Harmonic Mitigation in AC–DC Converters for Induction Motor Drives by Vector Controlled

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Abstract

This paper deals with autotransformer-based multipulse ac–dc converters with reduced magnetics feeding vector controlled induction motor drives for improving the power quality at the point of common coupling. The proposed 12-pulse ac– dc converter-based harmonic mitigator consists of an autotransformer alongwith a passive shunt filter tuned for 11th harmonic frequency. This results in the elimination of 5th, 7th, and 11th harmonic currents. Similarly, the proposed 18-pulse ac–dc converterbased harmonic mitigator eliminates the 5th, 7th, 11th, 13th, and 17th harmonic currents, thereby improving the power quality at ac mains. The experimentation is carried out on the developed prototype of autotransformers-based ac–dc converters. Different power quality indexes of the proposed 12-pulse ac–dc converters are obtained from simulation and verified from experimental results.

1. Introduction

The use of induction motors has increased in industrial applications due totheir advantages such as improved efficiency, ruggedness, reliability and low cost. For variable efficiency, ruggedness, reliability and low cost. For variable speed drives, dc motors have been used until now because of their flexible characteristics. To incorporate the flexible characteristics of a dc motor into an induction motor, vector control technique is adopted as a widely accepted choice. Normally ac- dc power converter feeding power to the VCIMD consists of a 6-pulse diode bridge rectifier, an energy storage element at dc link, a 3-phase voltage source inverter (VSI) and an induction motor. The diode bridge rectifier suffers from operating problems such as poor power factor, injection of harmonic currents into the ac mains etc. In order to prevent the harmonics from affecting the utility lines negatively, an Standard 519 has been reissued in 1992 giving clear limits for voltage and current distortions. Several methods based on the principle of increasing the number of rectification pulses in ac-dc converters have been reported in the literature. The conventional wye-delta transformer based 12-pulse rectification scheme is one such example. But the kVA rating of the transformer is 1.03 PO, where PO is the active power drawn by the converter. To reduce the transformer rating, autotransformer based multipulse ac-dc converters of reduced rating have been reported in the literature. For applications where the demand for harmonic current reduction is more stringent, an 18-pulse ac-dc converter is generally preferred. This converter is more economical than the 24-pulse ac-dc converter, while being more effective than the 12-pulse ac-dc converter. Autotransformer based 18-pulse ac-dc converters have been reported in for reducing the THD of ac mains current. However, the dc-link voltage is higher, making the scheme non applicable for retrofit applications. Hammond has proposed a new topology, but the transformer design is very complex to swtoplofy the t1ansformer design. Paice has reported a new topology for 18-pulse converters. But the THD of ac mains current with this topology is around 8% at full load. Kamath et.al. Have also reported an 18-pulse converter, but THD of ac mains current is high even at full load (6.9%) and as load decreases the THD increases further (13.1%THD at 50% load). In this paper, a novel autotransformer based 18-pulse ac-dc converter (Topology 'D'), which is suitable for retrofit applications, where presently 6-pulse converter is being used, referred as Topology 'A', shown in Fig. 1, have been proposed to feed VCIMD. The proposed ac-dc converter results in eliminationof 5th, 7th, 11th and 13th harmonics. A set of tabulated results giving the comparison of the different power quality parameters is presented for a VCIMD fed from an existing 6-pulse ac-dc converter and different 18 pulse ac-dc converter. Moreover, the effect of load variation on various power quality indices is also studied. To demonstrate the effectiveness of proposed 18- pulse ac-dc converter feeding VCIMD. A laboratory prototype of the proposed autotransformer is designed and the developed and different tests have been carried out to validate the working of the proposed harmonic mitigator. The test results are found to be in close agreement with the simulated results under different operating and loading conditions.

