AC-DC CONVERTER BASED HARMONIC MITIGATOR FOR VECTOR CONTROLLED INDUCTION MOTOR DRIVES

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Abstract:

This paper deals with Autotransformer based multipulse AC-DC converter with reduced magnetic feeding vector controlled industrial motor drives. This helps to improve the power quality at the point of common coupling. The proposed methods are 12-pulse and 18 pulse ac-dc converter based harmonic mitigator are implemented to eliminate 5th ,7th ,11th,13th and 17th harmonics currents along with passive shunt filter to improve the power quality at AC Mains. The power quality parameters such as distortion factor, ripple factor and total harmonic distortion are also calculated for the proposed method. The results are carried out by MATLAB/Simulink software.

1. INTRODUCTION

Induction motors have been regarded as a universally accepted choice in industrial applications due to their advantages such as improved efficiency, ruggedness, energy savings, and low cost. For variable speed drives, dc motors have been used because of their flexible characteristics i.e. armature and field currents decoupled from each other. To incorporate the flexible characteristics of a dc motor into an induction motor, vector control technique has been adopted, and this has been widely accepted in industry.

The advances in power semiconductor devices have led to the increased use of solid-state converters in various applications such as air conditioning, refrigeration, pumps, etc. employing variable frequency induction motor drives. These variable frequency drives generally use the three-phase squirrel cage induction motor as the prime mover due to its advantages like rugged, reliable, maintenance free, etc. These induction motor drives are mostly operated in a vector control mode due to its capability of giving a performance similar to that of a DC motor. These drives are fed by a six-pulse diode bridge rectifier, which results in injection of harmonics in the supply current, thus deteriorating the power quality at the point of common coupling (PCC), thereby affecting the nearby consumers. Harmonics can be reduced using different active or passive wave shaping techniques. The active wave shaping techniques result in an increased loss, complex control and higher overall cost. The passive wave shaping techniques use passive filters consisting of tuned L-C circuits. However, they require careful application and may produce unwanted side effects, particularly in the presence of power factor (PF) correction capacitors. The most rugged, reliable and cost effective solution to mitigate these harmonics is to use multi pulse methods .These multipulse converters have gained importance because of their robustness, efficiency, and simplicity in control. Many researchers have used different configurations based on 12- and 18-pulse rectifications. These methods use two or more converters, where the harmonics generated by one converter are cancelled by another converter, by proper phase shift. In multipulse converters, the autotransformer-based configurations provide the reduction in magnetics rating as the transformer magnetic coupling transfers only a small portion of the total kVA of the induction motor drive. To ensure equal power sharing between the diode bridges, and to achieve good harmonic cancellation, it requires the need of interphase transformers. With the use of a higher number of multiple converters, the power quality indices are improved.

2.PROPOSED METHOD

The objective of this paper is the use of autotransformer based multipulse AC-DC converters with reduced magnetic feeding vectorcontrolled induction motor drives the power quality improves at the point of common coupling (PCC) and also reduces the harmonics at ac mains by using multipulse converters and shunt passive tuned filters. In this thesis there are two proposed methods i.e. 12-pulse and 18-pulse AC-DC converters along with shunt passive filter will eliminate the harmonics ac mains side. In the 12-pulse converter along with shunt tuned passive filter which is tuned to 11th harmonic frequency will eliminate 5th, 7th, 11th harmonic components. For 18-pulse converter along with tuned filter which is tuned to 17th harmonic will eliminate the 5th, 7th, 11th, 13th, 17th harmonic components at the ac mains supply. It is to be proposed to compare the different power quality indices such as power factor (PF), displacement factor (DPF), distortion factor (DF) at the PCC, THD and crest factor of ac mains current and ripple factor at dc bus fed VCIMD for 6-pulse, proposed 12-pulse,proposed 18-pulse converters.

12-PULSE HARMONIC MITIGATOR

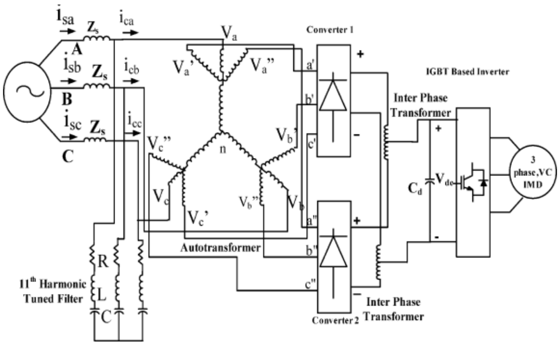

Figure (1) : 12-pulse harmonic mitigator fed VCIMD.

