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An investigantion on Windings in New Generation of Synchronous Generators Based on XLPE Cable Known as Powerformers

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Abstract

Nowadays cable wound synchronous generators known as powerformers has been applied in modern power plants. Winding of them is so different compared to conventional winding used in customary synchronous generators. In this paper, the winding of them has been investigated and two appropriate wiring for armature winding has been presented. Then the advantages and disadvantages of them have been studied and one of them has been suggested. Finally analysis and simulation of a sample powerformer that used introduced wiring, based on finite element method has been done. The obtained results show the accuracy of claim.

Keywords: high voltage generator; powerformer; wiring; XLPE; FEM;

1. Introduction

Nowadays the three phase synchronous generators are used in all power-plants in the world. The output voltage of these synchronous generators due to insulation limitations is limited to maximum 30 kV. Therefore in power-plants a step-up transformer is necessary to increase of the generator output voltage to the voltage of transmission lines.

In 1998 for the first time a new generator called powerformer was invented. It could generate voltage in the level of transmission lines by using an innovation in configuration of armature winding of stator.

With these new generators and by generating of the high voltage in terminals of generator, the step-up transformer in power-plant can be removed. Figure 1 shows the difference between conventional power-plants and powerformer power-plants. [1], [2]

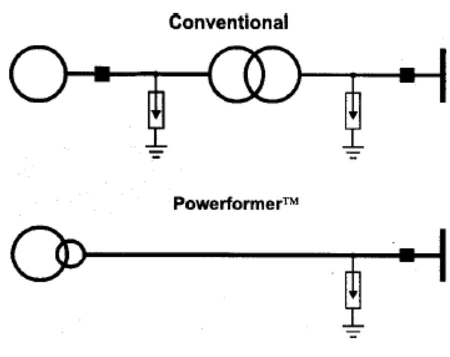

Figure 1. Single line diagrams, conventional (top) and Powerformer power-plants

In powerformers, high voltage XLPE cables are used as armature winding instead of rectangular coil used in conventional generators. Therefore the insulation limitations that exist in conventional generators, by replacing rectangular coil with the round cable have been removed and generating of high voltage in terminals of generator has been possible. [3]

Because of increasing of phase turn numbers due to increasing of voltage, and also using circular cross section cables as conductors, powerformers slot are different compared to conventional slot in synchronous generators. The slot of these generators is deeper than that of in conventional generators, so that more number of turns could be placed in each slot of them. Also the cross section of the slot designed to enclosure the cables.

Because of the increasing turn numbers in each slot, the induced voltage in a powerformer stator winding will gradually increase from the neutral point to line terminal. Therefore, the cables in the slot are exposed for different electrical stress along the length of winding. It is therefore feasible, to use different cables with different thicknesses in each slot. For example if the neutral point placed near to first cable inside slot close to rotor surface, the first turns of the winding are thinner and thereafter the thickness of insulation increases to the last turn. So the designers of these generators use different thicknesses of insulation in armature winding to optimize the cost of cable and to have some level voltage. Figure 2 shows two different slot configurations and their inside conductors used in conventional generator and powerformer.[4]

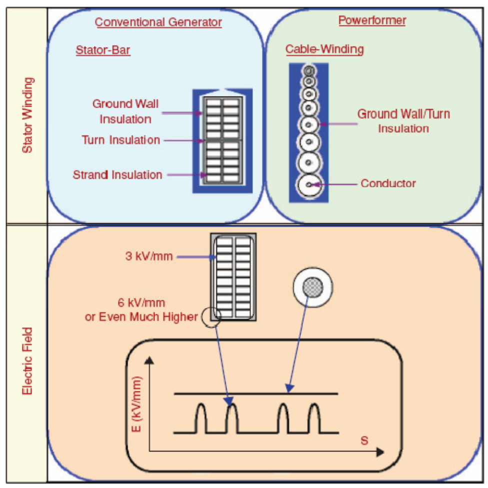

Figure 2. Two types of slot used in conventional generators and powerformers with two different windings

In this paper, first, by considering the new shape of conductors and slots, an innovation method to wiring of these new generators has been introduced and applied to a sample designed powerformer rated at 25 MVA and 63 kV. Then some characteristics of the machine such as noload output voltage, balanced of winding, magnetic flux density distribution and magnetic flux lines has been analyzed by using finite element method; finally the accuracy of design as well as fitting of the wiring used in the design has been investigated.