2. Performance Of Harmonic Mitigation Alternatives

Variable frequency drives often have strict demands placed on them to mitigate harmonic distortion caused by non-linear loads. Many choices are available to them including line reactors, harmonic traps, 12-pulse rectifiers, 18-pulse rectifiers and low pass filters. Some of these solutions offer guaranteed results and have no adverse effect on the power system, while the performance of others is largely dependent on system conditions. Certain techniques require extensive system analysis to prevent resonance problems and capacitor failures, while others can be applied with virtually no analysis whatsoever. In some cases harmonic mitigation technique decisions were based on a technical misunderstanding, lack of information, theoretical data or on invalid assumptions. This Chapter explains the theory of operation of various passive harmonic mitigation techniques and demonstrates their typical real life performance. It takes the guesswork Out of harmonic filtering by demonstrating the typical performance of various harmonic mitigation techniques and offering a quantitative analysis of alternatives for real life VFD Operating conditions. Since power distribution transformers frequently have impedance ratings between 1.5% and 5.75%, one would expect that source impedance is often relatively high and that harmonics should therefore be quite low. However, transformer impedance ratings are based on transformer rated KVA, so when the transformer is partially loaded, the effective impedance of the transformer, relative to the actual load, is proportionately lower, [i.e.: 1.5% impedance at

Line Reactors: The use of AC line reactors is a common and economical means of increasing the source impedance relative to an individual load. Line reactors are connected in series with the six pulse rectifier diodes at the input to the VFD, as shown in Fig 2.1.

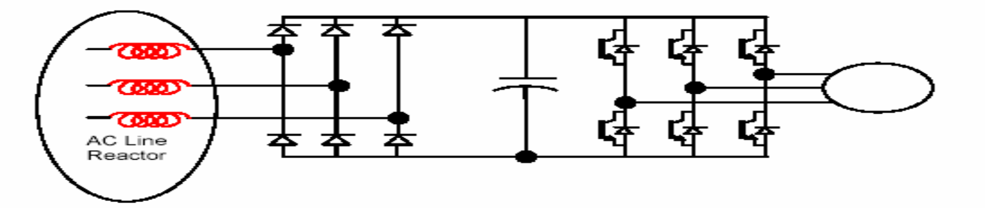


Fig AC line reactors connection at supply side

The typical harmonic spectrum data for a six pulse VFD load fed by a power supply with an

Effective source reactance of 3%, 5% and 8% looks as follows:

h	3 % reactance	5% reactance	8% impedance 3% dc choke & 5% ac reactor
5th	39%	32%	27%
7th	17%	12%	9%
11th	7%	5.8%	4.5%
13th	5%	3.9%	3.2%
17th	3%	2.2%	1.8%
19th	2.2%	1.7%	1.4%
23rd	1.5%	1%	0.8%
25th	1%	0.9%	0.75%
THID	44%	35%	29%

Table: 2.2. Typical harmonic spectrum data when effective reactance of 3%, 5% and 8%

These data represent the harmonics measured at the input to the six pulse rectifier and will reduce to lower percentages when measured further upstream, provided there are other linear loads operating on the system. If 20% of the system load is comprised of VFDs with 5% input impedance, and 80% has linear loads, the harmonic current distortion at the VFD input will be 35% THID, but only 7% at the supply transformer secondary. Typically costing less than 3% of the motor drive system, line reactors are the most economical means of reducing harmonics. Practical ratings can achieve 29% to 44% THID at the input to the six pulse

3. Reactor Performance at load

The harmonic mitigation performance of reactors varies with load because their effective impedance reduces proportionately as the current through them is decreased. At full load, a 5% effective impedance reactor achieves harmonic distortion of 35% THID, however, at 60% load it's effective impedance is only 3% {0.6 x 5% = 3%}, and harmonics will be 44% THID. Although THID increased as a percentage, the total rms magnitude of harmonic current actually decreased by nearly 25% {1 – ((.6 x 44%) / 35%) = 24.5%}. Since voltage distortion at the transformer secondary is dependent upon the magnitude and frequency of current harmonics that cause harmonic voltage drops across the transformer's internal reactance, the voltage distortion (THVD), at the transformer secondary, actually decreases as this load is reduced.