The above figure (1) shows the 12-pulse autotransformer based harmonic mitigator fed VCIMD. Here two 6-pulse diode bridge rectifiers are connected to autotransformer. To ensure an independent operation of two rectifier groups, two interphase transformers (IPT), which are relatively small in size, are connected at the output of the rectifier bridges. With this arrangement, the rectifier diodes conduct for 12°per cycle. Moreover, the autotransformer arrangement yields equal leakage reactance in series with each line of the rectifier bridges, which contributes to equal current sharing. A tuned passive shunt filter is connected at the input of the autotransformer. The passive filter is tuned to eliminate the most dominant 11th harmonic current in the supply. The passive filter is designed such that the supply current is less than the converter ac current. This shows the effectiveness of the shunt filter to sink harmonic current resulting in reduction in supply current and an increase in system efficiency.

18-PULSE HARMONIC MITIGATOR

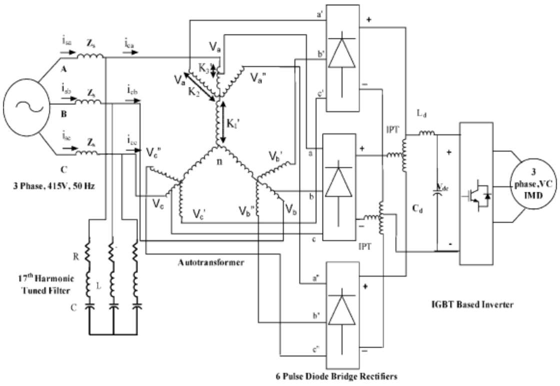

Figure (2): Proposed 18-pulse harmonic mitigator fed VCIMD.

The above figure (2) shows the 18-pulse autotransformer based harmonic mitigator. For 18-pulse rectifier output here three 6-pulse diode bridge rectifiers are used as shown in fig. 5.5. A tuned passive shunt filter is connected at the input of the autotransformer. The passive filter is tuned to eliminate the most dominant 17th harmonic current in the supply. The passive filter is designed such that the supply current is less than the converter ac current.

3. DESIGN EQUATIONS

The impedance of the filter branch is given by

$Z=R+j[w_L-l/(w_C)]$ …….(1)

Resonance occurs when the imaginary part is equal to zero, at which time the impedance is limited by the value of R. The frequency for which the filter is tuned is given by the value of w that results in series resonance. This frequency is given as

$f = 1/(2\pi\sqrt{LC})$…………(2)

Defining the harmonic number n as the frequency of the harmonic divided by the fundamental system frequency allows the impedance of the inductive and capacitive reactances to be

$X_{ln} = n\omega L$………………(3)

$X_{cn} = 1/(n\omega C)$…………(4)

Since the imaginary part is zero at the resonance harmonic n=r, then:

$X_{lr} = X_{cr}$……………..…(5)

Solving for r results in the design formula

$r^2=(X_C/X_L)$…………..…(6)

The quality of the filter is a measure of the sharpness of tuning. Mathematically, quality, or Q, is defined as

$Q = \omega_0/(\omega_1 - \omega_2)$…….(7)

where w_o is the tuned frequency, and w_1 and w_2 are the - 3dB points. This simplifies to

$Q = \frac{\sqrt{\frac{L}{C}}}{R} = \frac{X_{lr}}{R} = \frac{X_{cr}}{R}$……..(8)

where the reactances at the resonance frequency are given by $X_{Lr}$and X_{cr}.

Power Quality Indices

The input power factor is defined as the ratio of mean input power (real power) to the total rms input voltamperes (apparent power) given to the converter (or rectifier) system.

