

Performance Investigation of Six Pulse Rectifier with Transformer Vector Groups

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Abstract----Power quality is one of the main factors which govern the performance and the productivity of an industry. Diffusion of power electronics topologies in the system are the foremost causes to the devaluation of power quality. Three phase rectifiers, widely advantageous, ordinarily adopted in industrial distribution network and its contributions to the degradation of power quality are no more hidden. Harmonics mitigations in the system in a reliable and cost effective method are prime objectives. Transformers vector groups are very important in electrical network for the better service requirements. Transformer's leakage reactance plays an excellent role as a magnetic trap to the harmonics. This paper presents the importance and applications of transformer vector groups in electrical network system and analysis the performance of three phase six pulse rectifier with various vector groups of transformer in terms of total harmonics distortion of voltage and current at PCC of a typical industrial distribution system. The conclusions show total harmonics current distortion reduction and the converse effects on voltage profile of various transformer winding configurations.

Index Terms—Power quality, point of common coupling, three phase rectifier, transformer vector groups.

I. INTRODUCTION

PERFORMANCE of industrial process and its productivity rest on the working efficiency of its individual components such as motors. Later on operation of these individuals is influenced by the power quality of the system. Power quality problems are deviations in current, frequency or voltage from their standard, caused by the emerging applications of power electronics devices [1]. Overloading of wires, temperature rise of motors and transformers, reduced PF, capacitor failures are the main results of harmonics in the system [2]. Harmonics from the electronic loads in the system connected at PCC consequence malfunctioning in system operation [3]. One of popularly used power electronics device

in industries is *the three phase six pulse rectifier* with very large applications. These rectifiers are very vigorous and cost low price, contrast; it has the great contribution to the devaluation of power quality in the system.[4] A typical distribution system of a industry is depicted in Fig.1 a three phase rectifier and other working devices are connected at the

secondary side of three phase transformer. Harmonics injected at PCC by rectifier can greatly affect the working process of overall system.

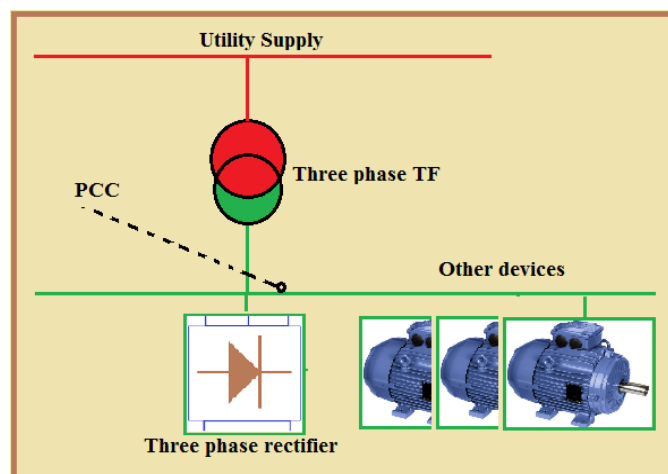


Fig.1. A typical distribution network of industrial process

Harmonics analysis and its mitigation in a reliable and cost effective way is one of major concern of researchers. Commonly used mitigation techniques include linear chocks, isolating transformers, passive filters [5] *phase shifting transformers* [6] and active filters [7].

There are various studies on harmonics mitigation are found in literature such as [8,9] analyzed the performance and the impact on power quality when an AC utility is linked with 3- ϕ rectifier through three phase power transformer considerable results were achieved.

In spite of many harmonics controlling schemes, a transformer is always utilized to bring down the supply voltage at a handling capability of power electronic devices. There are fourteen (14) vectors groups of transformers will be discussed in coming sections given in Table.1. Literature shows harmonics compressibility limit of some of vector groups of transformers. Harmonics generated by different nonlinear utilities are different in nature, thus for a specific application a specific vector group would give optimum results.