Tuned Harmonic Trap Filters:

Harmonic Trap Performance:

Tuned harmonic filters (traps) involve the series connection of an inductance and capacitance to form a low impedance path for a specific (tuned) harmonic frequency. The filter is connected in parallel (shunt) with the power system to divert the tuned frequency currents away from the power source.

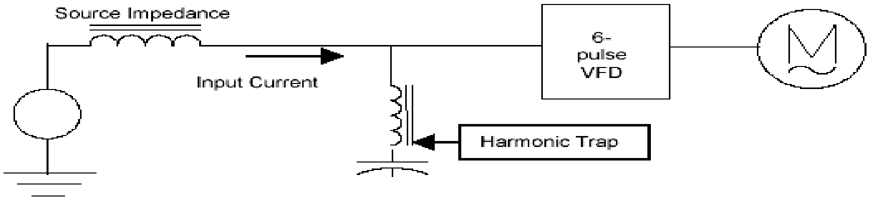


Fig: Harmonic Trap Performance with 0.25% source impedance

At that time we will give a non sinusoidal input to the as shown below:

Unlike line reactors, harmonic traps do not attenuate all harmonic frequencies. Most often they are tuned for 5th harmonic mitigation. If applied to a low impedance power source, as demonstrated in *Fig. 2.4*, the harmonic mitigation performance of this filter is quite limited and the benefit of this filter may be unrecognizable. To improve the performance of a trap filter, a

5% impedance line reactor may be connected in series with the input to the filter, as shown in

Fig. 2.6.

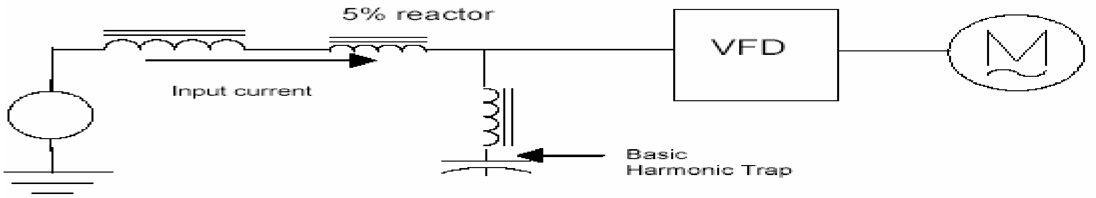


Fig.2.6. Line reactor performance with 0.25% source impedance

If the VFD has internal line reactance, then harmonic trap performance may improve slightly. The typical residualzTHID for a six pulse rectifier with a tuned 5^{th} harmonic trap is between 20 % to 30 % at full load, provided there is significant source impedance. The watts loss of this type of filter can be 2-3% of the load and it can cost ten times the price of a line reactor. Tuned harmonic traps will alter the natural resonant frequency of the power system and may cause system resonance, increasing specific harmonic levels. They may attract harmonics from other non-linear oads sharing the same power source and must be increased in capacity to accommodate the addition of new loads. For best results, a power system study should be performed to determine the magnitude of harmonics to be filtered (from all loads), the power system resonant frequency and the impact of future addition of loads.

4. Harmonic Traps at Light Load onditions

Harmonic traps achieve their best attenuation of harmonics at full load conditions. At light load, the resultant THID can increase significantly and may be no better than the performance normally achieved with a line reactor. *Fig*.2.8. demonstrates the input current waveform of a six Pulse rectifier with a tuned 5th harmonic trap, operating at 50% load, when the line voltages were 3% unbalanced. Notice the similarity to a non-linear single phase load.

