Harmonic Mitigation Techniques For Synchronous Alternator

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Abstract- *The general effect of harmonic mitigation technique in electrical machines are well known and have been extensively studied. There are various harmonic internal and external mitigation techniques. In this paper internal techniques are studied which includes damper bar cage, stator skewing and pole skewing. An excel tool is implemented for design of 10 KVA synchronous generator by conventional method. Methods suggested in this paper can be tested on appropriate software and appropriate mitigation technique for 10 KVA salient pole single phase synchronous generator will be selected.*

Keywords- harmonics; damper bars; skewing; salient pole synchronous generator..

I. INTRODUCTION

Practically waveform is not sinusoidal because of uneven distribution of flux in machine. This non-sinusoidal waveform is due to presence of harmonics.A typical case of 10 KVA alternator is considered which has THD content of 5%.
Efficiency of alternator is most important parameter for analysis performance of machine and it is affected by harmonics. Harmonics can be effectively addressed by various magnetic circuit and electrical circuit design aspects.

Various mitigation techniques are used like optimization in design and by using filters. In design parameters like distribution, chording, skewing can reduce harmonics in machine.

II. LITERATURE SURVEY

A. A Fast Method for Modelling Skew and Its Effects in Salient-pole Synchronous Generators (SG)

In this paper finite element method is used to analyse Total Harmonic Distortion (THD) in current and voltage in a Stator Skewed SG. A single slice (SS) method is implemented to measure THD at no-load and with load operations. For further validation experimental measurements were performed and comparisons showed excellent similarities. However further at higher loading the validation of this technique weakens. The SS method reduces the computational time by 22 hrs as compared to multiple slice (MS). The proposed SS method achieves its goal of fast and accurate technique for modelling skew in Synchronous generator.

B. Improved Damper Cage Design for Salient-pole Synchronous Generators

In this paper modifications in rotor damper bars geometry is done to reduce damper cage loss and the output voltage THD in salient-pole Synchronous Generator. The validation of Finite Element Method of a 4-MVA synchronous machine is tested at several loading conditions by comparing with experimental results. Magnetic permeability of the stator slot wedge, bar pitch and asymmetric displacement of damper bars are the main parameters which are investigated.

C. Design and Analysis of Synchronous Alternator for Reduction in Harmonics and Temperature by Short Pitch Winding

For manufacturing synchronous alternator full pitch winding is used and stamping design is kept constant. As stamping design cannot be changed as the may lead to increase in cost so major concentration was made on distribution winding. Use of distribution winding gave benefits in terms of reduction in harmonics, temperature rise and resistive drop. To reduce or to eliminate harmonics short pitching was done i.e. when coil is pitched short $\frac{\pi}{n}$ or $\frac{3\pi}{n}$ no harmonic of order n survives in the coil emf. The triplen harmonics that may be generated in a three-phase machine are normally eliminated by star connection of the phases. At time of winding design the attention is mainly directed for the attenuation of 5^{th} & 7^{th} order harmonics by adopting a suitable chording angle. Chording angle of 30^0 i.e. coil- pitch = 150^0. Advantages were that short pitching reduces high frequency harmonics, eddy current and hysteresis losses. Chording helps to reduce vibration level. Finally, they concluded that time resistance of 2/3 winding pitch is more than 5/6 winding pitch which is measured by heat run test therefore temperature rise of 2/3 winding pitch is more than 5/6 winding pitch.

D. Effect of skewing and pole spacing on magnetic noise in electrical machinery.

The operation of rotating electrical machinery over a wide range of speeds often leads to the emission of intense magnetic hum due to resonant vibration of the machine frame at some speeds in the running range. These vibrations may lead to creation of harmonics in the system. It is possible to reduce the exciting force on frame to zero by suitable disposition of field poles with respect to armature or vice versa. The existing of such forces may be due periodic change of reluctance in the magnetic circuit, due to slotting of stators and rotors has been considered. To overcome with such forces, pole skewing method was implemented i.e. pole is inclined with respect to armature slots or slots are inclined with respect to poles. Machine operates in four modes of vibrations. For such modes of vibration work input should become zero for pole skew of one slot pitch and maximum for unskewed this is applicable to only first, second and fourth modes of vibration. In third mode of vibration it becomes zero for unskewed poles and maximum for pole skew of one slot pitch. To overcome the problem of third mode of vibration pole spacing technique is used. The disadvantage of using pole spacing is that chording advantage is lost. To eliminate this disadvantage herringbone skewing is done. In herringbone skewing, they skewed the pole one-slot pitch on either side of its centreline and at the same time keep it symmetrical about this centreline, thus established a condition of zero resultant exciting force for the third mode as well as for the other modes of vibration.

