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Elimination of Harmonics in 12-Pulse Diode Rectifier Using Current Source

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***Abstract*—12-pulse converters are generally used to supply high power industrial loads. Its ability to achieve dc output with very low harmonics to effectively and cheaply its use in the industry even as active front end becomes cheaper and more reliable. Beside it has many benefits, the 12-pulse converter is not able to reduce the ac-side harmonics to a level acceptable by IEEE standards without the use of additional filter. In this paper, we describe a new method to profile the converter output current to be triangular due to which it has low ac-side harmonic present. Extra advantage of this type of approach is that we use the dc-side filter to minimize volt-amperes rating of current source used to profile the dc-side rectifier current. One more additional benefits of the proposed method is simple integration of dc energy storage and its reducing harmonic even, initial rectifier current is discontinuous.**

Keywords— Index Terms—12-pulse diode rectifier, energy storage, harmonics, active power filter.

I. Introduction

Presence of reliable and low cost semiconductor devices has increase to large power electronics complex industrial loads requiring dc power supply for efficient operation. When a number of dc-powered loads are in large number, it can be done for them to share a common dc bus. Many such system benefits from local dc storage system to perform the following things: 1) Reduce the power demand from the power grid..2) It available for backup power for emergency condition.3) Store locally generated renewable power rather than feeding it back to the power grid.

The use of local dc distribution system is as follows: i. local dc distribution system is very useful for the data centre ii. These can be used for the purpose of dc-level plug-in van charging. iii. These can also used for air craft and electric ship. V. these can also used for submarine system and for the traction system where dc supply are required. v. these dc distributions system can be useful for radar and large no. of electronics device.

II. Theory

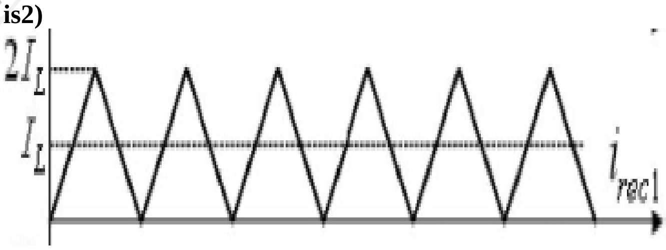
(A) Principle of harmonic elimination

By analyzing the operation of 12-pulse diode converter some method are required to shape the 12-pulse converter output current so that the ac-side harmonics (i_a,i_b,i_c) formed by the operation of the converter.

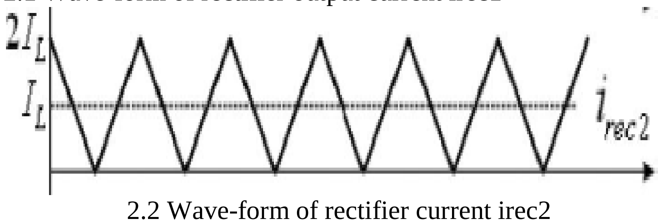
The exact shape should be triangular to elimination of ac-side harmonics completely

Other of previous IEEE paper shows that triangular wave form represent good approximation of the ideal rectifier output current so that the completely elimination of ac current harmonics. So assume the rectifier output current is profile to be triangular.

Fourier series expansion of rectifier output current (is1, is2)



2.1 Wave-form of rectifier output current irec1



2.2 Wave-form of rectifier current irec2

$$i_{rect1}=I_L+4I_L\sum_0^\infty \frac{1-(-1)^n}{n^2\pi^2}.\cos(6n\alpha t)$$

i_rect2= I_L

$$+4I_L\sum_0^\infty \frac{1-(-1)^n}{n^2\pi^2}.\cos 6\left(n\alpha t+\frac{\pi}{6}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