TABLE I: vector groups of three phase transformer

H.T side delta connected			H.T side star connected		
Sr. No	V.G	Phase shift	Sr. No	V.G	Phase shift
01	Dd0	0	09	Yy0	0
02	Dy1	-30	10	Yd1	-30
03	Dy11	+30	11	Yd11	+30
04	Dy5	-150	12	Yd5	-150
05	Dy7	+150	13	Yd7	+150
06	Dd6	+180	14	Yy6	+180
07	Dd2	-60			
08	Dd4	-120			

A Six pulse rectifier itself creates current distortion, not voltage distortion,[10] but when a transformer is used at interface to mitigate current harmonic distortion, what could be the impact on voltage profile. The objective of this paper based on the above problem statements is to develop simulation model and performance investigation of six pulse rectifier with various vector groups of transformers.

II. METHODOLOGY

In order to achieve the objectives the methodology exercised in this paper has the following steps:

- Review of three phase six pulse rectifier and its basic harmonics characteristics.
- Review of vector groups of transformer and their application and importance
- Development of simulation model of three phase rectifier with various transformer vector groups using MATLAB
- Simulation and performance analysing of three phase rectifier with various vector groups of transformer

A. Review of Three Phase Six Pulse Rectifier

A six-pulse three phase diode rectifier with a resistive load, R is shown in Fig.2 the objectives of three phase rectifiers is to provide dc power to the industrial motor drive systems and DC/DC converters [10].

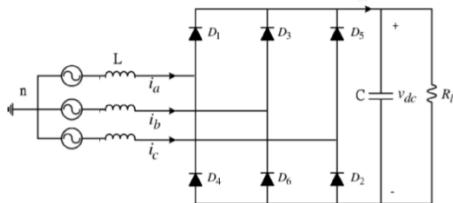


Fig.2. Basic circuit diagram of three phase rectifier

Reactance of transformer and inductance of line L is denoted by L that is in between the supply and rectifier. A filter C at output is used reduce ripples in dc current.[11]

B. THD and PF Three Phase Six Pulse Rectifier

Total harmonics distortion (THD) of a wave form is a quantity of the distortion present due to harmonics. Mathematically it can be written as:

$$THD = \sqrt{I_2^2 + I_3^2 + \dots + I_N^2} / I_{rms-f} \quad (1)$$

I_{rms} Is the RMS current of the N^{th} harmonics, and I_{rms-f} is the RMS current of the fundamental frequency.

Harmonics exist in a signal are in pairs of $pn \pm 1$. In case of three-phase 6-pulse rectifier 5th, 7th, 11th, 13th, and so on, that will be the harmonics present in the spectrum of current [12]. Theoretically, the total harmonic distortion, THD, of a 3-phase 6-pulse rectifier is $THD = 29.89\%$ [11].

Power factor is a measure how efficiently a facility uses the electrical energy. Power factor for purely sinusoidal waveforms is the ratio of active power to apparent power or simply $\cos\phi$ that is called displacement power factor. In case of non sinusoidal signals which consist of harmonics is given as:

$$PF = \text{Displacement}_{PF} \times \text{Distortion}_{PF} \quad (2)$$

$$\text{Where, } \text{Distortion}_{PF} = \sqrt{\frac{1}{1+THD^2}}$$

$$\text{And } \text{Displacement}_{PF} = \cos\phi$$

The current THD for diode rectifiers is usually higher than 30% and the power factor is 0.954[12]

C. Review of Vector Groups of Transformer

Three phase power transformers and its windings with primary and secondary terminals are shown in Fig.3. It can be configured in many fashion to meet the application requirements [13] International Electro technical Commission (IEC), uses standard coding for each winding connection of three phase transformer, called transformer vector group, usually attached on the transformer body[14]. A phase shift can exist between two side line voltages vary in step of 30° for various connections [15]. The phase shift between HT and LT line voltage is very similar to clock system [16]. Minute needle is for (H.T) voltage and it

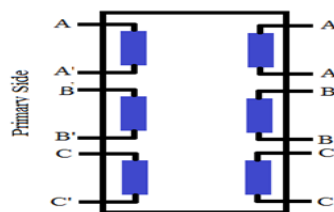


Fig.3. Three phase transformer



Fig. 4. Concept of phase shift

is always stationary at 12 O'

Clock, and hour needle for (L.T) line voltage which moves clockwise (HT voltage leading) or anti clockwise (LT voltage leading) with respect to minute needle, that can be easily

understood from Fig.4. [17]. For example the vector group Yd11 shows HT side is star connected, LT side is delta connected and 11 means phase shift between the two line voltages is 30° , LT line voltage leading HT line voltage.