III. STANDARD DESIGN PROCEDURE

To study mitigation techniques it is necessary to know the design of synchronous generator by conventional method. An excel tool was implemented for studying the conventional method of designing synchronous generators. As vessel for studying the design a 10 KVA salient pole single phase synchronous generator is considered. The temperature in stator and rotor field is brought within limit in accordance to H class insulation. The inclusion of slot fill factor was done to know the percentage of conductor material within the winding area of a slot, indicating how full the slot is and how difficult it will to wind. The mitigation technique used should not increase the limits of temperature rise, losses and efficiency defined in conventional method. The total harmonic distortion in 10 KVA alternator is 5%, with 3rd harmonic as dominating harmonic. The purpose for studying of different techniques is to achieve THD level less than 5%.

IV. HARMONIC MITIGATION TECHNIQUE

The main cause of harmonics is the non-sinusoidal field form, if this is made sinusoidal then harmonics would be eliminated. Different methods for elimination of harmonics are distribution, chording, skewing, fractional slot windings, and large length of air gap. Some more mitigation technics are described below.

A. Damper Cage Design

The main reasons for provision of damper cage are as follows:

1) Damping oscillation caused by a periodic shock due to short circuits.
2) Terminal voltage is balanced during unbalanced loading.
3) Overheating of pole tips of single phase generators is prevented.
4) During current surges in armature winding there is reduction in insulation stress level of field winding.
5) Preventing distortion in voltage waveform.

Most sensitive parameters to damper cage loss and voltage THD are asymmetric displacement of damper bars, the bar pitch and magnetic permeability of the stator slot wedge.

- Magnetic Permeability of the stator slot wedge

By using different materials for slot wedge, slotting effect on the air-gap flux density can be reduced. Increasing permeability of slot wedge material reduces slotting effect on rotor surface as well as damper bars. With higher permeability the stator surface which faces the main air-gap becomes more isotropic. With increase in permeability slot flux leakage also increases which causes in less flux crossing the air-gap. This will result in higher voltage drop and torque reduction. For reducing voltage drop excitation current can be increased but at a cost of extra copper loss. An appropriate material can be selected which maintains balance between resulting slot flux leakage and quality of air-gap flux density.

- Bar Pitch

The effect due to damper bar pitch is an important player in terms of damper cage loss. The damper bar pitch (d) strongly relates to the stator slot pitch (s). It can be varied from 0.8s to 1.2s. The damper cage is kept symmetric with respect to the polar axis and the bar pitch is varied and the results are studied. The irregular damper bar pitch interacts with stator slot in a way to reduce air-gap dependent harmonics.

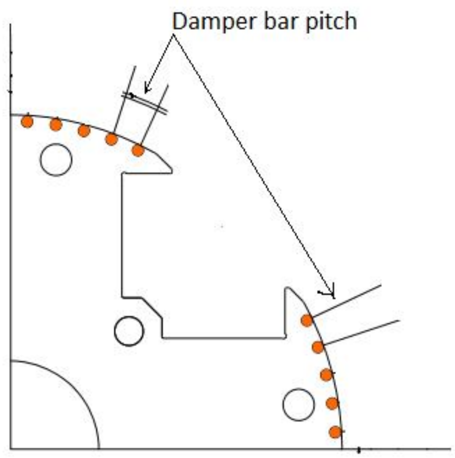

Fig.1. Damper bar pitch

- Asymmetrical displacement of damper bars

The damper cage can be displaced by a particular angle as a fraction of the stator slot pitch with respect to the polar axis to improve voltage THD. The improvement in THD should be done considering significant margins of losses in damper cage.

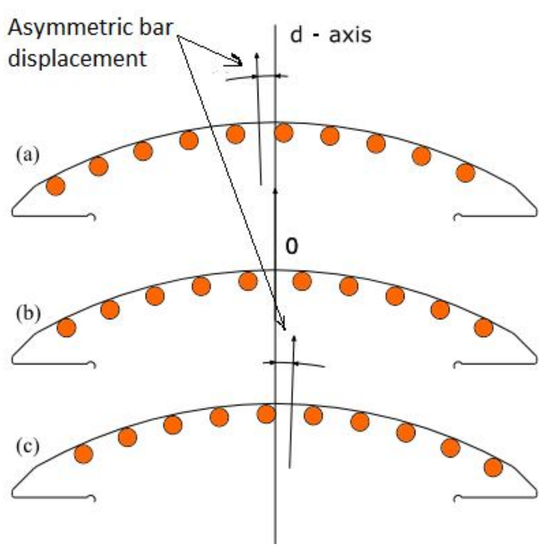

Fig.2. Asymmetric bar displacement

B. Skewing of Stator Slots

By providing skewing following aspects can be achieved

1) Reduced harmonics
2) Reduced vibrations
3) Reduced Tooth Ripples

Along the axial length of stator slot appropriate angular offset can reduce oscillations in air-gap flux density due to tooth harmonics.

