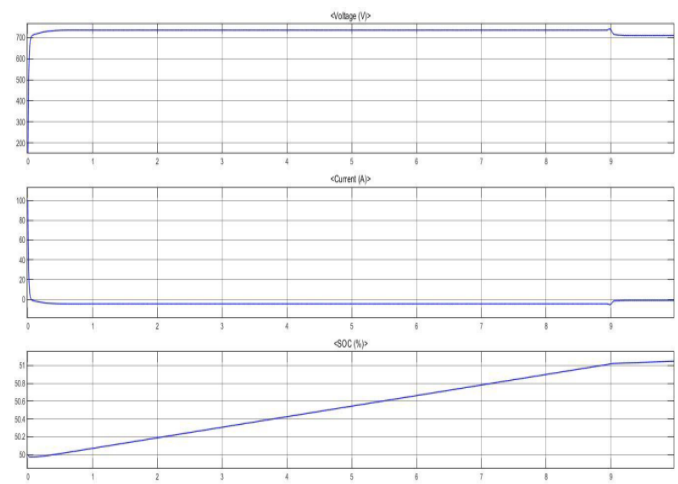

Figure 12: Battery Output Waveform

7. CONCLUSION

In this paper, the performance of the Vienna Rectifier is simulated and analyzed in terms of power factor and THD using MATLAB/Simulink software. The proposed converter is having improved power factor in the ac mains and reduced input current THD of 3%. The Vienna Rectifier is more admirable power converter in terms of efficiency, THD, and power factor for the electric vehicle charging stations. The LCL filter is designed for the rectifier to reduce the input current harmonic and it is achieved less than 5%. The proposed converter is designed for 30kW battery load of lithium ion and it is simulated and the output waveform is verified and analyzed with the conventional rectifier. The simulation results shows that Vienna Rectifier satisfies the all the requirements like Sinusoidal input current,Unity power factorandSource current THD less than 5%.

8. REFERENCES

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