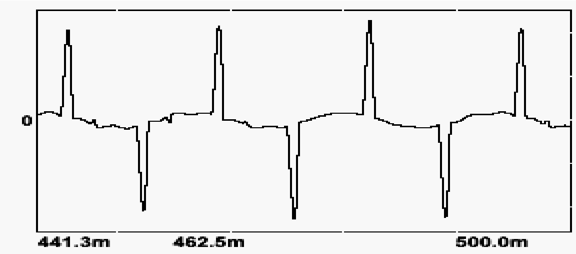


Fig.2.8. input current waveform with 3% line voltage unbalance and 0.25% source impedence.

Here the Harmonic current distortion = 139% THID.

2.4. Twelve Pulse Rectification

Twelve pulse rectifier configurations have been used for applications demanding lower harmonic levels than can be achieved using either traps or reactors. The theoretical benefits of 12-pulse rectification include cancellation of 5th, 7th, 17th, 19th, etc harmonics. However, real life harmonic mitigation resulting from the use of twelve pulse rectifiers can be quite different than one's theoretical expectations.

The most common method of twelve pulse rectification involves the parallel connection of two bridge rectifiers, each fed by a 30 degrees phase shifted transformer winding. Often the transformer has a single primary winding and dual secondary windings. One secondary winding is a delta and the other is connected in wye configuration to achieve 30 degrees of phase shift between secondary voltages.

"A major design goal in multipulse operation is to get the converters, or converter semiconductor devices, to share current equally. If this is achieved, then maximum power and minimum harmonic currents can be obtained." In order to achieve cancellation of harmonics, the two individual bridge rectifiers must share current equally. This can only be achieved if the output voltages of both transformer secondary windings are exactly equal. "Because of differences in the transformer secondary impedances and open circuit output voltages, this can be practically accomplished for a given load (typically rated load) but not over a range in loads."Typical losses of a twelve pulse transformer are 3% to 5% of the transformer KVA rating.

5. Twelve Pulse Performances with Balanced Line Voltages

Fig.2.9. illustrates actual measurements of input current harmonic distortion for a twelve pulse rectifier supplied from a balanced three phase voltage source while operating at full load conditions. For test purposes, the transformer had a delta primary with delta and wye secondary windings (each rated at one-half line voltage). To obtain "best case" results, the bridge rectifiers were series connected so equal DC current flowed in each converter. The data shows that when the current through both sets of rectifiers is equal, harmonics can be as low as 10% to 12% THID at full load. Current sharing reactors will help parallel connected bridge rectifiers to share current equally. While current sharing reactors are highly recommended for twelve pulse configurations,they are usually omitted in the interest of minimizing cost. Even with balanced. current however, harmonic distortion can increase appreciably at light load conditions.

6. Twelve Pulse Performances when Line voltages are not balanced:

Practical aspects of multipulse transformer winding configurations and circuit parameters make unlikely that perfect balance can be achieved between all six secondary voltages, especially when the load is varied from *full load* to *no load* conditions. Additionally, facility power system voltage unbalance is common (according to ANSI C84.1, 34% of facilities surveyed in the USA experienced between 1% and 3% voltage unbalance at the service entrance point and even greater unbalance in the facility and closer to the loads). It is interesting to note that occasionally pulse drives are sold without the transformer, shifting responsibility for the transformer specification and system performance from the supplier to the user or installer. *Fig. 2.10* demonstrates the impact of both line voltage unbalance and light loading conditions on the harmonic mitigation performance of twelve pulse rectifiers. Even with perfectly balanced

line voltages, the resultant %THID increases as the load is reduced (i.e.:23% THID at 20% load).

