Study of Stator Strength for Hydroelectric Generator – A Literature Review

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Abstract

This paper summarizes the features that must be considered, and specified in the design stage fabricated stator frame of hydroelectric generator is designed for electrical and mechanical applications. The stator frames are of larger diameters widely used in electrical machines and the arrangement of the same are different in shape and size. These frames are subjected to static as well as dynamic loads which may be uniform or non-uniform in nature depending upon its operating conditions. The study of complete stator is very much useful even to modify or optimize a small parameter.

Keywords –*Generator, stator frame, static loading, dynamic loading, Electrical machines*

I. INTRODUCTION

The initiation of the design of a large hydro-electric generator requires a specification of performance usually drawn up by the customer or a consulting engineer acting on his behalf. The main data required by the design engineer are kVA, power factor, line voltage, frequency, numbers of phases, temperature rise of the windings and core, rated speed, over speed and flywheel effect [1]. These electrical and mechanical parameters for a specific generator output are chosen in such a way that the design provides a sufficient amount of strength and stability to the system. Stator is the largest part in the whole hydro generator. Many a factor in its design is controlled by the manufacturer's standard and technology availability. To certain extend customer requirement also plays an important role for the operation and maintenance point of view. Also the feasibility of stator manufacturing at works and transportation to site is very important. There has been a lot of work done on the specific problem occurring in stator frame but an elaborate study of stator assembly has not been done till date.

II. DESIGN CONSIDERATIONS

The generators have been designed based on many conventional methods and regular practices related to the prevailing technology. Moreover, the design of hydro generator depends on the conditions of site, which may vary for two generators of same rating. Out of all the critical items used, stator plays its important role with respect to the performance *of stator to ensure that a generator as whole meets the technical performance requirements. The*

parameters of the whole system. The major components of stator assembly comprises of

- Stator winding (bar/coil)
- Stator frame and core
- Stator sole plates

The above mentioned components should have ample strength for the application of below mentioned forces.

- Mechanical forces acting on structure (axial, radial and tangential)
- Unbalanced magnetic pull between stator and rotor
- Static load acting on frame.

The stator frame is designed to take the above forces. The induced forces on the top bracket are transmitted through the stator frame which in turn is passed on to the foundation.

III. STATOR WINDING

The winding almost invariably consists of diamond-shaped coils, all alike, dropped into open slots. There is the same number of coils as slots, one side of each coil lying at the top of a slot, its other side at the bottom of a slot. The coils overlap so that each slot contains a top and bottom coil side; the coil ends also form two layers. The coils in each pole pitch are divided into three groups representing the three faces, within each group consecutive coils are connected in series, and corresponding groups under successive poles are inter-connected, in series or parallel according to the voltage and current rating of the machine. Stator coils may be either of the pulled type or the formed type. The pulled coils are simpler in construction and cheaper to manufacture, and are in very general use where the coil span is not too great. This type of coil is produced by winding the group of strips or wires forming the conductor round two pins, so as to form a narrow loop of the required number of turns, and pulling the sides a part to form a diamond coil. In machine of large pole pitch, coils formed on a mould are generally substituted. The ends can then be given true involute form, with uniform spacing, lying on a cone giving the best compromise between axial and radial extension. Large formed coils are often made as single coil sides jointed at both ends in position. Alternatively, to the usual lap winding with diamond coils, the coils ends may be bend in the opposite directions to form a wave winding. The end connections are simplified, since no group-group connectors are required; but the coil span at one end is now greater than the pole pitch, and the increased axial extension of the winding may result in increased load losses. Each coil may consist of a single turn, or of two or more turns wound continuously in series, according to the current and voltage rating of the machine, and the number of identical parts in the winding which can be connected in parallel. Very large generators may have two or more circuits in parallel, even with single turn coils, while smaller high voltage machines may require several turns per coil and all coils in series. Very often also arrangements such as two turns per coil with three circuits in parallel are used to obtain equivalent of a frictional number of conductors per slot. The most advantageous arrangement can only be decided in individual cases [2].

The process of winding multi-turn coils involves bending the top coil side after the bottom coil side has been placed in the slot. To ensure that this bending does not damage the insulation at the point where the coil side emerges from the slot, the insulation has to have sufficient flexibility, increase in the case of the inherently flexible bitumen insulation by heating the coil during winding. Obviously with coil sides approaching the limits of 7.5cm x 2.5cm, the danger is increased particularly with short coil pitches (<35cm). These difficulties also arise when fault coils have to be replaced in service. With the bar winding, bottom and top bars are laid in the slots separately and no bending is involved [1].

