A Recent Trend in Power Generation Using Powerformer in Thermal Power Station

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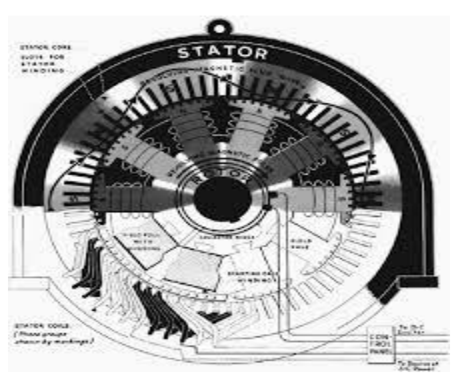
Abstract :Modern power systems are continuously being expanded and upgraded to cater the need of ever growing power demand. Conventional high-voltage generators are designed with voltage levels rated maximum of 30 kV. The power grids with voltages as high as 1,100 kV cannot be directly supplied from these generators, power step-up transformers are used to transform the generated voltage to high transmission voltage level suitable for the interface with the transmission grid. So developing a high-voltage generator, the Powerformer, that could be connected directly to the power grid, without step-up transformer. The reliability of implementing power former in thermal power station was explained in detail and simulation is done by MatLab. The technological advantage offered by the power former was studied in good detail and their impact on thermal power station is explained in detail.

I. INTRODUCTION

Today, the three-phase synchronous generators are used in all power plants around the world. The output voltage of the synchronous generators is limited to a maximum of 30 kV due to insulation restrictions. Therefore in power plants, step-up transformers are necessary to increase the output voltage of the generator to the voltage of transmission lines. In 1998 for the first time a high-voltage generator called Powerformer was invented. It could generate voltage at the level of transmission lines through an innovation in configuration of the armature winding of stator. With these new generators and by generating of high voltage in terminals of the generator, the step-up transformer can removed in thermal power plant. Overall in India thermal power plant is dominating in power production so implementing powerformer both in new and existing power stations in India is discussed.

EXISTING GENERATOR

The stator windings of the conventional generators consist of rectangular conductors, which are placed in the stator slot[1a] .The main objectives of the rectangular conductor shape selection are to maximize the load current and the filling factor. According to Maxwell's equations, the shape of these conductors leads to an uneven electric field and a magnetic field distribution with values, established at each of the four corner slots, as shown. This intensification of the corner field dictates the use of insulating materials with extremely high dielectric strength (e.g.: mica sheet set in epoxyresin).The practical consequence of a rectangular conductor in an electric machine is that the insulation and the magnetic materials of the machine are highly stressed and loaded` non-uniformly, and this leads to an inefficient use of the materials involved. A defect in the machine because of high electrical voltages of the insulating materials is also very likely. Therefore complex measures have to be taken in the end winding region, in order to control the electric field, in order to avoid partial discharges and corona. In order to minimize the eddy current losses in the stator coils, the copper laminations constituting the conductors must be transposed along the winding according to an elaborate scheme.



(1a.cross section view of stator)

POWERFORMER

In contrast to conventional generators, the windings of Powerformer have cylindrical conductors. As can be deduced from Maxwell's equations, there is an even electric and magnetic field distribution in cylindrical conductor, which is a prerequisite for a high voltage electrical machine. As already mentioned, there is a stator winding of high voltage cables in the Powerformer.
Consequently, the output voltage of the Powerformers is limited by the state-of-the-art high Voltage cable technology. Recently, insulation materials and production techniques provide reliable cables at operating temperatures gradients in the order of 10 kV / mm and more.

Such a high electric field is not suitable for conventional mica / epoxy based coil insulation [1b]. Circular cross-section of cable solves the two main problems arising from the use of conventional rectangular stator windings:

• First, within the stator slots, insulation performance and the voltage rating of the cable is maximized by the uniform electric field in the insulator.
• Second, by bending a cable with circular cross-section there are no kinks and sharp edges that arise when using a rectangular cable. Thus, even in the end regions where the cable is bent to make transition from one slot to the next slot, the electric field inside the insulator is free from singularities. Even at the end regions of Powerformer, the electric field is confined within the cable. Hence the need to control an external electric field, as in a conventional machine, is eliminated in the Powerformer.

*(*1b.cross section of Powerformer stator)

Powerformer reliability parameters Stator winding reliability

The reliability evaluation and failure rate of stator winding can be performed by using the failure data obtained from old and conventional three phase cables that were installed in the distribution and transmission systems during 10 to 30 years ago. Based on the information in reference(02) , failure rate for the stator and the related joints are as follows:

$$\text{Failure Rate for Stator} = 0.02\frac{\text{faults}}{(100 \text{ three phase circuit} - \text{km} - \text{years})},$$

$$\text{Failure Rate for Joint} = 0.05\ \frac{\text{faults}}{(100 \text{ joint} - \text{years})}.$$

The calculated failure rate for high-voltage stator winding is also equal to 0.53 faults/(100 generator-years). So the amount of mean time to failure (MTTF) is calculated as follows:

$$\lambda_{\text{stator}} = 0.0053\frac{\text{faults}}{\text{years}},$$

$$\text{MTTF} = \frac{1}{0.0053} = 190 \text{ years}.$$

In case the fault is inside the stator core and a severe fault occurs, the stator laminations should be completely replaced. In this situation, the mean time to repair (MTTR) is estimated to be about 13 days. Also, the unavailability of the high-voltage stator winding in these generators is as low as 0.019%. Thus, according to the evaluations performed, it can be concluded that the
Powerformer failure rate is significantly lower than the recorded failure rate at the conventional generator of Thermal power plants.