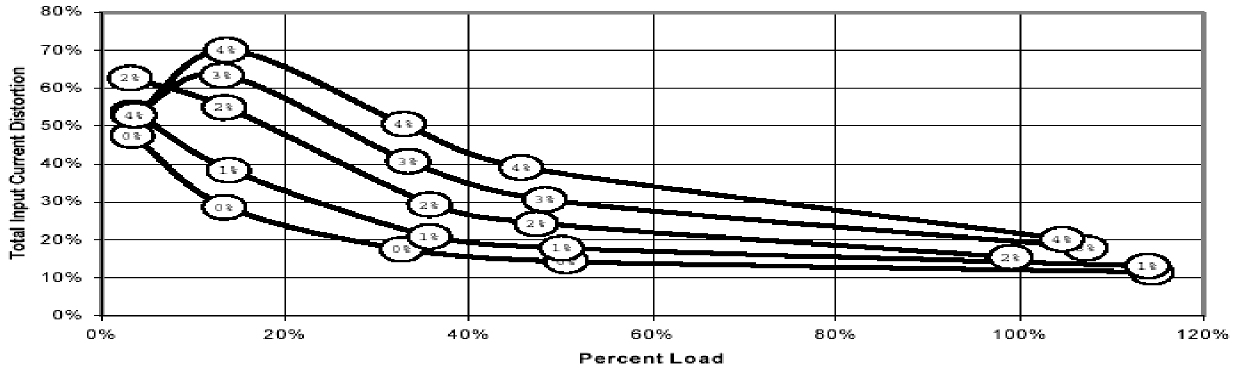


Fig12-pulse total input current harmonic distortion-varying with load

7. Multi - Pulse Converters Solutions For Harmonic Mitigation In Ac Drives

More and more ac drive installations are requiring manufacturer's to improve line side harmonics to ultimately meet IEEE Harmonic Std 519 Standard AC drive topologies utilize AC- DC-AC power conversion with a three phase rectifying bridge for the AC-DC function. A three- phase diode or SCR bridge generates 6 pulse types current that is ~ 32% rich in total harmonic current distortion. As ac drives proliferate, equipment system specifications limiting the amount of harmonic current injected into the grid are becoming more common and thus solicit cost effective harmonic mitigation solutions. System specifications are often written so measured total harmonic distortion at the *Point of Common Coupling* (*PCC*) in fig. 3.1 Complies with the maximum low voltage total harmonic Distortion levels (*THDV*) and system classification of IEEE 519 and current limits are shown in table 3.1.

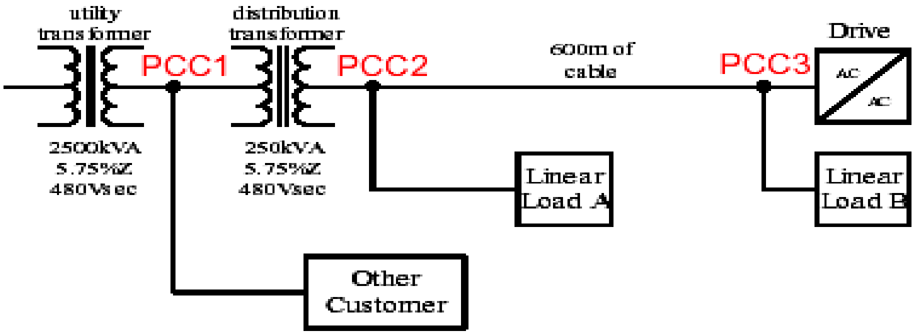


Fig point of common coupling

The PCC is usually at the power metering point (*PCC*1) where other customers connect to the common line voltage but may also be at (*PCC2*) or (*PCC3*) within a plant where linear and non- linear loads are connected. System classification and (*THDV*) options are *Special Application @3%*, Dedicated System *@ 10 %* and most specified option of General System *@ 5%*. Current harmonic distortion (*THDI*) of a single non-linear load is defined as the square root of the sum of the squares of all harmonic currents divided by the fundamental component of the non-linear load. However, defines total harmonic current distortion limits in a *system* as *Total Demand Distortion* (*TDD*).*TDD* limiting values are dependent on the ratio of short circuit current (*ISC*) at the *PCC* to the maximum demand load current (*IL*) supplied by the user. There are five classifications of (*ISC/IL*), but worst case *TDD* limit of 5% for an (*ISC/IL*) < 20 is often used.