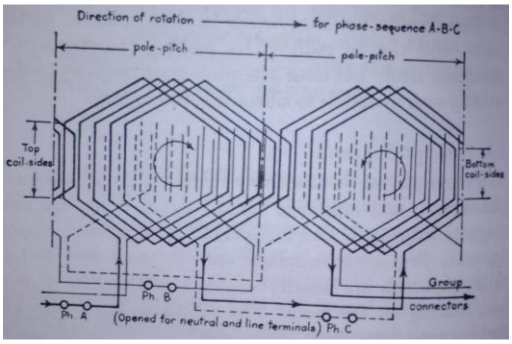

Fig-1: Arrangement of 3-phase Lap Winding [2].

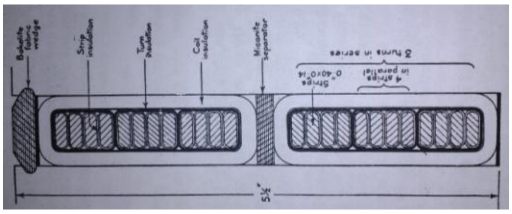

Fig-2: Cross-section of typical stator slot [2].

Fig-3: Stator winding inside stator core slot.

The stator end windings are subjected to very large forces during sudden short circuit forces at the line terminals. The maximum current under this condition is given by (E/xd”) and with a typical value of xd”=0.18 p.u. the peak of the instantaneous asymmetrical short circuit is 1/0.18 2√2=15.7 p.u. considering to a maximum peak force of (15.7)2=250 times the forces with the rated current. The force is tangential, axial and radial. The latter force is outwards in the salient pole generator where the rotor pole is more or less than the same length as the stator core so that the main leakage flux links the end windings and the end face of the stator core, pressure fingers and stator frame, thus producing a radial force. The tangential force occurs between the groups of conductors in each face and pole. Up to few years ago, it was a usual practice to support the winding against radial forces by one or two circular rings made of steel in the portion occupied by the rings as shown in figure and supported by 4-6 steel brackets. Nowadays with new practices and availability of advanced material, the supporting of these windings has not been an issue so far [1].

Fig-4: Stator segment assembly.

In this way the winding in stator assembly are to be carefully arranged to take valuable forces acting from the external and internal sources. These winding have to sustain all the forces to extend of up to 30-40 years in many cases or even more in some cases.

IV. STATOR FRAME AND CORE

The stator frame is made of welded steel construction and manufactured with thick steel plates to prevent distortion during operation. It is adequately designed to prevent deformation during transportation and lifting. Robust and rugged, these casings are designed to withstand the mass of a stator core, bending stresses and deflections. The stator frames are designed to handle mechanical and electrical forces. The casing is machined in a manner to ensure a uniform air gap between the rotor and stator, thereby minimizing the unbalanced magnetic pull. These casings are designed to withstand the extreme stresses due to short circuits. Each machine is designed to be assembled on a robust concrete foundation or steel base. The casing is fabricated from structural steel plates to ensure an extremely robust and rigid support structure. The stator core assembly consists of segmented and insulated laminations of cold-rolled low-loss silicon steel, clamped between substantial side plates. Therefore, the mechanical design of the stator is performed to withstand tangential stresses in the stator core as well as to transfer a huge amount of forces to the concrete foundation. All the stresses and forces depend on stator stiffness and temperature in the stator core and stator frame [3].

The outside diameter of the stator frame of large hydro-electric generators will usually exceed 3.5m and may reach 18m [1]. The stator frame is usually designed in polygon shapes, which are splited into a number of sections to facilitate transport of the wound segments keeping in view the restrictions on the maximum size and weight of the package that can be transported to site. To ensure these sections are all similar and thus simplify manufacture and assembly it is necessary for the number of lamination segment to be divisible by the number of sections. Stator cores are assembled on axial ribs on the inner peripheral of a welded steel frame; this serves the clamp the core axially, to direct the outgoing air to the cooling equipment, and to maintain a through circular form with freedom from vibration under the magnetic pull of the rotor [2].

In these electrical machines the necessary radial depth of the frame is normally determined by the area required for conveying the cooling air, issuing uniformly from the core bend-ducts, to a single opening discharging to the air coolers, usually at the bottom. The frame may then increase considerably in depth towards the bottom, from a minimum necessary for rigidity at the top, and additional internal plates are sometimes fitted to prevent obstructions by eddying. The mechanical rigidity of the frame under the bending moment arising from the load at the feet, and from possible unbalanced magnetic pull, must of course is adequate.

Large stators have very commonly to be divided vertically, occasionally into many (2 or 3 or 4 or more) parts, to meet transport limitations as to either weight or dimensions. The frame joints are made by deep flanges, with fitted bolts serving also as dowels. The ends of the stampings projects slightly beyond the faces of the frame, to ensure a close magnetic joint in the core itself, the consequent space between the outer edges of the flanges is maintained by a packing shim so that true circular form is obtained with the joints finally bolted up [2].

