Analysis between different types of 4-quadrant switches used on EV's Charger Rectifiers

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Abstract. This research paper presents an analysis of different types of 4-quadrant switches topologies for 3 phase rectifiers, namely T-type, NPC-type, and VIENNA-type. The aim of the study is to compare and contrast the performance of these topologies in terms of power output. The analysis is conducted through simulation studies using the PSIM software, which includes modelling and simulation of each topology. The results reveal that each topology has its unique advantages and limitations. Overall, this study contributes to the understanding of different 4-quadrant switches topologies and suitability for different applications.

Keywords. 3 phase rectifiers, 4-quadrant switches, electric vehicles (EV), battery chargers.

1. Introduction

In the recent years is notable the ever-rising trend of automobile makers in developing Electrical Vehicles (EVs) models. Sales of EVs doubled in 2021 from the previous year to a new record of 6.6 million, which account for 10% of global car sales [1].

This increase in sales also come with the increase of the electrical grid usage, [2] states that the spread of electric vehicles will lead to an additional increase in electricity consumption of 7-10% by 2040.

In order to obtain a great balance between efficiency, power-density and overall complexity is to use unidirectional AC/DC rectifiers [3]. This type of rectifiers allows to adopt semiconductor devices with half of the with respect to conventional 2-level inverters, strongly enhancing the switching frequency capability of the converter while also ensuring minimum converter complexity [4].

It is expected to see the rise of 3-phase unidirectional chargers in charging stations since they can output a great amount of power and don't need the bidirectional capability that a house charger can expect. So, it becomes important to analyze the effects that different types of 4-quadrant switches can have on the charger. In this paper it will be shown the comparison between the power output on the T-type, NPC-type and VIENNA type topologies using simulations on the PSIM software.

2. Methodology

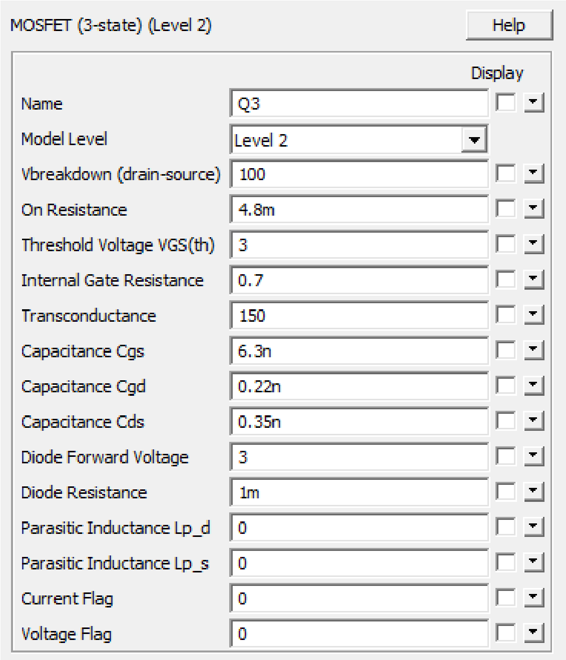
To analyze the effects on power output of the different types of 4-quadrant switches, three simulations were made in the PSIM software, each of them using one of the switches topologies and similar control signals on the MOSFETs. Then, the load voltage, current and power output were measured and compared.

2.1 3 phase Rectifier components specifications

The load choose was a simple 2.5 ohm resistor and for the capacitor, an ideal 1 F capacitor. The source used was a sinusoidal three phase 220V 60Hz source, which is the residential voltage used in the coast parts of Brazil.
All the components which are not associated with the 4-quadrant switches were defined as ideal on the simulations.

2.2 Switch MOSFET and Diode specifications

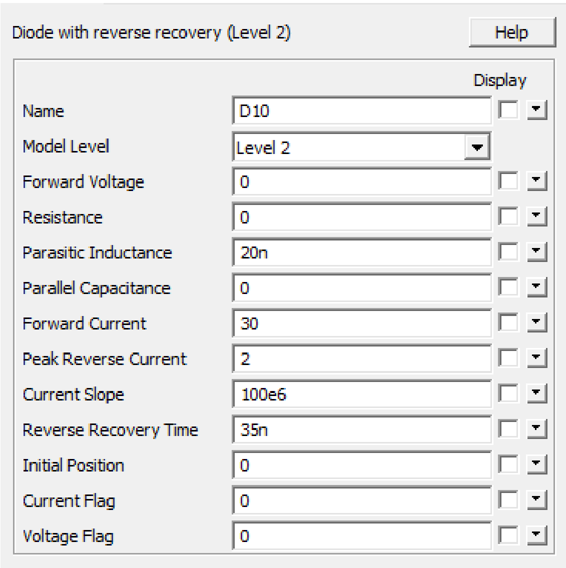
The MOSFETs and the diodes used were the "level-2" available on PSIM with the following specifications that can be seen on the figures 1 and 2.



