Types of Harmonics in Induction Machine Drive and their Mitigation Techniques

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Abstract— Nowadays in many industries, variable frequency and variable speed motors are used according to load and consumer demand. So, it is important to change the speed of a motor for achieving load characteristics, for that to control the speed of a motor different types of electric drives are used due to their versatile qualities. Squirrel cage induction motor is mostly used in industries for a motion control system and many other industrial applications. Nonlinear loads act as a source of harmonics and they are responsible for many nuisances. Nonlinear loads are responsible for increasing harmonics in an induction motor. This paper contains examine of the impact of harmonics on induction motor performance and on power factor. This paper also discusses the reduction of harmonics using filters and prescribed method to the improvement of power factor. It also gives the introduction about harmonics injection method which is used to control the harmonic current.

Key words: Types of Harmonics, Induction Machine Drive, PWM, Harmonic Injection, Harmonics, Induction Motor

I. INTRODUCTION

The Induction motor is an AC electric motor, which contains two main parts that is stator and rotor. Stator having field winding which responsible to induces magnetic flux [1] in rotor winding due to mutual induction between stator and rotor winding. According to Lenz's law due to rate of change of flux it is produces rotating torque. Mechanical load is connected to rotor shaft. According to construction of induction motor consist two types that is three phase induction motor and single-phase induction motor. Available from these two types, three phase induction motors are a self-starting motor. Both motors having same working principle but controlling mechanism is different. More than 80% load today in industries is connected to induction motor and characteristics of that load is controlled by different drives. In recent years, with increasing use of power electronics appliances, the quality of electricity supply, has become key issue, and company energy responsible are more and more aware of the benefits of paying attention to that. Harmonics are key problem of power quality which directly affect efficiency and power factor of induction motor and also responsible for increasing losses of motor, due to that maintenance cost of motor increases. In endeavouring to comprehend the execution of an enlistment machine, we think about that the air-gap flux wave is purely sinusoidal. For that it is important to minimize the effect of harmonics on induction motor drive system. Harmonics defined as "it's a component of voltage and current whose frequency is integer multiple of fundamental frequency" [5]. Nonlinear load is characterized as, impedance variations with voltage henceforth current are not quantity with voltage. For industrial applications for numerous machines' AC is changed over into DC for various purposes. Because of this change numerous machines draw near peak current. [2] Electronic load draws non-sinusoidal current wave which produces distortions and that current distortions are responsible for causes voltage distortions. Induction motor drive contains inverter for controlling the speed and inverter are electronic device which used to change DC into variable frequency AC. In induction motor air gap flux set up by three phase stator winding carrying sinusoidal current which having non-sinusoidal shape. Conferring to Fourier series examination, non-sinusoidal flux is mixture of many sinusoidal fluxes of essential and advanced order harmonics. Field winding are placed in slots of stator due to non-uniform air gap of slots field winding generates non-uniform fluxes and that flux consisting slot Harmonics. Slot Harmonics can't minimize by external means; it can be minimizing by superior mechanical construction of slots on stator. To decrease the damaging effect of harmonics, many preparations are existing [3]. Passive filters are used to suppress the effect of harmonics. Other approaches are also use such as active filters, but these additional circuit increase system complexities. Another one is course of third Harmonic current from dc-connection to the line flow of current [2]. In induction motor 5^{th} and 7^{th} harmonics produces a crawling effect where 5^{th} harmonics produces predominant in reverse turning, fifth harmonic pivoting at a speed of (1/5) of synchronous speed and forward revolving seventh Harmonic pivoting at a speed of (1/7) of synchronous speed. 5^{th} harmonic flux produces a breaking torque. 7^{th} harmonic produces a torque which aid with fundamental torque and due to this motor torque falls below the load torque and motor will not accelerate up to its usual speed. This crawling can be reduced by using chorded stator winding [4]. In previous 25 years there is substantial alteration in applications and power system [2]. In this paper discusses the review which comprises the modification in last 25 years regarding harmonics, their effect on machine performance, power factor and efficiency and how they should be minimize.

II. TYPES OF HARMONICS IN INDUCTION MOTOR.

$$Fn = (n) \times (\text{Fundamental frequency})$$

Where Fn is an integer numeral. Distortions due to harmonics are alter the shape of sinusoidal waveforms, hence it is also called the mixture of multiple waveforms. Several types of harmonics are classified depending on their integer multiplication with fundamental frequency. Since the transition wave shapes have half-wave symmetry, every even harmonic (2,4, 6, …) are missing as indicated by Fourier arrangement examination [4]. A non-sinusoidal motion can be settled into motions of major and higher request odd harmonics (3^{rd},5^{th},7^{th},11^{th},13^{th}, etc.). These harmonics fluxes induce voltage and that voltage produces harmonic current which circulate in the rotor windings. These harmonic

current in rotor interact with harmonic fluxes and produce vibrations, harmonic torque, crawling, noise [4][2].