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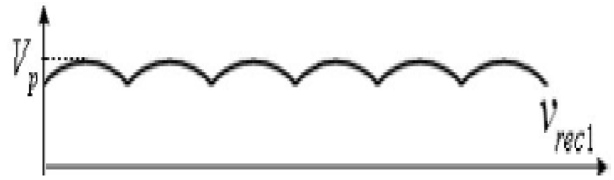
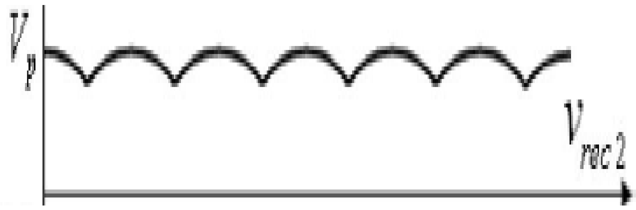
Where,
α=line frequency
I_L=load current
i_{rect1} And i_{rect2}=rectifier output current based on operation of 6-pulse rectifier

Fourier series expression of rectifier output voltage is:



2.3 Wave-form of rectifier output voltage



2.4 Wave-form of rectifier output voltage

Vrec 1=Vrec1-dc +Vrec-1 ac

$$v_{rect1}=\frac{3V_P}{\pi}+\frac{6V_P}{\pi}\sum_0^\infty \frac{-(-1)^n}{36n^2-1}.\cos(6n\alpha t)$$

$V_{rect\ 2}$=vrec-2 dc+V rect-2 ac

$$v_{rect2}=\frac{3V_P}{\pi}+\frac{6V_P}{\pi}\sum_0^\infty \frac{-(-1)^n}{36n^2-1}.\cos 6(n\alpha t + \frac{\pi}{6}) \qquad (2)$$

Where,
Vp =peak value of ac input voltage
Vrec1, Vrec2=rectifier output voltage
Assuming that profiling current is triangular it is very simple to calculate the ac side harmonics

$$i_a = (i_{a1} - i_{c1})/\sqrt{3} + i_{a2} \qquad (3)$$

We can express the ac-side current i_a as the sum of Fourier expansion of the rectifier current Irec1 and Irec 2.

$$i_a=\frac{i_{irect1}.S<30^\circ - i_{irect1}.S<150^\circ}{\sqrt{3}} + i_{irect2}.S<0^\circ \qquad (4)$$

Where,

$$s = \frac{2\sqrt{3}}{\pi}\left(\sin(\alpha t) - \frac{1}{5}\sin(5\alpha t) - \frac{1}{7}\sin(7\alpha t) + \frac{1}{11}\sin(11\alpha t) + \frac{1}{13}\sin(13\alpha t)\right) \qquad (5)$$

By finding numerically ac side harmonics are approximately 1%.
By analyzing all the equation we find,
Both Vrec and Irec have large ac component which are 6 times the supply frequency.
Fundamental ac component of both voltage and current are in same phase for each 6-pulse rectifier.
But these voltage and current are out of phase as compare to upper and lower converter.
Hence, fundamental voltage and current are in phase hence we use these component in LC filter design

III.PROPOSED WORK

A new proposed approach in this project is insert three current source in to the circuit .two current source i_{s1} and i_{s2} are used to profile the rectifier output current to be triangular so that the harmonic content in ac-side can be eliminated.
In addition to inject active power in to the system we also show that the proper use of lc filter design we can minimize the VA rating required for current source to eliminate the harmonic.
For example, in direct profiling case the direct comparison with other proposed method is more difficult because the VA rating of the voltage source be a function of design of whole system.
The hardware implementation of three current source are shown in figure and current source can be design using two cascade buck-and-boost converter and which two provide two independent current source i_{s1} and i_{s2}.third current source i_{s3} result from combination of current source i_{s1} and i_{s2} ($i_{s3} = i_{s1} - i_{s2}$).