2. A Different Method of Wiring for High Voltage Synchronous Generators that Use Different Cables

In conventional synchronous generators, usually two layers of coils in each slot are used and because of equality of insulation thickness for both layers, wiring will be placed in a way that the upper layer will be the outward current path and the lower layer in another slot will be the inward current path. With this operation a half turn of a turn is placed in upper layer and the other half turn placed in lower layer. This matter for high voltage generators whose cables are optimum designed and their insulation which has different thicknesses is impossible. For example in order to wire a cable generator with 8 cables inside each slot, if the thickness of all cables are equal, it will be possible to use 4 upper cables for the upper layer and another 4 lower cables for the lower layer and the wiring of this machine can do the same as conventional generators.[5]

But if the cables in the slots are optimum designed and the cables have different thicknesses, the above method will not be possible. Because in the case, for each turn whose each half is placed in the upper layer and the other half turn placed in lower layer, the thickness is not the same.

For solving this problem, it is feasible to wire each adjacent pair cables as conventional winding so that one cable is used as upper layer and another cable as lower layer. This operation is done for all pair cables with the same insulation inside the slot and for around of the stator all and finally all of them connected in series mode to obtain the desired high voltage in line terminals. In this winding, the number of cables inside the slot must be even and two cables that are wired to each other must be the same. [6],[7]

Figure 3 shows two divisions of the cables for wiring the powerformers for the same or different cables inside them.

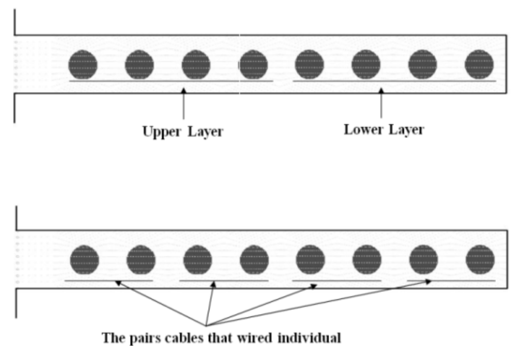

Figure 3. Two divisions of the cables for wiring

3. Wiring of a Sample High Voltage Hydrogenerator Based on Introduced Method

Table 1 shows the designed results of a high voltage hydro-generator, rated at 63 kV and 25 MVA.

TABLE I. DESIGNED PARAMETERS OF 63KV AND 25MVA POWERFORMER

Generator parameter	Designed Quantities
Output Power(MW)	25×0.9
Nominal Voltage(kV)	63
Number of pole	32
Frequency(Hz)	50
Stator Inner Diameter(m)	7.22
Stator outer Diameter(m)	6.04
Length of core(m)	1.185
Cable per slot	12
Number of Slots per pole per phase	2.25
Diameter of conductor(mm)	12
Diameter of 63kV cable(mm)	42
Diameter of 33kV cable(mm)	33
Diameter of 11kV cable(mm)	23
Deep of slot(m)	0.47
Pitch fraction angle	20°

As shown in table 1, to optimize the cost of cable and ability to have several output level in terminals, three kinds of standard XLPE cables rated at 11,33 and 63 kV are used in stator slots of this powerformer. In each of its slot, there are 12 XLPE cables in the way that two the first cables near to rotor surface are 11 kV cables and the next four cables after them are 33kV and the last six cables are 63 kV. The designed slot of the powerformer and the cables used inside, have been shown in figure 4.