If V_s= rms value of supply phase voltage,
I_s== rms value of supply phase current including fundamental and harmonics
I_{s1}= rms value of fundamental component of supply current I_s
Φ_1= phase angle between supply voltage V_s and fundamental component I_{s1} of supply current $I_{s;}$
Then, the input power factor is given by

$$\text{Power factor} = \frac{\text{mean ac input power}}{\text{total rms input volt ampers}} \quad \ldots (9)$$

$$= \frac{V_s.I_{s1}.\cos\phi_1}{V_s.I_s} = \frac{I_{s1}.\cos\phi_1}{I_s}$$

For a given power demand, if input pf is poor, more input volt-amperes and hence more input current are taken from the supply.

Input displacement factor (DPF)

As stated above, the phase angle between sinusoidal supply voltage Vs and fundamental component I_{s1} of supply current $I_s$is Φ_1 This angle Φ_1, shown in Fig. 4.5, is usually known as input displacement angle. Its cosine is called the input displacement factor DF.

Therefore DPF=$\cos\Phi_1$ … (10)

DF is also called fundamental power factor.

Input current distortion factor (CDF)

It is defined as the ratio of the rms value of fundamental component I_{s1} of the input current to the rms value of input, or supply, current I_s

$$CDF = \frac{I_{s1}}{I_s} \quad \ldots \quad (11)$$

It is seen from Eqs. (10) to (11) that PF = (CDF) x (DPF) or input power factor = (input current distortion factor) x (input displacement factor)

Input current harmonic factor (HF)

Non-sinusoidal inpu or supply, current is made up of fundamental current plus current components of higher frequencies. The harmonic factor (HF) is equal to the rms value of all the harmonics divided by the rms value of fundamental component of the input current.

If I_h= rms value of all the harmonic-components combined

$$= \sqrt{I_s^2 - I_{s1}^2} \qquad \ldots (12)$$

Then, as per the definition,

$$HF = \frac{I_h}{I_{s1}} = \frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = \frac{\left[\sum_{n=2}^{\infty} I_{sn}\right]}{I_{s1}} \qquad \ldots (13)$$

where I_{sn}= rms value of nth harmonic content.

Harmonic factor is a measure of the harmonic content in the input supply current. HF is also known as total harmonic distortion (THD). Greater the value of HF (or THD), greater is the harmonic content and hence greater is the distortion of input supply current.

$$HF = \sqrt{\left(\frac{I_s}{I_{s1}}\right)^2 - 1} = \sqrt{\frac{1}{CDF^2} - 1} \qquad \ldots (14)$$

Higher value of input distortion factor CDF indicates lower magnitude of harmonic content in the source current.

Crest Factor (CF)

Crest factor for input current is defined as the ratio of peak input current I_{sp} to its rms value I_s.

$$CF = \frac{I_{sp}}{I_s} \qquad \ldots (15)$$

CF is used for specifying the current ratings of power semiconductor devices and other components.

Ripple Factor (RF)

The load (output) voltage and the load (output) current at the output terminals of ac to dc converters are unidirectional but pulsating in nature.

The voltage ripple factor is defined as the ratio of ripple voltage Vr, effective value of the ac component of output voltage to the average output voltage V_0.

$$VRF = \frac{V_r}{V_0} = \frac{\sqrt{V_{rms}^2 - V_0^2}}{V_0} \qquad \ldots (16)$$

$$VRF = \left[\left(\frac{V_{0r}}{V_0}\right)^2 - 1\right]^{1/2} \qquad \ldots (17)$$

Current ripple factor (CRF) is defined as the ratio of rms value of all harmonic components of output current to the dc component I_0 of the output current.

$$CRF = \frac{I_r}{I_0} = \frac{\sqrt{I_{rms}^2 - I_0^2}}{I_0} = \left[\left(\frac{I_{0r}}{I_0}\right)^2 - 1\right]^{1/2} \qquad \ldots (18)$$

4. PRINCIPLES OF VECTOR CONTROL

The fundamentals of vector control implementation can be explained with the help of fig. 6.3, where the machine model is represented in a synchronously rotating reference frame. The inverter is omitted from the figure, assuming that it has unity current gain, that is, it generates currents ia, ib and ic as dictated by the corresponding command currents ia*, ib*and ic* from the controller. A machine model with internal conversions is shown right. The machine terminal phase ia ,ib and ic are converted to idss and iqss components by 3-Φ/2-Φ transformation.