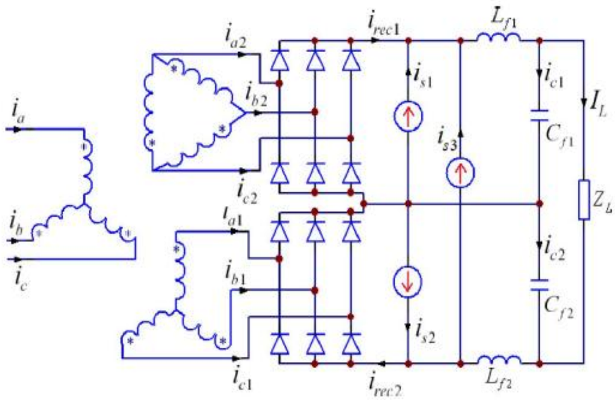


fig.3.1 12-pulse diode rectifier using current source

The supply of dc bus is form the dc bus of cascade buck-and-bust converter, same as active filter design; otherwise this dc bus can be used as dc energy storage.

Advantage of proposed method with respect to existing method:

(i).parallel connected current source can be used as both energy storage system and to inject active power.

(ii).additional 360 Hz transformer is eliminated which are used in ref.no [8]-[11].

(iii).proposed method still work if the output current is discontinuous but existing method cannot be used when output current are discontinuous and only used for continuous current.

(iv).the current source work when the difference between current source i_{s1} and i_{s2} compensation are comparatively less.

3.2: System Analysis And Parameter Optimization

We design a system whose main function is to shape the rectifier current of each 6-pulse rectifier to be triangular. To improve the efficiency of the system we should need to minimize the VA rating of the current source by the use of proper choice of filtering component.

The equivalent circuit of the 12-pulse converter is shown in fig.

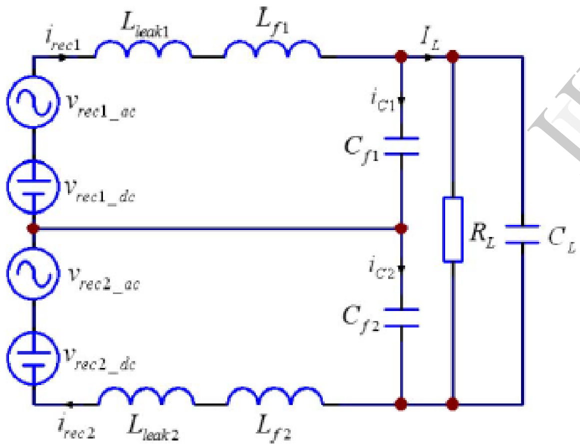


Fig.3.3 Equivalent circuit of 12-pulse rectifier circuit

Considering the fundamental and DC component of each 6-pulse rectifier are connected in series. Two voltage source are connected in series produces DC current to load i_{rect}

The DC load current is,

$$I_L = \frac{6.V_p}{\pi R_l}$$

To attenuate V_{DC}, we use LC filter which are formed by additional inductor L_f towards load and leakage inductance $L_{leakage}$.

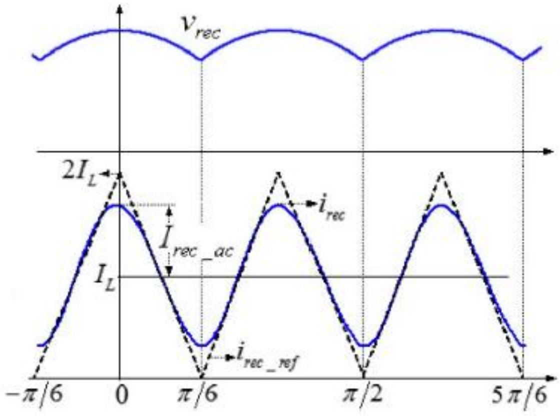


Fig.3.4 rectifier output voltage and current.

Because at resonance the impedance are infinite for other parallel circuit and hence i_{rect} can be determine by the V_{rect_ac} and ESR of the LC filter.

Hence peak value of the ac component of i_{rect},

$$I_{rect\_ac} = \frac{6.V_p}{35\pi\ ESR_{lc}}$$

Where,

ESR_{lc}=equivalent series resistance of LC filter. And which are depends on the load current.

