Design of High Voltage Direct Current Rectifier: A Review

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Abstract - *As the population increases, the need for more power increases but we can't directly feed the beneficiaries our generated power. So, bulk power transmission is carried out from the generating stations to our demand or load centres. Researches have proved that for bulk power transmission, a High Voltage Direct Current (HVDC) transmission is better than High Voltage Alternating Current (HVAC) transmission. As in HVDC, no radiation, induction and no dielectric losses are there which will increase the life of the conductor. For transmission in compare to three conductors used in the transmission of 3-φ HVAC, only two conductors are used for the transmission of HVDC. Our power-generation worldwide is alternating, so there is a need for a special power electronic device for the conversion of AC into DC and then reconverting DC into AC after transmission, for the distribution purposes. So the price of HVDC transmission increases but it is feasible as it is providing other benefits. After converting it into DC, we can do the bulk power transmission. But for getting a pure DC from an alternating input, we need to increase the number of pulses. In this paper, there is a detailed review and comparison of twelve, twenty-four, thirty, thirty-six Pulse HVDC rectifiers.*

Key words: **Transmission, alternating current, direct current, rectifiers, pulse, Total Harmonic Distortion, autotransformer, thyristor, diode.**

1. INTRODUCTION

Many methods are proposed to achieve the ideal value of THD i.e. zero of the input line current. We can start with a conventional 3-φ 6-pulse rectifier and then go up with the multiple of 6 to reduce the THD and increase the number of pulses for constant output. We can also use two 6-pulse rectifiers using a three winding transformer so one pair is connected as Y-Y and the other as Y-Δ to get a 12-pulse output which will result in the removal of the 5th and the 7th harmonics [2]. Poor power factor, high THD occur when non-linear loads are connected to the grid. Due to the presence of a non-linear load, there are huge amounts of harmonics present in the input line current as well [4]. HVDC transmission is used for bulk power transmission but it requires converting AC into DC and vice versa after the transmission as our whole grid is alternating. HVDC transmission is much cheaper and the power loss is also low in comparison to HVAC transmission for high power transmission [17]

2. 12-PULSE RECTIFIER

2.1 12-Pulses Rectifier with Interphase Reactor

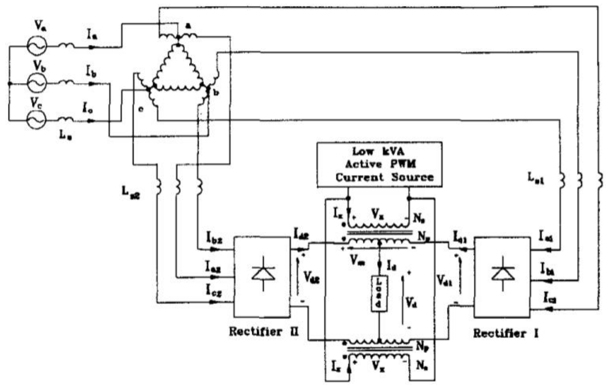

Fig-1: Interphase connection of 12-Pulse rectifier [4]

A conventional 12-pulse rectifier is used with interphase reactor which will ensure the independent working of the two parallel-connected 6-pulse rectifiers. These operations will cancel the 5th and the 7th harmonics from the input line current resulting in lowering the THD near to 1% (theoretically). We will get a 12-pulse output with a 30° phase difference between them [4].

2.2 12-Pulse Rectifier with Zigzag-connected autotransformer

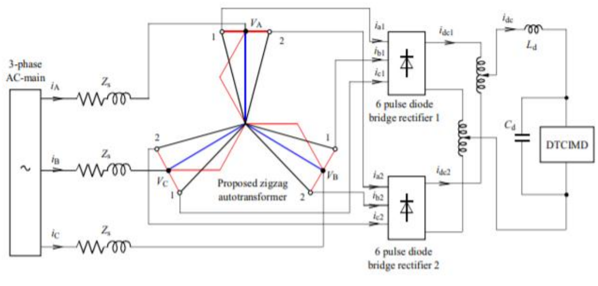

Fig-2: Zigzag-connected autotransformer with a 12-Pulse Rectifier [7]

A Zigzag connection of transformer is used in this scheme where two 6-pulse uncontrolled rectifiers are connected in parallel. This will result in 12-pulse rectifier or a 12-pulse AC-DC converter. This connection is proposed to increase rectification without much change in the installation to reduce the THD. Here the

THD of input AC is 7.36% at full load with a phase difference of 30° between the output pulses [7].