III. SPACE HARMONICS

- These harmonics produced in induction motor due its mechanical construction. Space harmonics are delivered because of the "Magneto Motive Force" (MMF) of the air gap and so it can't be disposed of however can be decreased by utilizing an enhanced structure of the machine. It generates beginning issues in the machine and reasons of pulsations [6].
- Space harmonics are created due to distribution of the winding, hence called 'phase belt harmonics' [6].
- Harmonics are created due to slot opening and closing are called 'slot harmonics.
- Slip of space harmonics is huge and it is relatively equivalent to the harmonics request amid ordinary working conditions.
- Space harmonics can't have eliminated completely but keep as minimum as possible by good winding design and by optimizing construction of machine.
- Usually space harmonics are little when machine is all around planned.
- Space harmonics will generate huge torque dips in the subsequent motor torque at starting as well as at acceleration state.

IV. TIME HARMONICS

- This type of harmonics is not generated in motor itself. These harmonics is due to source which applied to stator winding of induction motor.
- Time harmonics is main concern related to motor performance due to variable frequency drives, if supply provided by VFDs (variable frequency drives) then time harmonics could be large.
- Due voltage source, voltage harmonics produced, which further produces current harmonics and it also produces a combination of voltage and current harmonics.
- Slip of time harmonics is near to 1, and this is a cause that time harmonics current is autonomous of induction motor load current, so for k^{th} order harmonics, the harmonic current is constant for no load capacity to full load capacity.
- Time harmonics increases heating effect of motor, due to excess heating copper loss of induction motor increases.
- Nonetheless, the time harmonics gives smooth torque qualities bend for that period these harmonics have little impact on it.
- Due to its slip value near to unity, so it gives little effect on motor starting. During starting of induction motor current is large and due to time harmonics, that starting current also increases, which also increases copper losses of induction motor

V. SUB-HARMONICS

- It is defined as component of voltage and current whose frequency is less than the fundamental frequency.
- These types of harmonics mostly present in transformer. Due to subharmonics leakage reactance are decreases. It affects magnetizing current which increases up to its peak value and then saturates. From proportional relation between magnetizing current and maximum flux of transformer. Flux get saturates which affect induced EMF (E= 4.44 f ¢m) after saturation, that EMF having constant value. Due to this transformer act as constant voltage transformer and CVT is not suitable for Distribution as well Transmission purpose.

VI. EFFECTS OF HARMONICS

Following fig. shows the effect of harmonics which distort a pure sinusoidal waveform.

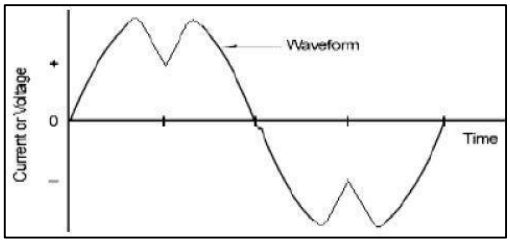

Fig. 1: Distorted Waveform [8]

Major Possessions of harmonics inside the induction motor:

- Harmonics present with higher frequencies, which responsible for increasing heating loss and higher core losses, which can condense lifespan of motor [8].
- The relation concerning voltage and current are not clearly defined if waveform of current and voltage are inaccurate. This inaccurate waveform are gives influence on power factor so it is not like as pure waveform.
- series resonance and parallel resonances intensify the harmonizing dimension of machine.

VII. FUNDAMENTALS OF HARMONICS MINIMIZATION

There are different types of methods for computation the impact of space distortions on the performance of squirrel cage induction motor such as Time stepping method in this time harmonics are use [7]. For time harmonics flux has h=6k +1 and h=6k-1 where, k=1,2, 3… time harmonics order. + for forward harmonic order and – for backward harmonic order. If provided supply voltage for field of induction motor is sinusoidal then harmonics present in induction motor is only space harmonics.

VIII. PWM TECHNIQUES

The PWM (Pulse Width Modulation) inverter has been broadly utilized in numerous industrial applications one of them is uninterrupted power supply (UPS) [10] for induction motor drive. Main characteristics of PWM techniques is that it is provided consistent abundant pulses. The modulated width of this pulses for inverter, is responsible for output voltage control of inverter and it reduces its harmonic content. For minimizing time harmonics frequency of a PWM must be a lot advanced method than that of balancing signal so the vitality conveyed to motor and its load for the most part relies upon the regulating signal [10]. PWM technique having low power consumption, simple to actualize and control, no variety in temperature and aging caused degradation in

linearity. PWM techniques proves the effective way of minimizing time harmonics and also it provides effective way of regulating speed of an induction motor.