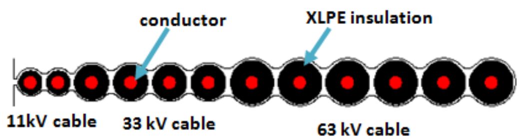

Figure 4. Slot of a 63kV powerformer with twelve cables inside it

In the combination it is clear that the neutral point is close to first conductors of the slots (close to rotor surface) and the terminals of generator are close to the cables in the end of the slot.

Regarding the introduced method of wiring for high voltage generator with different cables in the slot, in this section for each adjacent pair cables, fractional slot winding with slot per pole equal to 2.25 has been applied, so that each pair of the cables are wired in conventional way for the surrounding of the stator and then the cables are connected in series to generate high output voltage. Figure 5 shows the paths of current for pairs of cables inside the slot for 27 slots and four poles equal to one period of winding.

1	2	3	4	5	6	7	8	9
A+	A+	A+	B-	B-	C+	C+	A-	A-
A+	A+	B-	B-	C+	C+	A-	A-	A-

10	11	12	13	14	15	16	17	18
B+	B+	B+	C-	C-	A+	A+	B-	B-
B+	B+	C-	C-	A+	A+	B-	B-	B-

19	20	21	22	23	24	25	26	27
C+	C+	C+	A-	A-	B+	B+	C-	C-
C+	C+	A-	A-	B+	B+	C-	C-	C-

Figure 5. The wiring of each pair cable inside slot for slot per pole per phase equal to 2.25

4. the Simulation Results of the Sample High Voltage Hydrogenerator

In this section, the designed high voltage hydro-generator has been analyzed based on Maxwell equations by using finite element method. The introduced wiring has been applied for the machine and the current sources for excitation and armature winding has been given, also the boundary condition for four poles of the machine has been determined.

Regarding the above circumstances, analysis of the machine has been done by using finite element method and the following results have been obtained.

4.1 Noload Output Voltage

Figure 4 shows waveform of noload output voltage for three phase of the high voltage hydro-generator.

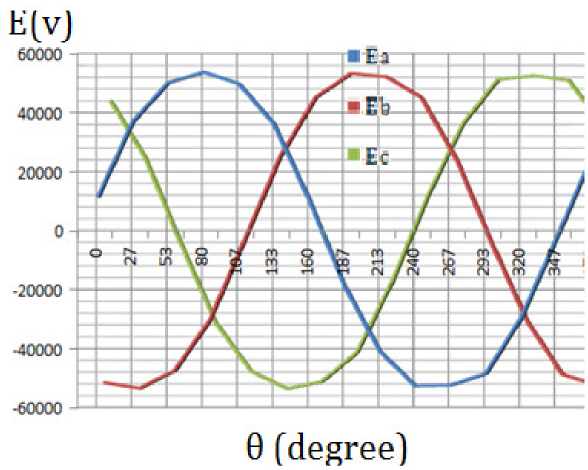

Figure 6. Noload output voltage waveform of three phases of the powerformer

As shown in fig 4, the output voltage waveform is the symmetric sine and the expected high voltage is created. This indicates that the introduced wiring is appropriate for high voltage generators especially for those use different cables inside each slot. Figure 5 shows the flux lines distribution resulted from rotor excitation of the powerformer, using FEM.

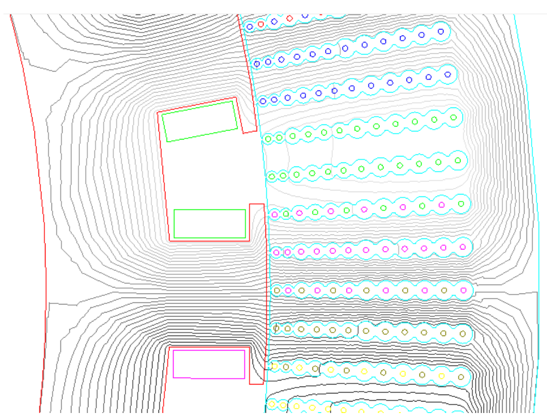

Figure 7. Flux distribution resulted from rotor excitation calculated by FEM

4.2 Flux Density Distributi on Model

Regarding the change of the conductors slots and teethes in powerformers, and generally speaking the innovation in winding and stator configuration compared to conventional generators, analysis of the saturation status in the new machine is so important. For this purpose, nominal currents have been applied to excitation and armature winding and then by specifying the boundary condition, saturation status has been investigated. Magnetic flux density and magnetic flux distribution resulted from the analysis has been shown in figure 8.