8. Vector Control

Introduction

The various control strategies for the control of the inverter-fed induction motor have provided good steady state but poor dynamic response. From the traces of the dynamic responses, the cause of such poor dynamic response is found to be that their air gap flux linkages deviate from their set values. The deviation is not only in magnitude but also in phase. The variations in the flux linkages have to be controlled by the magnitude and frequency of the stator and rotor phase currents and instantaneous phases. The oscillations in the air gap flux linkages result in oscillations in electromagnetic torque and, if left unchecked, reflect as speed oscillations. This is undesirable in many high- performance applications. Air gap flux variations result in large excursions of stator currents, requiring large peak converter and inverter ratings to meet the dynamics. An enhancement of peak inverter rating increases cost and reduces the competitive edge of ac drives over dc drives.

Separately excited dc drives are simple in control because they independently control flux, which when maintained constant contributes to an independent control of torque. This is made possible with separate control of field and armature currents, which in turn control the field flux and the torque independently. Moreover, the dc motor control requires only the control of the field or armature current magnitudes.

As with the dc drives, independent control of the flux and torque is possible in ac drives The stator current phasor can be resolved, say, along the rotor flux linkages, and the component along the rotor flux linkages is the field producing current, but this requires the position of the rotor flux linkages at every instant; note that this is dynamic, unlike in the dc machine. If this is available, then the control of ac machines is very similar to that of separately excited dc machines. The requirements of phase, frequency, and magnitude control of the currents and hence of the flux phasor are made possible by inverter control. The control is achieved in field

9. Principle of Vector Control

The fundamentals of vector control can be explained with the help of figure 3.5, 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 i_a, i_b,

and i_c as dictated by the corresponding command currents i_a^*, i_b^*, and i_c^* from the controller. A

machine model with internal conversions is shown on the right. The machine terminal phase

currents i_a, i_b, i_c are converted to i_{ds}^s and i_{qs}^s components by 3φ-2φ transformation. These are then

converted to synchronously rotating frame by the unit vector components cos θ_e and sin θ_e before

applying them to the d^e- q^e machine model.