3. 24-PLUSE RECTIFIER

3.1 24-Pulse rectifier with tapped interphase connection

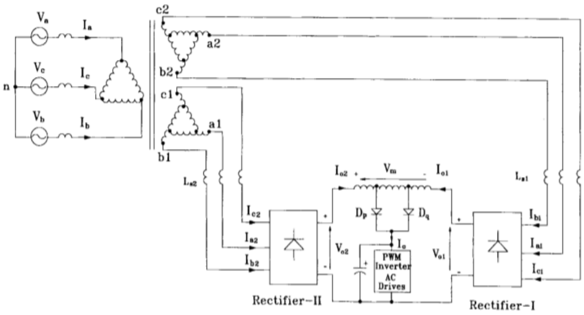

Fig-3: Trapped interphase connection of 24-Pulses Rectifier [2]

Trapped-interphase transformer is used in controlled rectifiers with multiple tapping which will require a complex triggering pattern. By just adding two extra taps to a conventional 12-pulse rectifier, we can convert it into a 24-pulse rectifier. We can eliminate 5th, 7th, 11th, 13th, 17th, 19th harmonics from the input AC by using this scheme. This will result in 3.4% THD in input current with high performance and clean power. The phase difference between the pulses is 15° [2].

3.2 24-Pulse Rectifier with Zigzag-connected autotransformer

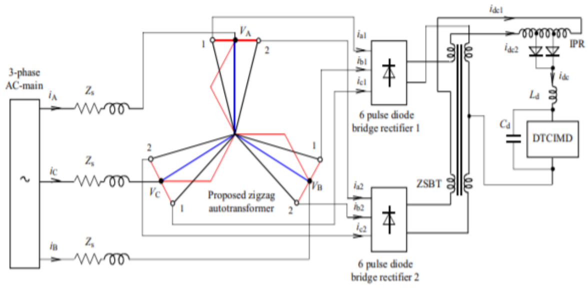

Fig-4: Zigzag-connected autotransformer with a 12-Pulse Rectifier [7]

In this schematic of Zigzag-connected autotransformer, we can see that two 6-pulse uncontrolled rectifiers are used to create a 12-pulse rectifier and then by using a pulse-doubling technique that requires a ZSBT those 12 pulses are converted to 24 pulses which will have 15° phase difference between them. At full load, the THD of input AC is achieved to be 4.51% [7].

4. 30-PULSE RECTIFIER

4.1 30-Pulse rectifier with T-connected autotransformer

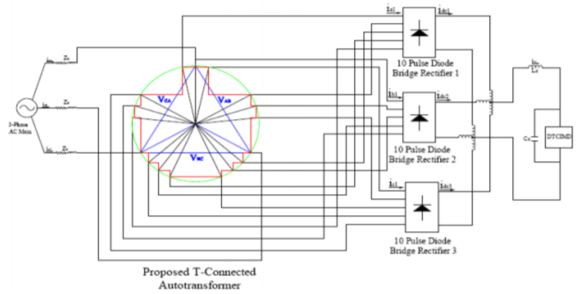

Fig-5: T-connected autotransformer configurations for 30-pulse rectifier [10]

T-connected autotransformer is used to connect three 10-Pulse rectifiers to get a 30-pulse output. We can get a 30-pulse output by connecting five 6-pulse rectifiers but this configuration is better as more suitable for a novel T-connected autotransformer. By these connections, we can achieve a THD of input current as 3% at full load. The phase difference between the output pulses is 12°, as this is a 30-Pulse three-phase rectifier [10].

5. 36-PULSE RECTIFIER

5.1 36-Pulse rectifier with T-connected autotransformer

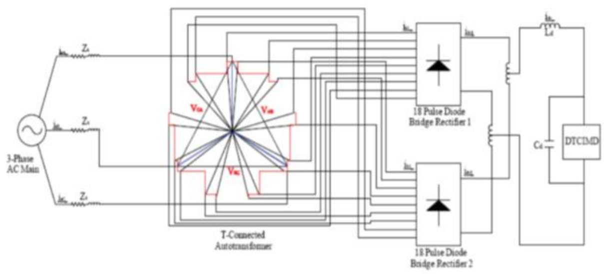

Fig-6: T-connected autotransformer configurations for 36-pulse rectifier [8]

A novel T-Connected autotransformer is used in this 3-φ 36-Pulse rectifier. 36 pulses in the output are gained by connecting two 18-Pulse rectifiers in parallel. As we increase the pulses we can get a constant output. T-connected autotransformer only uses two single-phase transformers unlike three single-phase transformers in delta-polygon connection of autotransformer, so this will reduce the overall cost of the project. We can achieve 2.82% THD of input current at full load through this connection. Here the phase difference between the pulses in the output is 10° [8].