These are then converted to synchronously rotating frame by the unit vector components and before applying them to the de-qe machine model as shown. The controller makes two stages of inverse transformation, as shown, so that the control currents ids* and iqs* correspond to the machine currents ids and iqs, respectively. In addition, the unit vector assures correct alignment of ids current with the flux vector ψr and iqs perpendicular to it as shown. Note that the transformation and inverse transformation including the inverter ideally do not incorporate any dynamics, and therefore, the response to ids and iqs is instantaneous.

There are essentially two general methods of vector control. One is called the direct or feedback method, and the other, known as the indirect or feed forward method.reactive-power control variable q for the series converter of the iUPQC. In this way, the iUPQC will provide reactive-power compensation like a STATCOM to the bus A of the grid. As it will be confirmed, this functionality can be added into the fuzzy controller without degrading all other functionalities of the iUPQC.

5. INDIRECT OR FEEDFORWARD VECTOR CONTROL METHOD

The indirect vector control method is essentially the same as direct vector control, except unit vector signals ($\cos\theta_e$ and $\sin\theta_e$) are generated manner. Indirect vector control is very popular in industrial applications. Fig 6.6 explains the fundamental principle of indirect vector control with the help of a phasor diagram. The d^s-q^s axes are fixed on the stator, but the d^r-q^r axes, which are fixed on the rotor, are moving at speed $w_r$as shown. Synchronously rotating axes d^e-q^e are rotating ahead of the d^r-q^r axes by the positive slip angle θ_{sl}corresponding to the slip frequency w_{sl}.

Since the rotor pole is directed on the de axis and

$$\omega_e = \omega_r + \omega_{sl}$$

… (6.12)

We can write

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl}$$

… (6.13)

Note that the rotor pole position is not absolute, but is slipping with respect to the rotor at frequency w_{sl}. The phasor diagram suggests that for decoupling control, the stator flux component of current i_{ds} should be aligned on the d^e axis and the torque component of current i_{qs} should be on the qe axis, as shown.