ESR can also be optimized for one value of load current.

Let m be the optimal ratio between ESR_{lc} and of R_L,

$$\text{Hence, m} = \frac{i_{rect\_ac}peak,}{I_L,}$$

By solving m numerically that gives minimum difference between fundamental component and reference value.

For the waveform in the fig

M=.77

Hence,

$$\frac{ESR_{lc}}{R_l} = \frac{1}{35m}$$

Hence ESR can be chosen for a certain load resistance.

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3.3: Injected Current Flow:

Using superposition theorem current can analyze that the current source which are using for current profiling can flow current through three possible paths.

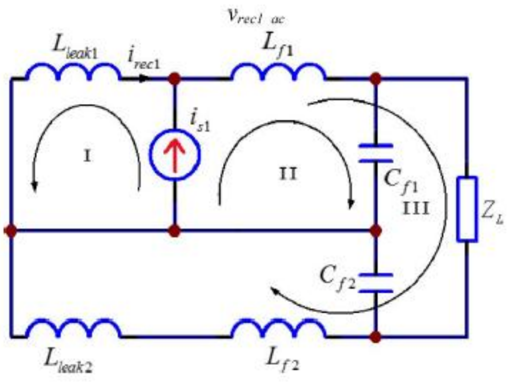

Fig .3.6 current loop analysis.

Ideally current should flow through the path ì.
Assuming worst condition, the output current is purely DC in that case,
Current source needed to inject current,

$$4I_L \sum_0^\infty \frac{1-(-1)^n}{n^2\pi^2}.\cos(6n\alpha t)$$

Hence fundamental current required frequency is 360 HZ.
Hence if L_f is higher than that $L_{leakage}$ then the current take a path first.
At 360 HZ, when L_f and C_f are at resonance only path one and two are possible.
Hence to insure that current will flow through desire path we should minimize the transformer leakage inductance and ESR .so that most of current can flow through path one.

3.4: Control Strattegy

Our main focus on that section is to control the current flowing through the two inductors L_{f1} and L_{f2} with the help of control of three current sources. If we control the current I_{S1} and I_{s2} then automatically it control the current through two inductors respectively. Similar to active filter design we use the simple proportional controller to act on the error between reference current I_{S1} and I_{s2_ref} and similarly error between current I_{S2} andI_{s2_ref}.

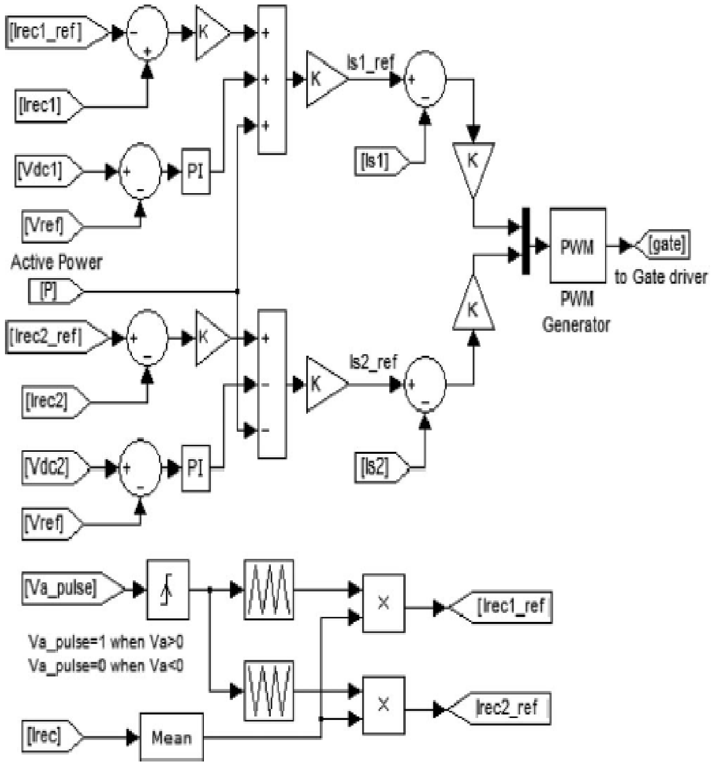

Fig.3.7 Control circuit

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IV.RESULT

4.1: Parameters of the ac/dc rectifier for simulation:

Buck and boost DC link voltage	1200V
Buck and boost output filtering inductor	100µH
Buck and boost switching frequency	20 KH
Rectifier output capacitor (C_{f1} ,C_{f2})	3.6 mF
Total equivalent series resistance of L_f and C_f	18.6m Ω
Output power	1 MW
Transformer primary voltage	4160 V
Transformer secondary voltage	240 V
Transformer leakage inductance	5µH
DC side inductor	44.3µH

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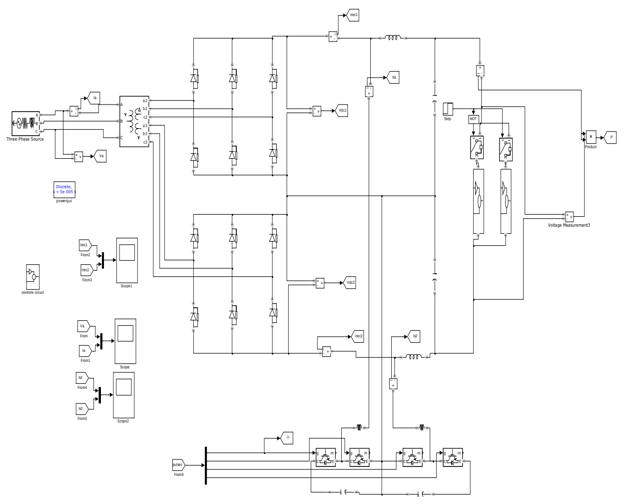

5.2: Wave Form Of 12-Pulse Diode Rectifier With Current Controlling Circuit

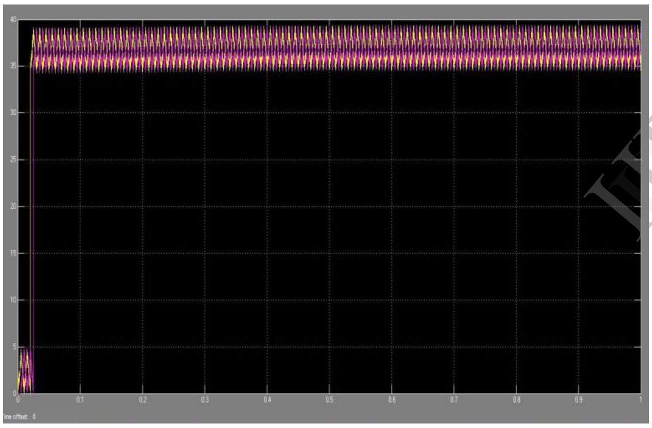

FIG5.3: Waveform of i_{s1} and i_{s2}.

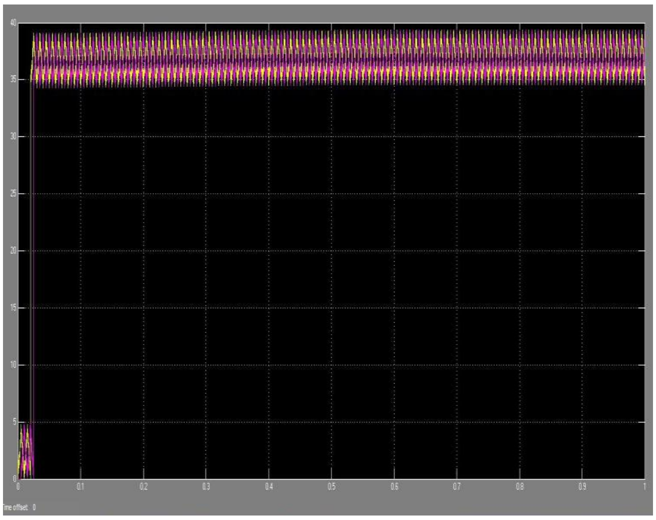

FIG5.4: Waveform of i_{rect1} and i_{rect2}.