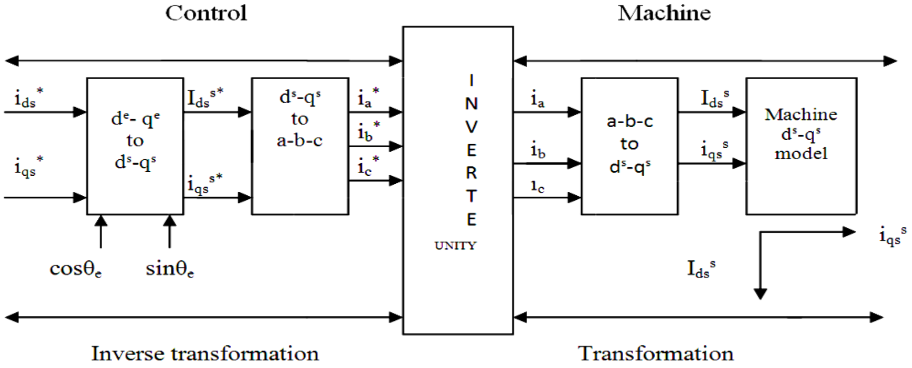
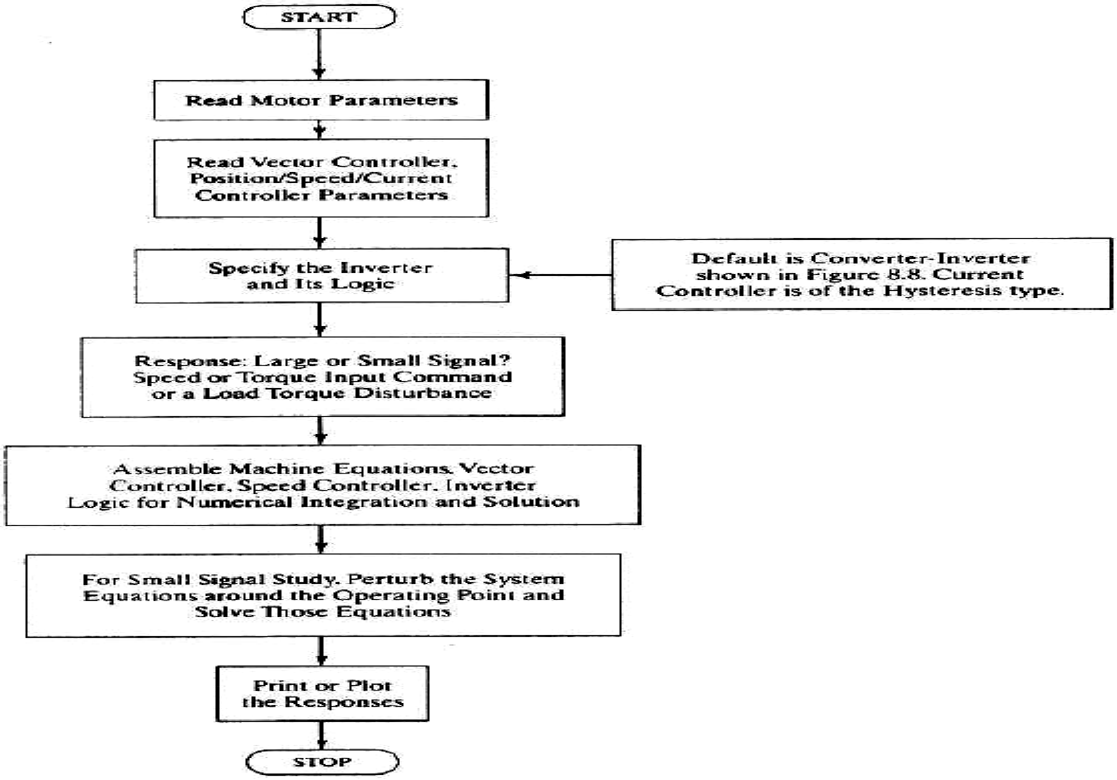


Fig 4.5 Basic block diagram of vector control

Vector control implementation principle with machine d^S-q^S model as shown The controller makes two stages of inverse transformation, as shown, so that the control currents i^*_{ds} and i^*_{qs} correspond to the machine currents i_{ds} and i_{qs}, respectively. In addition, the unit vector assures correct alignment of i_{ds} current with the flux vector $\hat{\Psi}_r$ and i_{qs} perpendicular to it, as shown. It can be noted that the transformation and inverse transformation including the inverter ideally do not incorporate any dynamics, and therefore, the response to i_{ds} and i_{qs} is instantaneous (neglecting computational and sampling delays).

Flow Chart for implementation of Vector control of induction motor



10. Conclusions and Future Scope Of Work

7.1. Conclusions:

1. A novel autotransformer based eighteen-pulse ac-dc converter has been designed and modeled with a VCIMD load
2. The proposed harmonic mitigator has been observed suitable for retrofit applications with variable frequency induction motor drives operating under varying load conditions.
3. The performance of the proposed harmonic mitigator fed VCIMD under varying load conditions is found to be satisfactory.
4. The proposed harmonic mitigator has resulted in reduction in rating of the magnetics leading to the saving in overall cost of the drive.
5. The observed performance of the proposed harmonic mitigator has demonstrated the capability of this converter to improve the power quality indices at ac mains in terms of THD of supply current, THD of supply voltage, power factor and crest factor. On the dc link side too, there is a remarkable improvement in ripple factor of dc link voltage.

7.2. Future Scope:

In this project simulated an 18-pulse ac-dc converter which is based on autotransformer based transformer. Extended this project in to 18-pulse to 36pulse and also Verify the power quality maintains or not and with the using of this project control the HVDC
System & also implement in the traction systems.

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