5.2 36-Pulse rectifier with Delta-Polygon connected autotransformer

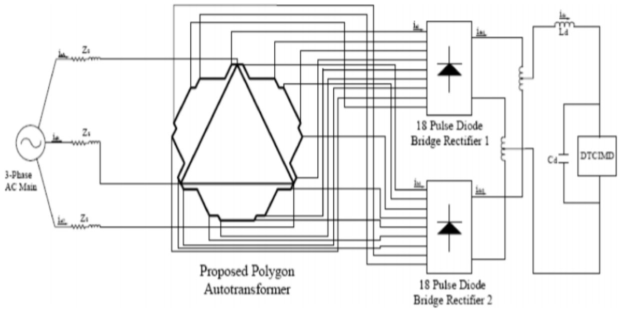

Fig-7: Delta-Polygon connected configuration for 36-pulse rectifier [11]

In this Delta-Polygon connected autotransformer, we are connecting two 18-pulses rectifiers in parallel in order to increase the pulses in the output. By connecting two 18-pulse rectifiers we get the result as 36-pulse output means we will have 10° phase difference between the output pulses. The THD of the input current is reduced to 2.93% at full load and 3.95% at 20% of full load. Delta-Polygon connected autotransformer is more costly than other connections, so the overall cost of the project is increased. But this connection will reduce the size and weight of the transformer [11].

5.3 36-Pulse Rectifier with Zigzag-connected autotransformer

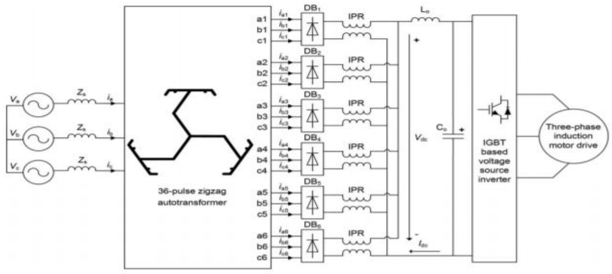

Fig-8: Zigzag connections of a 36-Pulse Rectifier [13]

To achieve a constant output we try to increase the number of pulses in our output side by attaching multiple 6-pulses rectifiers. In this Zigzag connection of autotransformer, we are connecting six 6-pulse rectifiers to reduce the output ripple. This will result in 36 pulses in the output with a phase difference of 10°. To decrease the size of an autotransformer we can choose the phase shift angle as ±5°, ±15°, ±25°. Another benefit of this configuration is that the harmonic components of one rectifier are cancelled by the harmonic components of another rectifier. Due to this type of connection, we can get the THD on input current as 3.03% [13].

6. COMPARISON TABLE

Table-1: Comparison of THD of $I_{in,}$ Phase difference between pulses.

No. of Pulses	Transformer Connections	Total Harmonic Distortion at full load of input AC current	No. of semiconductor switches used	Phase difference between two pulses	Complexity
12	Interphase Zigzag	1% [4] 7.36% [7]	12	30°	More More
24	Interphase Zigzag	3.4% [12] 4.51% [7]	24	15°	More Most
30	T-connected	3% [10]	30	12°	Most
36	T-connected Polygon Zigzag	2.82% [8] 2.93% [11] 3.03% [13]	36	10°	Most Most Most

6. WORKING OF A YYΔ 12-PULSE RECTIFIER

We know that the output ripple reduces as we from 3 pulses to 6 pulses in a three-phase rectifier. In the same manner, as we increase the output pulses from 6 to 12 pulses then we can get more reduction. A 12-pulse rectifier can be made by using two 6-pulse rectifiers.

We can use a transformer with two secondary i.e. one can be Y-connected and the other one can be Δ-connected, so we will have a 30° phase difference between line voltages of both. From one secondary we will get 6 pulses and from another secondary, we will get 6 pulses. The final output is the sum of both the secondary and we will have a 12-pulse rectifier with a 30° phase difference between the pulses [16].

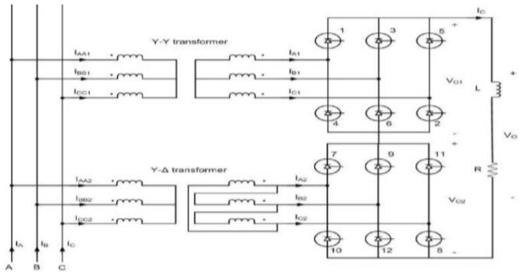

Fig-9: Y/Y/Δ configuration of 12-Pulse rectification [16]

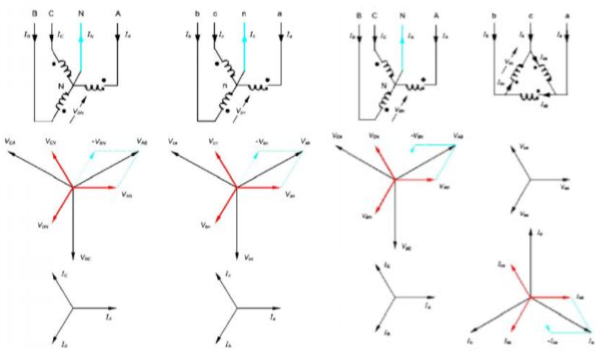

Fig-10: Phasor diagram for Y-connected and Δ-connected secondary [16]