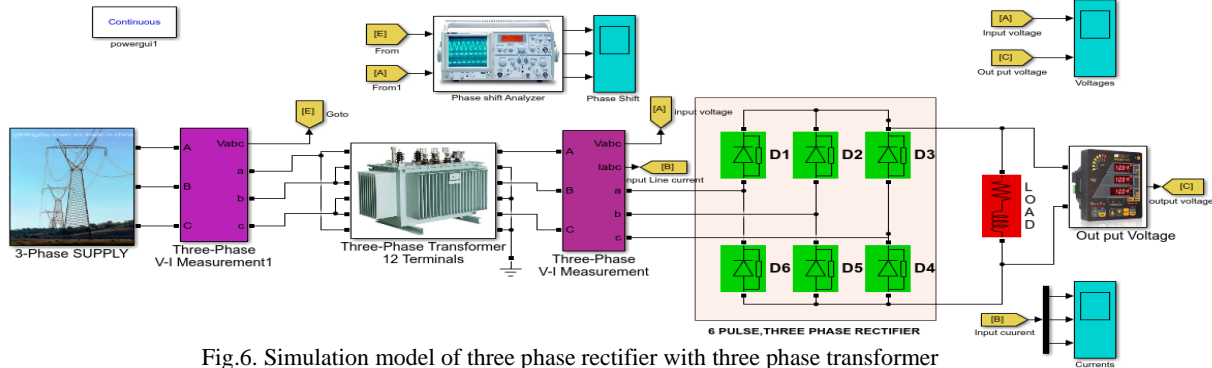


Fig.6. Simulation model of three phase rectifier with three phase transformer

D.Importance of Transformer Vectors Groups

Electrical distribution network’s performance is very well concerned with winding configuration of transformers. These have the harmonics canceling capability at PCC [18] Either it is stability problem, parallel operation of these transformers or it is the control of real power flow in transmission network selection of a proper vector group at a strategic point for a specific mean has the significance responsibilities[19].

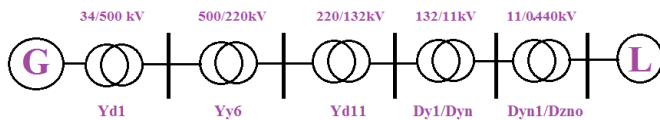


Fig 5.Transformor connections from generation to distribution levels

Applications of various vector group of transformer are depicted in Fig.5 which shows a single line diagram of power system network. Generation side uses Yd or Dy standard vector group. Since transmission system voltage is very high and it is encountered to large unbalance loading, Dd0 or Dd6 usually selected to suppress unbalance loading ripples. Yd1 or Yd11 are suitable to step up voltage level and Dy1 or Dy11 are designed to step down voltage level [20].

III. SIMULATION MODEL

To investigate the performance of the three phase six pulse rectifier with various transformer vector groups, comprehensive simulations are performed on MATLAB environment. Simulation model is shown in Fig.6.

A. Assumptions

The three-phase ac supply is supposed to be lossless and balanced. Other electrical parameters which assumed; supply voltage 400 line rams, supply frequency 50Hz, and load R 100Ω, L 400mH. The simulations of the three phase rectifier are confined in range of the core saturation limit.

IV. RESULTS AND DISCUSSIONS

The performance of three phase six pulse rectifier is analyzed utilizing FFT algorithm of MATLAB. Simulations are carried

out
for
both

resistive and inductive loads. In order to compare the performance of three phase six pulse rectifier when connected through various vector group of transformer, first it is simulated and analyzed alone to confirm the theoretical calculated THD of three phase rectifier without connecting any transformer vector group.