There are some drawbacks of skewing and they are:

1) Output voltage reduced.
2) Reduction in torque available at shaft.

Skewing produces better winding distribution but at cost of reduced winding factor which in turn reduces performance. Damper cage losses are reduced as the slot harmonic effect is reduced due to slot skewing.

C. Pole Face Design

Most of electrical machineries creates noise and vibrations in the system. These vibrations are due to the periodic forces in the system which are of magnetic origin. The existence of forces is due to:

1] Change in magnetomotive force.
2] Slotting of stators and rotors resulting into periodic change of reluctance in magnetic circuit.
3] Distortion of the iron circuit due to magnetostriction.
The main reason for vibration of frames is the pulsating forces on poles arising due to periodic alteration of magnetic reluctance between each pole and a slotted armature.

- Forces on pole

The force on any pole body can be resolved into steady state component and a component which is variable in magnitude and direction. From fig 3(a) there is a variable force at point A of pole face which has a moving vector that describes closed curve C_A similarly with point B that has moving vector C_B. But in pole face elements that are selected randomly, however their phase relationship are not known so instead of comparing pole face elements we can consider parallel strips extending from pole tip to pole tip refer fig 3(b). Advantage of using this directed pole element is that phase relations can be known through their geometric considerations. The configuration of armature slots under pole strip is shown in fig (4) whole of the magnetic forces is distributed over its length and combined effect of these forces may be represented by resultant. It is apparent that pole is made inclined tangentially with respect to slots i.e. we are dealing with the skewed poles hence teeth and slots under pole strip are in phase among different strips. If these forces are not simple harmonics forces we may separate into harmonic constituents and phase displacement between corresponding harmonics at the pole ends and it will be $2\pi n$ where n is order of harmonics.

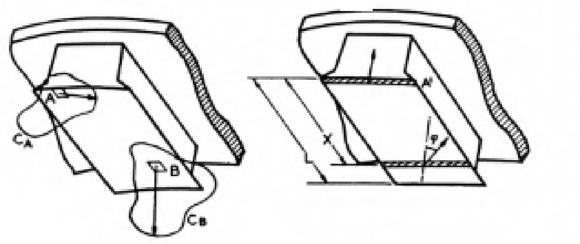

Fig 3(a) fig 3 (b)

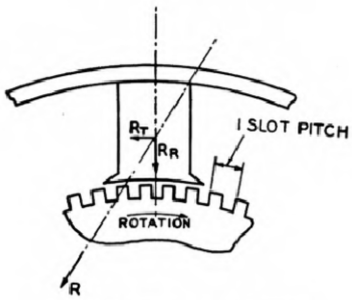

Fig 4
Forces on a pole

- Modes of vibrations

In case of motors the modes of vibration are due to presence of lumped pole masses which constituent principle masses of system.

First mode of vibration: In this mode poles are situated at antinodes which moves radially and each pole moves parallel to itself whereas adjacent poles are out of phase. Fig 5(a)

Second mode of vibration: in this mode poles are situated at the nodes of frame vibration and rotate from side to side as the slope of elastic line at nodes changes during motion. Fig5 (b)

Third mode of vibration: In this mode the poles are again at antinodes of the frame motion. The characteristic of this mode is that poles do not move radially but rotates in radial plane about tangent to frame cylinder midway between its end. The ends of each pole and adjacent poles are out of phase. Fig5(c)

Fourth mode of vibration: This mode involves extension and compression of frames. The frame goes periodic changes in diameter and remains circular in entire motion. The poles move radically and all are in phase. Fig 5(d)

Knowing the position of the poles in various modes the direct measure of this effect is given by input to vibration by forces. The energy input should be zero for all the modes of vibrations. The work input is zero for per pole in first, second and fourth mode of vibration for skewed poles whereas it is maximum for unskewed pole. In third mode of vibration work input is maximum for skewed poles for 2/3 of slot pitch and it is zero for unskewed poles.