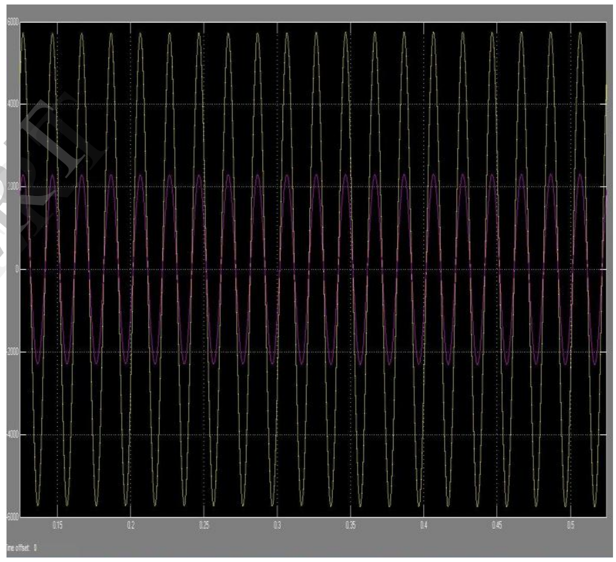

FIG5.5: waveform of v-I.

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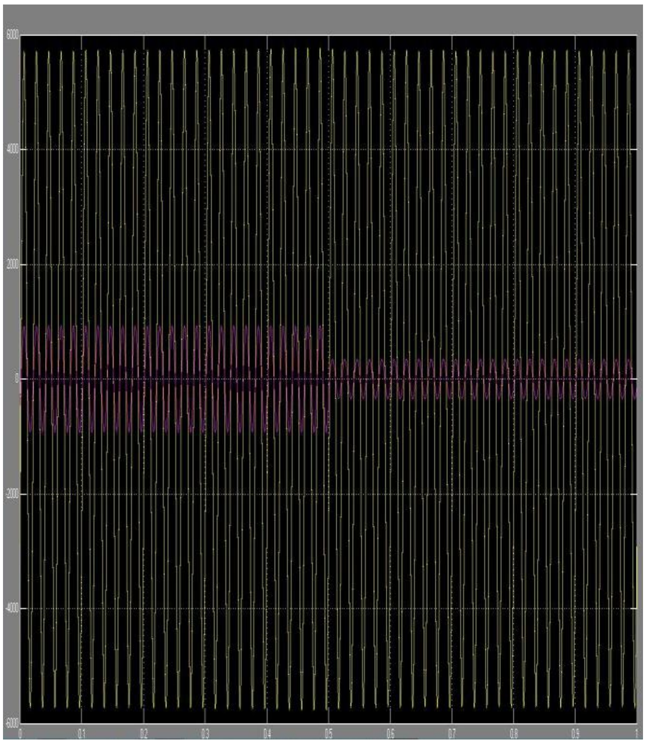

Fig. energy storing system,

V.CONCLUSION

In this project we reduce the harmonic content of the 12-pulse diode converter by the help of current profiling circuit .the current profiling circuit are used in parallel with the rectifier output current circuit. For the current source we use buck and bust circuit and which has used for dual purpose like energy injection and energy storage. VA rating of current source can also minimize with the help of proper DC side LC filter.

In comparison with other approach our approach is used even the load current is discontinuous which are not possible in other approach and we are advantage with that approach is that we are not using low-frequency transformer for profiling output rectifier current.
Energy storage system interface also verified with that approach and it work still when initial rectifier current is discontinuous. Dc storage system also can see with this approach and as a result we can see that the harmonic content in DC side of 12-pulse rectifier can be eliminated.

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