A. Direct connected to utility supply

Simulated FFT results of the ac utility line current input to the rectifier without connecting transformer are depicted in Fig.7 for both resistive and inductive load. Harmonics up to the 20th have been considered. It is observed from the result that inductive load causes approximately 3.06% greater harmonics than resistive load. In addition inductive load is also responsible for injection of DC component in the system.

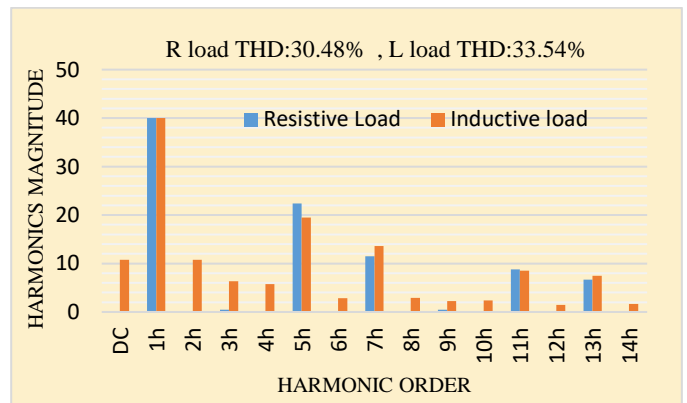


Fig.7. Harmonics current spectrum of three phase rectifier without connecting transformer

B. Connected through transformer

Simulated FFT results of ac line current input to the rectifier interfaced through various transformers winding configuration. For both resistive load and inductive load are shown in Fig.8 and given in Table 2. It can be seen from the FFT analysis that for resistive load vector group Dy11 and Dd0 give best performance with THD of 29.39% and 29.52%

which are reduction in total harmonics distortion of 1.09% and 0.96% respectively.

Vector groups Dd2, Dd4, Yd1, and Dy7, instead of reducing harmonics these increased current THD value of 1.3%, 0.7%, 0.49%, and 0.14%, respectively.

In case of inductive load vector group Dy7 and Yd7 reduced THD of line ac current from 33.54% down to 31.61% and 31.83% which are mitigation in total harmonics distortion of 1.93% and 1.71% respectively. On the other hand Vector groups Yy0, Dd4, and Dy11, Dy5, Dd2, Yd11 increased harmonics distortion value in average of 16.65% and 4.95% respectively.

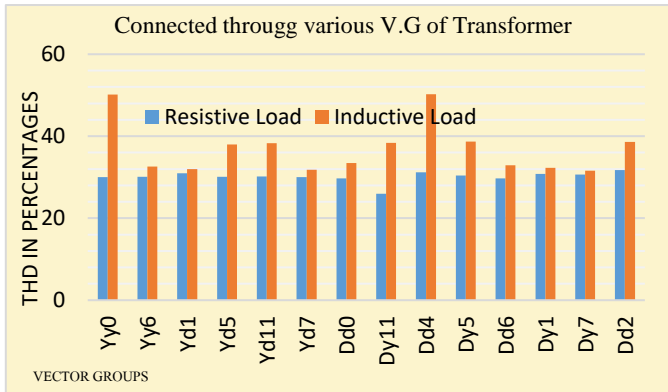


Fig.8. Harmonics current spectrum at PCC of three phase rectifier with transformer V.Gs

TABLE II: Current THD results of model with TF vector group

S.No	V.Group	Phase Shift	Current THD%	
			R	R-L
1	Yy0	0	30.06	50.13
2	Yd1	-30	30.97	32.00
3	Yd11	+30	30.19	38.31
4	Yd5	-150	30.08	37.98
5	Yd7	+150	30.76	31.83
6	Yy6	+180	30.13	32.64
7	Dd0	0	29.52	33.49
8	Dy1	-30	29.97	32.32
9	Dy11	+30	29.30	38.41
10	Dy5	-150	30.41	38.66
11	Dy7	+150	30.62	31.61
12	Dd6	+180	29.74	32.88
13	Dd2	-60	31.78	38.58
14	Dd4	-120	31.18	50.25

Three phase six pulse rectifier produces current harmonics in the system not voltage distortion, because voltage distortion is a function current harmonic flowing through the length of line impedance. A transformer introduces additional impedance when connected between ac utility and three phase rectifiers. This paper as a second objective analyzed the impact of various vector groups of transformers on the performance of three phase rectifier in terms of voltage profile at PCC that is the common point for the entire connected load in any system as shown in fig.