In vertically divided stators the great depth of the lower half usually ensures adequate stiffness of the whole frame, with division into 3 or 4 parts the bending moment at the joints needed to be very adequately dealt with. For the division into 3 parts a joint on the bottom centre line can be of great depth without interference with air flow, and can thus relieve the bending moment at the other joints.

The core is an assembly of thin segmental stampings of electrical sheet steel, half overlapped, separated at intervals by spacers to form radial ventilating ducts, and clamped between end plates. Electrical sheet steel is a very low carbon steel produced under specially controlled conditions to secure low magnetic hysteresis loss, with the addition of silicon to produce high electrical resistivity for the reduction of eddy currents within the thickness of the sheet. Eddy current loss varies as the square of the thickness, and core steel is usually between 0.014 and 0.020 in. thick [2].

The number of segments per circle is chosen to minimize the number of different stamping required. In a divided frame half segments are also required adjacent to the joints. The core is secured to the stator frame by axial dovetail keys. The core ducts, usually about 3/8″ wide are formed between pairs of segment, sometimes of heavier-gauge steel, to one of which numerous strips of steel, of rectangular of I-sections, are either riveted or spot welded on edge.

The radial fingers must extend near to the tips of the teeth, being subject to a high bending stress they are slightly inclined, so as to maintain heavy pressure on the teeth when the end plate are bolted down on to the core. To reduce extra loss near the ends of the core, the stampings are often cut back in steps or separated by ventilation ducts; this also allows the support fingers to be kept back with reduction of the loss in them. A further important reduction loss can be obtained by making the support fingers of non-metallic chromium steel.

The loss in the laminated stator core is usually the largest single loss in a generator and the design of the core particularly the choice of type and grade of steel is thus of paramount importance. To ensure a tight core very high axial clamping pressure were necessary varying from 0.14 to 0.21 kg/mm2. These pressures demand a heavy clamping structure with a corresponding stiff stator frame to withstand the reactions. The importance of the small thickness variation in cold-reduced steel in building a tight core is obvious, but the importance of a smooth surface further investigation. It was first assumed that pressing the core to tightness was necessary in order to flatten out waviness, which could amount to several millimeters. Experiments showed conclusively that the pressure required to remove this waviness was much below that to produce a tight core. A theoretical investigation was then made to determine the real area of contact between two surfaces which are pressed together with the assumption based on the Talysurf trace that the surface consisted of a large number of cones of varying height but with constant apical angle. It was further assumed that such a surface was pressed against a perfectly smooth rigid plane surface so that increasing pressure high peaks in contact deform and bring lower peaks into contact [1].

Real area of contact = compressive load / mean yield pressure of the surface irregularities.

The purpose of analysis of core and teeth pressures, 7 significant regions were determined which are shown in figure and table below.

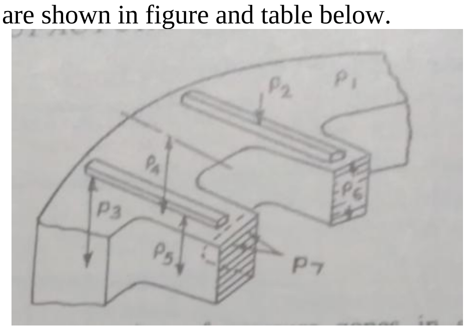

Fig-5: Location of Pressure Zone in Stator Cores [1].

Symbol	Location of pressure	Definition of pressure
P_1	Whole core	Total pressure exerted by core bolts divided by projected area of core.
P_2	On spacer	Total pressure exerted by core bolts divided by total area of spacers
P_3	Under spacer behind teeth	Average pressure under spacer length at back of teeth (see
P_4	Between spacers behind teeth	Average pressure between two adjacent spacers, behind teeth
P_5	On teeth	Average pressure under spacer on tooth
P_6	Tooth overhang at gap	Average pressure in unsupported tooth overhang at gap
P_7	Tooth overhang at gap	Pressure between two top punchings in tooth overhang

Table-1: Location of Pressure Zone in Stator Cores [1].

There are axial magnetic forces acting on the end of each tooth packet. These forces at each side of a duct face will be negligibly small due to the narrowness of the ducts (<10m) but, at the core end, the leakage flux are substantial and the resulting forces may lead to fracture of the outer laminations of the teeth [1]. The use of appropriate lamination at various locations in stator core will effectively reduce this problem.