MOSFET (3-state) (Level 2) — Help — Display

Name	Q3
Model Level	Level 2
Vbreakdown (drain-source)	100
On Resistance	4.8m
Threshold Voltage VGS(th)	3
Internal Gate Resistance	0.7
Transconductance	150
Capacitance Cgs	6.3n
Capacitance Cgd	0.22n
Capacitance Cds	0.35n
Diode Forward Voltage	3
Diode Resistance	1m
Parasitic Inductance Lp_d	0
Parasitic Inductance Lp_s	0
Current Flag	0
Voltage Flag	0

Fig. 1 – MOSFET specifications.



Diode with reverse recovery (Level 2) — Help — Display

Name	D10
Model Level	Level 2
Forward Voltage	0
Resistance	0
Parasitic Inductance	20n
Parallel Capacitance	0
Forward Current	30
Peak Reverse Current	2
Current Slope	100e6
Reverse Recovery Time	35n
Initial Position	0
Current Flag	0
Voltage Flag	0

Fig. 2 – Diode specifications.

2.3 Circuits

The circuit used for the T-type switch was the following:

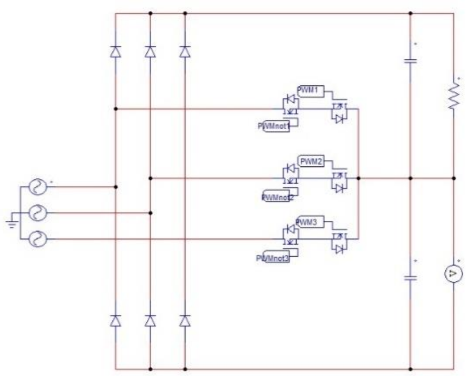


Fig. 3 – T-type circuit.

The NPC-type:

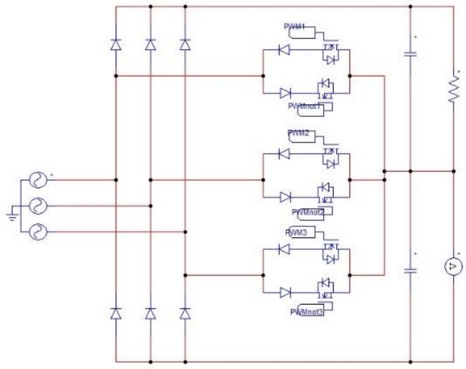


Fig. 4 – NPC-type circuit.

The VIENNA-type:

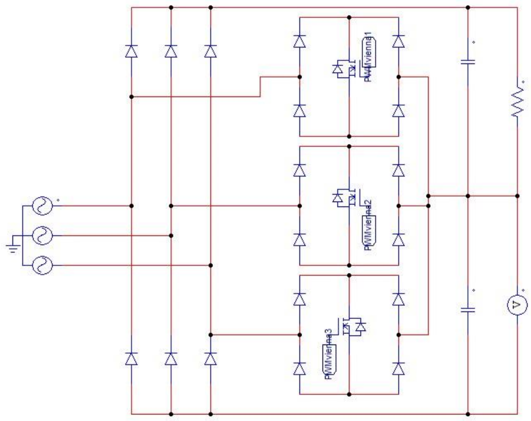


Fig. 5 – VIENNA-type circuit.

2.4 PWM control of the different switches

In order to control the different MOSFETs used on the T-type and NPC-type switches, six types of signals had to be generated, "PWM1" is a step signal which is defined as "1" when $\pi/6 < \alpha < 5\pi/6$. "PWMnot1" is equal as Signal One, but with a phase angle increase of π.