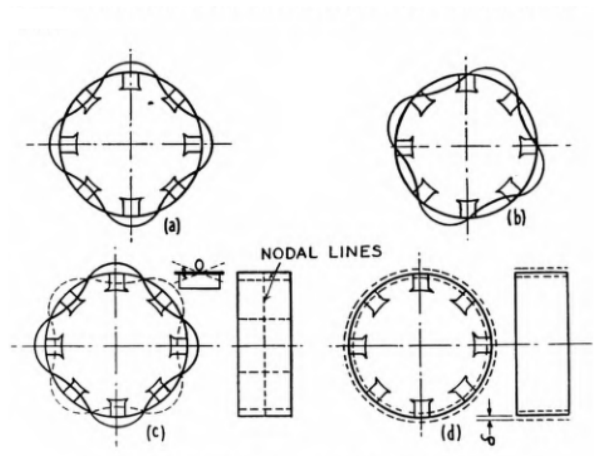

Fig 5 Modes of Vibrations

- Pole spacing

To overcome with the problem of third mode of vibration pole spacing can be implemented. The effect of pole spacing is that adjacent poles are made in phase when number of slots are divided by number of poles and made out of phase by dividing number of slots by number of pairs of poles. This will eliminate third mode of vibration but will also prevent excitation of first and second modes. Thus, both skewing and pole facing has to be done to eliminate all forces from four modes of vibrations. The disadvantage of pole spacing is that the advantage of chording is lost. So to avoid this we have to use another method which is independent of pole spacing i.e. herringbone skewing.

- Herringbone Skewing

In partial skewing only first, second and fourth modes of vibration are eliminated, to eliminate all four modes pole shape should be symmetrical with respect to its centreline in order to obtain in phase forces. In herringbone skewing we skew the pole one slot pitch on either side of its centreline and at same time keep it symmetrical about this centreline it establishes a condition of zero resultant exciting force for third mode as well as for the other modes of vibration. Refer to fig 6.

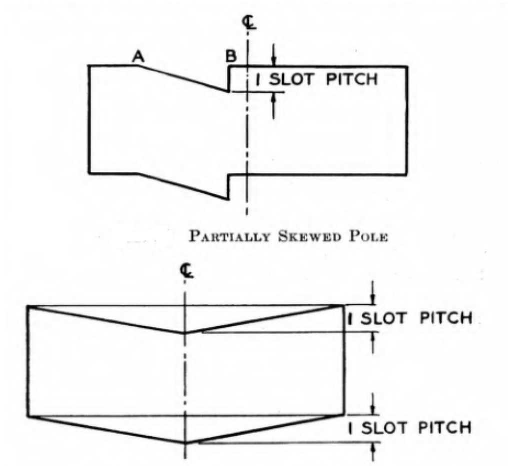

Fig 6. Herringbone skewing

V. COMPARISON OF DIFFERENT METHODS OF MITIGATION

Methods and point of Comparison	Method (A)	Method (B)	Method (C)
Method for reducing harmonics	• Influence of damper bar pitch • Influence of asymmetric bar displacement	Pole arc skewing with respect to armature slots.	Skewing of Stator slots
Magnetic design	Irregular bar pitch interacts with open slot in such a way that air-gap parasitic harmonics are reduced.	Disposition of field poles with respect to armature.	Stator slots inclined with respect to rotor poles.
THD reduction	Lower than 3% THD can be achieved	From 6.25% to 1.6% THD can be achieved	From 3-5% THD can be achieved.
Limitation of this method	Low THD's can be achieved but at the cost of ohmic losses which then generate heat and resulting in deterioration of total machine efficiency.	Advantage of chording of armature winding is lost.	Output voltage drop.

V. CONCLUSIONS

1] An attempt is made in this paper to present different techniques for harmonic reduction in case of alternator.

2] By improving damper cage design, the irregular bar pitch interacts with open slot in such a way that air gap parasitic harmonics are reduced. In this method low THDs can be achieved but at the cost of ohmic losses.

3] By skewing of pole arc, the input energy during vibrations should be zero and thus harmonics are reduced. The disadvantage of this method is that the effect of chording of armature winding is lost.

4] Skewing of stator slots results in inclination of stator slots with respect to rotor poles which reduces THD level at the cost of output voltage drop.

5] The combination of above methods can lead to better mitigation of harmonics.

6] Use of design software can lead to optimum design that mitigate harmonics.

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