6. SIMULINK MODELS

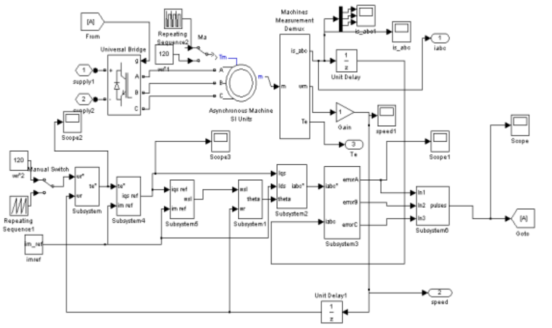

Figure (3): Simulink Model of Vector Controlled Induction Motor Drive

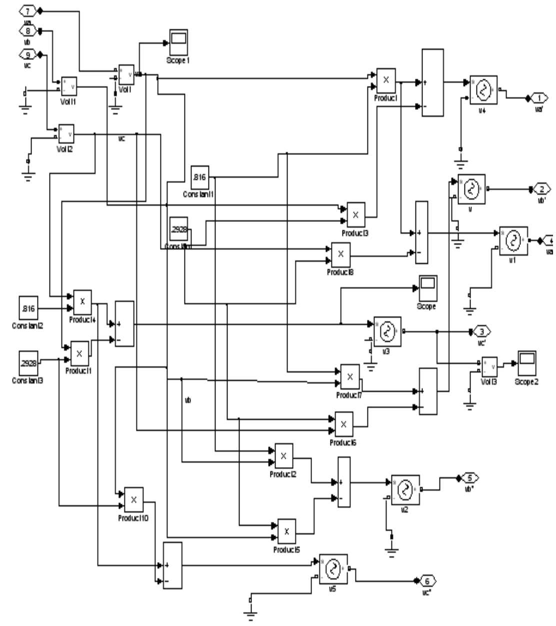

Figure (4) :Simulink Model of Autotransformer for 12-Pulse Converter

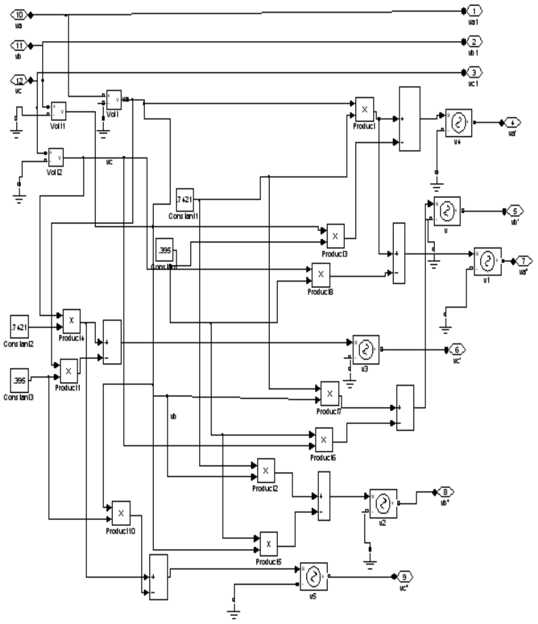

Figure (5) :Simulink Model of Autotransformer for 18-Pulse Converter

7. SIMULATION RESULTS

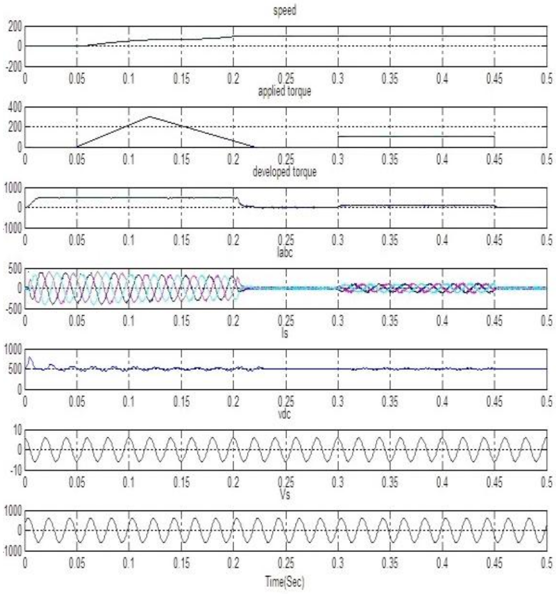

Figure (6) Dynamic response of 12-pulse ac-dc converter based proposed harmonic mitigator fed VCIMD at full load

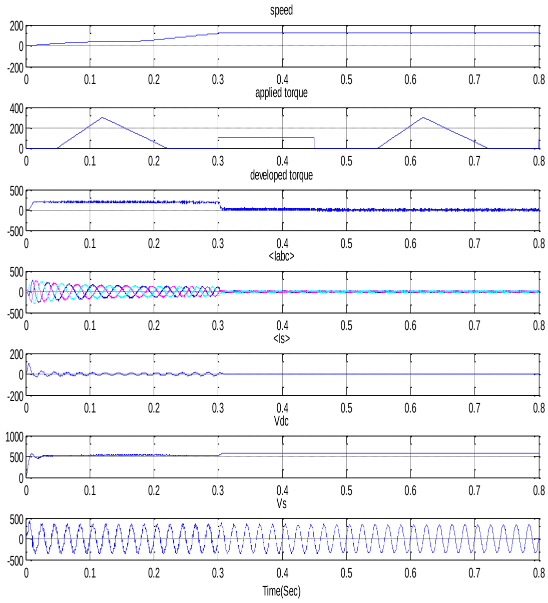

Figure (7) Dynamic response of 18-pulse ac-dc converter based proposed harmonic mitigator fed VCIMD at full load.

8. CONCLUSION

Two new harmonic mitigators based on 12-pulse and 18-pulse configurations have been designed, and developed MATLAB SIMULINK, which are suitable for retrofit applications with variable frequency induction motor drives operating under varying load conditions. The observed performance of the proposed harmonic mitigators has demonstrated the capability of these converters to improve the power quality indexes at ac mains in terms of THD of supply current, THD of supply voltage, power factor, and crest factor. There is an improvement in ripple factor of dc link voltage. Moreover, the 12-pulse-based harmonic mitigator can be used for retrofit applications where load variation is always higher than 50%. For drives with load variation in wider range, 18-pulse-based harmonic mitigator is able to yield satisfactory performance in terms of near-unity power factor and THD of ac mains current less than 5% limits.

9. REFERENCES

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