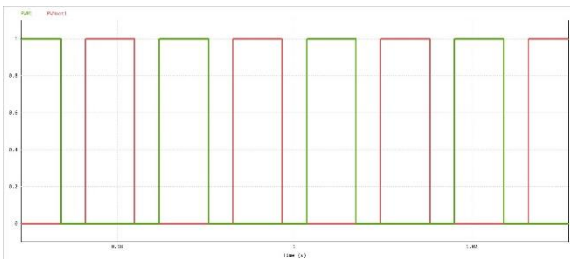


Fig. 6 – PWM1 and PWMnot1 signals.

"PWM2" and "PWM3" are also the same as "PWM1", but with a phase angle increase of $4\pi/6$ and $8\pi/6$ respectively. "PWMnot2" and "PWMnot3" are also the same as "PWMnot1", but with a phase angle increase of $4\pi/6$ and $8\pi/6$ respectively.

Then, for the Vienna switch, the signal “PWMvienna1” was generated simply by summing the signals “PWM1” and “PWMnot1”.

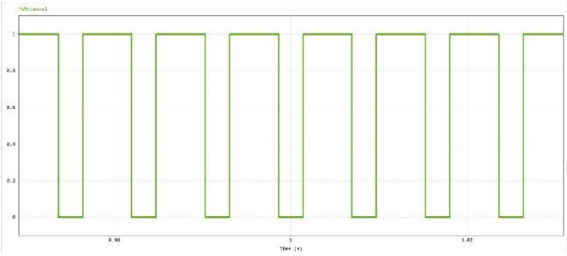


Fig. 7 – PWMvienna1 Control.

And lastly, “PWMvienna2” and “PWMvienna3” are also the same as “PWMvienna1”, but with a phase angle increase of 4 π/6 and 8 π/6 respectively.

In order to implement the signals described previously on the PSIM software, The following circuit was used.

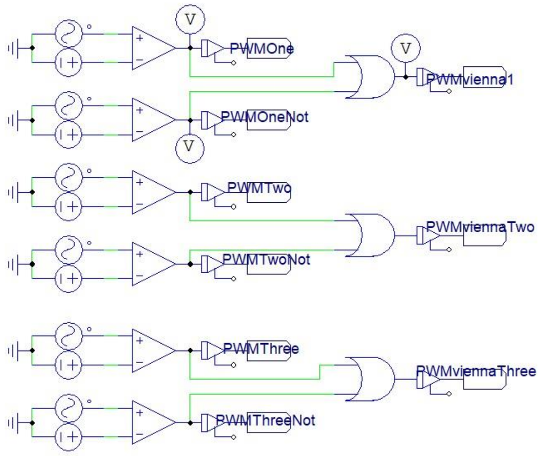


Fig. 7 –Control circuit.

The sources that are used on the Op amp input are a sinusoidal 60hz 1V source and a DC 0.5V source. The sinusoidal source has a phase offset depending on the signal that is being generated. For the Vienna signals, the PWM and PWMnot signals were summed using the logical operator “OR”.

3. Results

From the circuits used previously, it was possible to run a simulation for two seconds, so that the system could enter the steady state, and then, measure the following average values on that state of operation:

Tab. 1 – Power Output comparison.

Switch type	Average Voltage Output (V)	Average Current Output (A)	Average Power Output (KW)
T-type	160,04	6,40	10,24
NPC-type	168,03	6,72	11,29
VIENNA-type	170,18	6,80	11,58

4. Discussion

Based on the results the results we can conclude that the VIENNA-type was the switch that could output the most amount of power, but had the most impact on the MOSFET, since there is only one which to pass all the current.

The NPC-type has two different paths for the current to flow through, lowering the stress on each MOSFET and diode and had little power output difference in comparison to the VIENNA type.

The T-type on the other hand, had the lowest power output of the three. And also,it is possible to note that the MOSFETs suffer from the same stress as of the VIENNA-type, since the forward and reverse current has to flow through both of the MOSFETs used on the topology.

This study was limited only to the analysis of the power output of the different topologies, further analysis must be made to measure the impact on each component used on the different topologies and the cost of them (including the number of components and the complexity of the switch), so together with other parameters it’s possible to define the best topology for a specific application.

It is also important to note that the most common unidirectional AC/DC converter used in off-board charging system is the Vienna rectifier even though it has the drawbacks of having the limitations of restricted reactive power control, and the need of a dc-link capacitor voltage balancing [5].

5. Acknowledgement

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6. References

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