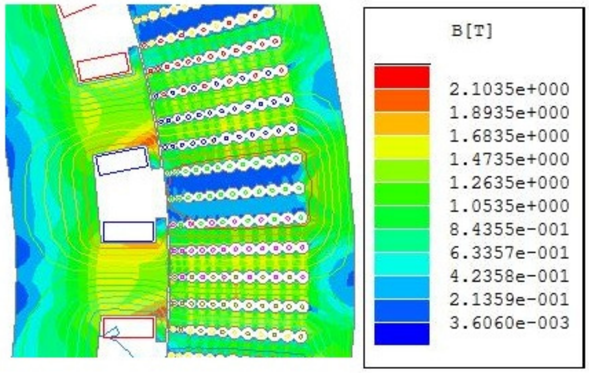

Figure 8. Magnetic Flux and fulux density distribution on model calculated by FEM

As shown in figure 6, flux density in poles and teethes is less than 1.8 T. therefore, it is resulted that the flux density on the model by innovation in design and wiring, is limited to critical spot and it shows the accuracy of the design. Of course, several investigations have been done to get the final and the best design.

5. Conclusion

The new generation of synchronous generators known as powerformers and the most differences in winding of them compared to conventional generators has been introduced and an innovation in wiring of them especially those which use different cables and have different voltage has been studied. Then the designed results of a sample high voltage hydro-generator have been presented. Finally the studied wiring has been applied to the sample powerformer and the design and wiring has been checked by finite element method. The obtained results show that if the powerformers using different cable inside their slots, are wired as the method introduced in this paper, all characteristics of the machine will be fit. Therefore, this wiring in high voltage generators is recommended by this paper.

REFERENCES

[1] M Leijon, L Getmer, H Frank, J Martinsson, T Karlsson, B Johansson, K Isaksson, U Wollstrom, “Breaking Conventions in Electrical Power Plants”, Report 11/37-3, Proc CIGRE Session, Paris 1998, 8pp.

[2] M Leijon, S G Johansson, F Owman, S Alfredsson, T Karlsson, S Lindahl, C Parkegren, S Thoren, “ Powerformer™ Experiences from the Application of Extruded Solid Dielectric Cables in the Stator Windings of Rotating Machines”, IEEE Pwr Eng Soc WM 2000, Singapore, Jan/Feb 2000, 9pp.

[3] Ibrahim A. Metwally, R.M.Radwan, A.M. Abou-Elyazzied, “Powerformers: A breakthrough of high-voltage power generators” IEEE potentials, pp. 37-44, May 2008.

[4] H.hooshiar, M. savabeghi, A. Vahedi, “Synchronous Generator: Past, Present and Future ’’, IEEE, 2008

[5] Meinolf Klocke, "Slot Leakage Inductance and Eddy Current Losses in Multi-Turn Stator Windings for Very High Voltage Synchronous Generators", ISTET conference, paper 43, Austria,2001

[6] M.taherzadeh, A. Akbari, M. Ardebili,"An Investigation on Slot Configuration in New Generation of Synchronous Generators Based on XLPE Cables,” Turkey International Conference(ELECO), 2009. pp.197-201

[7] M.taherzadeh, M. Ardebili, A. Akbari, “ new approch on leakage reactance calculation in different windings at cable high voltage generators” translated in persian, 18 th Iranian Conference on Electrical Engineering ,ICEE 2010 , Esfahan.