Final output equation of voltage and current are given in equation 1, 2 respectively. V_m is the maximum phase voltage and α is the firing angle of the thyristors.

$$V_{o(avg)} = \frac{6\sqrt{3}Vm}{\Pi} cos\alpha \quad (1)$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} \quad (2)$$

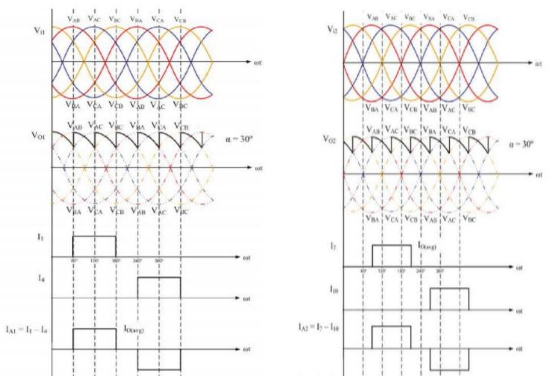

Fig-11: Output voltage and current waveforms of Y-connected and Δ-connected secondary [16]

7.1 Fourier analysis of input line currents from both secondary

Input line current in Y-connected secondary

$$i_A = \frac{2\sqrt{3}}{\Pi} I_{o(avg)}(cos\omega t - \frac{1}{5}cos5\omega t + \frac{1}{7}cos7\omega t - \frac{1}{11}cos11\omega t + ..)\ [16] \quad (3)$$

Input line current in Δ-connected secondary

$$i_A = \frac{2\sqrt{3}}{\Pi} I_{o(avg)}(cos\omega t + \frac{1}{5}cos5\omega t - \frac{1}{7}cos7\omega t + \frac{1}{11}cos11\omega t - ..)\ [16] \quad (4)$$

Addition of both analyses

$$i_A = \frac{4\sqrt{3}}{\Pi} I_{o(avg)}(cos\omega t - \frac{1}{11}cos5\omega t + \frac{1}{13}cos7\omega t - \frac{1}{23}cos11\omega t + ..)\ [16] \quad (5)$$

These Fourier series will only contain the odd number of harmonics in order of 12k ±1.

RMS value of the resulting line current

$$I_{A(rms)} = \left(\frac{4+2\sqrt{3}}{3}\right)^{0.5} I_{o(avg)}\ [16] \quad (6)$$

RMS value of the resulting fundamental current

$$I_{A1(rms)} = \frac{4\sqrt{3}}{\sqrt{2}\Pi} I_{o(avg)}\ [16] \quad (7)$$

Distortion factor

$$\frac{I_{A1(rms)}}{I_{A(rms)}} = 0.9886\ \ [16] \quad (8)$$

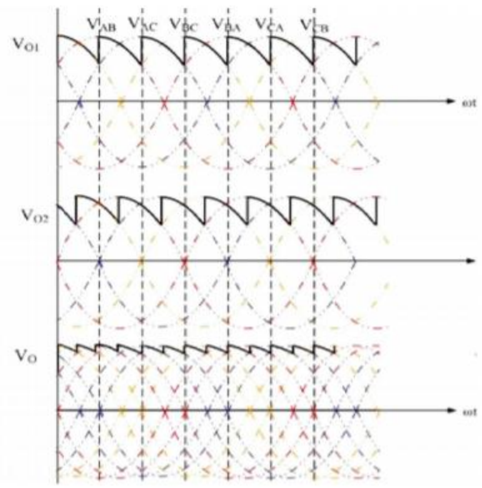

Fig-12: Total resultant output voltage waveform [16]

Total harmonic distortion of input AC current

$$THD = \sqrt{\frac{I^2_{A(rms)}}{I^2_{A(rms)}} - 1} * 100\% = 15.22\% \ [16] \qquad (9)$$

CONCLUSION

There are many advantages of HVDC over HVAC transmission line. But the main efforts are into setup a power electronic conversion of HVAC to HVDC and vice versa. Due to advanced engineering, we can convert HVAC into HVDC by using rectifiers. The output DC depends on how much pulses we are using and what filter we are using to remove the pulsation. As discussed in this paper there are several things that we can do to get a constant output voltage and current. We can see in the comparison table that as we increase the number of pulses the Total Harmonic Distortion of the input current reaches near to zero. THD should be as minimum as possible as we need to give a pure sinusoidal wave to a transformer, otherwise, the core of the transformer will saturate. We can do two things to filter out the pulsation, either we increase the number of pulses as discussed in this paper or we can increase the value of capacitance connected in parallel to the load. Our goal is to achieve zero THD and constant DC output.

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