It is now necessary to consider the design of the core relative to the structure which clamps it and holds it in position in the stator frame. In large generators probably the most widely used construction is that shown in figure in which the pressure is applied to the core end fingers and hence to the core bolts extending the full length of the core. A variant also used on long cores, is to replace the bolts at the back of the core by a series of screws tapped into the key bars as shown in figure. Another alternative is to extend the key bars through the side plates and to turn and thread the extension to allow it to be used as the tensioning member. Both these construction are associated with machines having core lengths of 0.75 to 3m where the core and the clamping structure are subjected to differential expansion effects occurring between cold and hot, i.e. shut down and full load. The design shown in figure will exhibit small differential expansion effects since the increases in temperature of the core and bolts relative to temperature of the stator frames are in practice in the ratio of about 2:1 which is about the ratio of the distances to the heel; of the clamping plate of the center line of the core and that of the bolts. The ideal arrangement to fit insulated tensioning bolts through holes actually in the middle of the radial depth of the core. This not only eliminates differential expansion effects, since the core and bolt would be at the same temperature, but would also substantially reduces the weight and cost of the clamping structure and the frame [1].

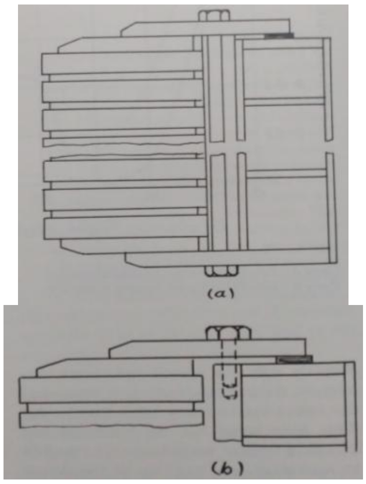

Fig-6: Stator Core Clamping Arrangement [1].

An important factor affecting the tightness of the cores in large machines is the method of securing the punching key bars to the stator frame. There are in principle two widely used methods. In one, the points on the frame to which the key bars are attached are machined and jig drilled. There are many practical difficulties observed in its application. The other method avoids all the difficulties associated with the above one. In this key bars are held loosely in position and about 15cm of core is built on to them. The punching are then accurately adjusted in position, radially by a rotating sweep gauge and axially by a number of accurately ground rectangular drifts placed in the winding slots. At this point, the ends of the key bars are welded on to the bottom member of the stator frame. A further length of the core is then assembled as before and key bars are welded to the first radial web plate of the stator frame. This process is repeated until the core is complete; when the nuts on the core bolt are tighten to give the required tension in the bolts and thus the required core pressure.

On completion of a core a final pressing with the hydraulic jacks are at the calculated nominal pressure is advisable since the tests showed that the deflection on removal of the pressure was about 20% less than that of pressure are applied before, indicating a certain degree of bending-in of the varnished punching. The final problem in core clamping is ensuring that the torsion applied to the nuts on core bolts gives the correct value of nominal pressure on the core. In view of the low pressures and thus the ease with which bolts and clamping structures could be overstressed, tests were carried out to determine the accuracy of tools used for tightening [1].

Therefore, the stator frame and core plays an important role in building a rigid structure to handle all the undue forces.

V. STATOR SOLE PLATES

The peripheral short circuit torque on the stator can be very great, it is transmitted from the stator frame to its support by dowels, and in large low speed units is a major factor in the design of the foundation. The radial unbalanced magnetic force between stator and rotor is supported by dowels between a top bearing bracket and the stator frame, or by dowels between a bottom bracket and its separate supports. Generator supports have thus the dual functions of transmitting the vertical downwards loads to the concrete and of transmitting large horizontal forces, through ribs or gussets, without exceeding the local shear strength of the concrete. The supports are completely embedded in the concrete. In vertical shaft machines stator supports, in order of increasing strength, may consist of separate sole plates, a shallow base ring, a deep conical framework and direct support from the turbine casing [2].

The sole plate may be a simple inverted box forming a local cap over the concrete, which completely fills it, and to which the generator frame or bearing is secured by long foundation bolts passing through the sole plate. Alternatively the sole plate alone may be directly secured by the foundation bolts to the concrete, in which it is embedded to support lateral forces, while the generator is attached to the soleplate by separate bolts.

Where a great load has to be carried, sole plates for vertical shaft units may well be extended peripherally, with flanges bolted and dowelled together, to form a complete ring, thus considerably reducing the local loading of the concrete. For a stator frame a complete base ring greatly increases the resistance to peripheral force, for a bottom bearing bracket it may afford valuable support to the edge of the pit. The foundation bolts are placed only in the deep concrete between the bottom air ducts, and the stator frame actually rests only in these regions. Such a structure can be constructed of welded steel plates or in cast iron [2].

VI. CONCLUSION

This study paper concludes that the there is a significant role of stator assembly in hydro-electric generators. The designing of the same may have many different parameters to be considered. Nowadays in this competitive environment customer need modern technology base and optimize design. Therefor this paper forms the literature review of the analysis of stator frame as a whole for large electrical machines.

The research paper is only to know the basic structural parameters of stator assembly. The future scope of this research paper is to undergo electromagnetic study of the stator assembly. The projection of this analysis would be to evaluate the electrical parameters of the system under design and execution.

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