Fig.9 shows FFT results of voltage total harmonics distortion and given in Table.3, produced by introducing a transformer

between the ac supply and three phase rectifier for both resistive load and inductive load. It can be seen for resistive the vector groups Yd5, Yd11, Dy11 and Dd4 introduced THD 5.58%, 5.57%, 5.7%, at PCC which is the violation of standard IEEE 519. In case of inductive load voltage THDs for entire vector groups at PCC are within the limits.

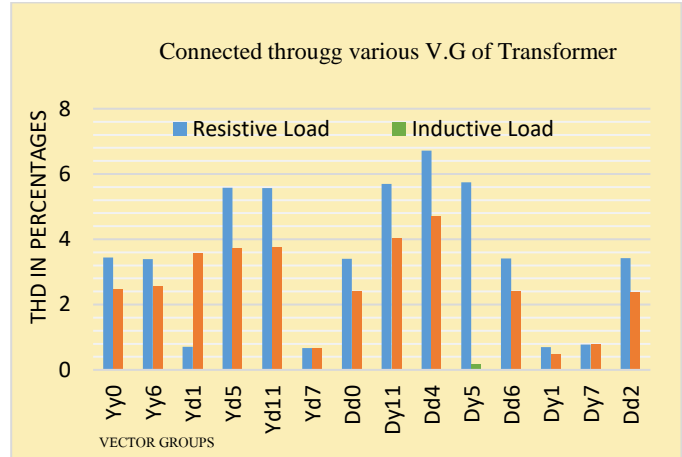


Fig.9. FFT result of voltage spectrum at PCC of three phase rectifier with transformer V.Gs

TABLE III: Voltage THD results of model with TF vector groups

S.No	V.Group	Phase Shift	Voltage THD%	
			R	R-L
1	Yy0	0	3.44	2.48
2	Yd1	-30	0.71	3.57
3	Yd11	+30	5.57	3.75
4	Yd5	-150	5.58	3.73
5	Yd7	+150	0.67	0.67
6	Yy6	+180	3.39	2.57
7	Dd0	0	3.4	2.39
8	Dy1	-30	0.7	0.48
9	Dy11	+30	5.7	4.03
10	Dy5	-150	5.57	0.17
11	Dy7	+150	0.78	0.78
12	Dd6	+180	3.41	2.4
13	Dd2	-60	3.42	2.37
14	Dd4	-120	6.71	4.71

V. CONCLUSION AND RECOMMENDATIONS

Harmonics produced due to three phase six pulse rectifier have their own natural spectrum, consequently mitigation of harmonics in the system from three phase rectifier and selecting a suitable and reliable method will be cost effective. This paper validated the performance of three phase six pulse rectifier with various vector groups of transformers in terms of total harmonics distortion of voltage and current at point of PCC of a typical industrial distribution system. Results concluded that in case of resistive load vector group Dy11 and Dd0 have best harmonics compressing capability of 1.09% and 0.96% respectively. In case of inductive load preference must be given to Dy7 and Yd7 which resourced current THD 1.93% and 1.71% respectively. A compromised is need to be made between current THD and voltage THD that is to be

minimized, since from the results it is clear that for resistive load vector groups Dy11 or Yd11 efficiently reduced harmonics than other vector groups but at the same time Dy11 or Yd11 has raised voltage THD beyond the standard limit. It thus recommended that when such a load which is very sensitive to voltage change connected at PCC then vector group Dy11 or Yd11 should not be used between three phase rectifier and ac utility supply system.

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