IX. FILTER IMPLEMENTATION

Need of harmonics filtration is to keep up quality in power supply [10]. There are most common harmonic filtration techniques, in which commonly used are passive filters for suppressing the harmonics, active filters used for injecting harmonics waveform in to supply waveform which is exactly 180 degrees out of phase with supply waveform, so it can cancel out harmonics waveform from supply, hybrid filters mixing, using zig-zag transformer which used to eliminate 3rd harmonics from supply but this is old method and cost of this method is also high, harmonics injection method (current harmonics injection method). Among all above methods for mitigation effect of harmonics using utilizing passive filters being utilized since numerous years, because passive filters having simple and affordable solution for harmonics filtration. Following fig. shows the MATLAB Simulink diagram of LC filter for inverter output. By using this filter, we can totally sift through the harmonics existing in motor drive system. Filter is utilized as a regulator to harmonics of separate period of yield produced signal wave delivered by inverter.

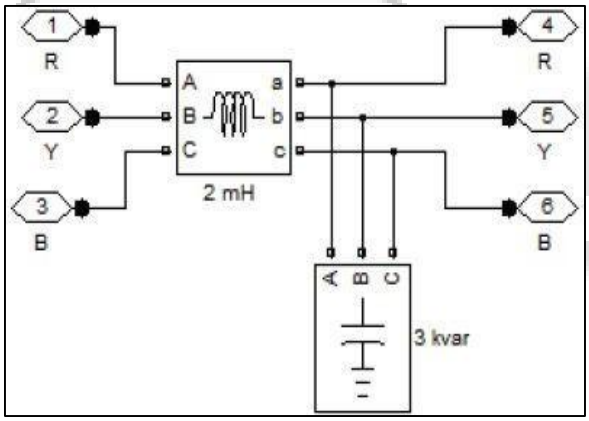

Fig. 2: Filter implementation on MATLAB Simulink.

By using different filters, LC segments is utilized for harmonic filtration and furthermore give reactive power compensation to induction motor drive framework. Thus, power factor of the system is enhanced alongside harmonics decrease. By using filter, we can achieve power factor enhancement by utilizing inactive channel segments for harmonic decrease [10]. Passive tuned filters are also used, which are tuned for specific frequencies, they are straightforward yet costly. Extra power electronic circuits, for example, active filters are used to complete elimination of time harmonics.

X. HARMONIC INJECTION

This method is complicated according to its implementation. Following fig. shows the block diagram of harmonic injection method. [3] The harmonic injection method requires special harmonic source. This special harmonic cause must be synchronized with supply source frequency. Both magnitude and phase angle of the source must be manageable.

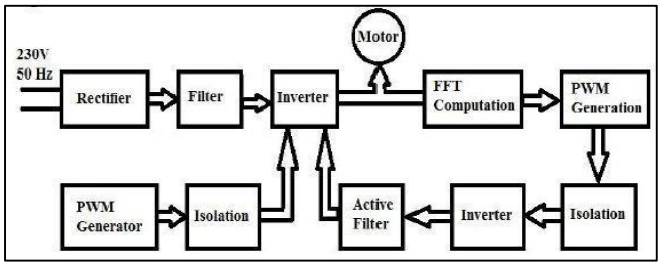

Fig. 3: Block diagram [2]

Above fig. shows the proposed method of harmonic injection. 230V, 50Hz supply given to rectifier which are used to change AC source into adjustable DC. Filter is use for to remove ripples from DC. Inverter are used to change DC into AC, variable voltage and variable frequency. PWM method are used to control duty cycle and provide pulse waveform [2]. Opto-isolator (isolation) are used to give disengagement between control circuit and power circuit and for high switching frequency. Inverter are used with IGBT switching topologies. The above block diagram is adjustable frequency drive. VFD are used to drive induction motor drive at adjustable frequency. From control circuit, inverter output harmonics are provided with active filter which is having exactly 180-degree phase shift with power circuit harmonics. Voltage source inverter are significant in this method. For successful implementation of this technique, load current signal is compulsory. The signal are used to quantify total harmonic alteration that is available in current signal. This signal further filtered to remove noise problem.

XI. CONCLUSION

This review paper introduces categories of harmonics and their influence on induction motor drive system performance. Harmonics are responsible to draws large current & distort shape of sinusoidal waveform. Various methods are used to overcome space and time harmonics problem. Each of them having advantages and drawbacks with respect to cost, power eminence, power factor, complexity. It is also observing that in induction motor, it is very important to minimize time harmonics for improving the performance of induction motor drive system. By using passive and active filters, harmonics are present in the system can be easily eliminated from source. PWM technique is also having useful according to its low power consumption. Operating constraints of PWM method such as decrease of harmonics, such as voltage harmonics, current harmonics, improvement of power factor, transferring frequency. Harmonic injection strategy used to reduce any type of harmonics by computing FFT. After injecting a harmonic in to the arrangement by using PWM inverter, load draws sinusoidal current. By using all this method, harmonics in induction motor drive system can be easily filtered.

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