Step-up transformer and substation equipment
Electric substations are the main source of failures and faults in power systems. Failures of station equipment, such as circuit-breakers, transformers and buses have significant effect on the power system reliability. So the system
can be made more reliable by removing some of the components that can fail, such as the transformer and the circuit-breakers. This can be done by powerformers.

Rotor reliability
There is no difference between rotor of powerformers and conventional generators. So, all of the various exciter systems in conventional generators can be used in powerformers. Thus, it is reasonable to suppose that the failure rates of conventional rotors and the rotors in powerformers are equal. **Table 01** shows the forced outage rate (FOR) for different power plants in two generators

used in this study (existing generators and powerformers).

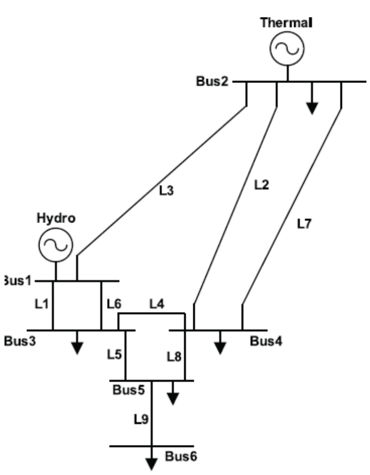
Machine \ Power Plant	Hydro Unit 2×50MW in bus 1	Thermal Unit 1×100MW in bus 2
Conventional Generator	0.025	0.05
Powerformer™	0.004	0.02

Table 01

Evaluation Method of the System Reliability with Powerformers

Basic reliability indices for power systems reliability evaluation with powerformers, are frequency and mean time to failure of load. These indices are categorized and based on the system and load point indices. System indices covered a large area of the system operating situations. In this paper, the expected energy not served (EENS) is the main index for the comparison of different evaluation methods.

Case Study Network: Simulation Results
The test network



To evaluate the effect of powerformers on the power system reliability, the 6-bus IEEE RBTS network is chosen. This test network is shown in Fig. In the simulation, four different cases are considered for the system. The characteristics of these cases are presented in **Table 2**.

Different cases of the system.

Cases	Powerformer™ Location
No. 1 (Basic Case)	Base Case: 3-Bus System with Conventional Generators
No. 2	Replacing Generator at Bus 2 with Powerformer (a 100MW Thermal Power Plant)
No. 3	Replacing Generator at Bus 1 with Powerformer (a 50MW Hydro Power Plant)
No. 4	Replacing all Generators with Powerformer™ Units

The specifications of the base case for the RBTS network are considered in the reference. Then, powerformers are replaced with conventional generators. The results for the two situations are compared together. The reliability parameters of the case study network are described in **Table 3.**

Elements		λ [fail/yr]	r [h]	U [h/yr]
Conventional generators	G1,G2 Hydro (50MW)	0.025	48	1.2
	G3 Thermal (100MW)	0.05	50	2.5
Powerformers	G1,G2 Hydro (50MW)	0.004	96	0.384
	G3 Thermal (100MW)	0.02	100	2.0
Transmission Lines		0.01	10	0.1
Transformers T1, T3, T4, T5		0.02	75	1.5
Transformers T2		0.015	60	0.9
Circuit-breakers		0.015	70	1.05
Disconnect Switch		0.01	20	0.2
Load Bus		0.015	10	0.15
H and B Buses (Reliable)		0.0	0.0	0.0

To explain the system reliability evaluation clearly, consider Fig above. This figure shows the reduced network of Fig. 6 with the same characteristics as with hydro- and thermal power plants as well as a load center. This network has 3 generation units with the total generation capacity of about 200MW (two hydropower plants each with a capacity 50MW and one thermal unit with a capacity of 100MW capacity). Also, the peak load of the network is 200MW. Fig. 5a shows an equivalent single line diagram to reduce the size of the calculations.

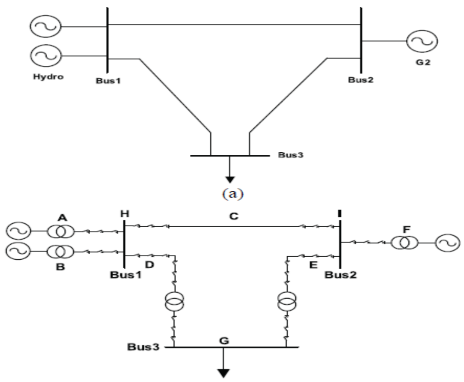


Fig. 5b – Reduced 3-Bus IEEE-RBTS network (system peak load =200 MW)

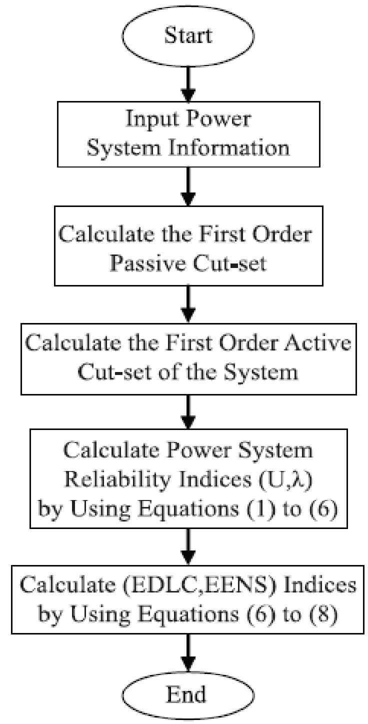
(a) Reduced single line; (b) Equivalent single line diagram of (a).
(b) It should be noted that the existing elements are the equivalent elements in the network and they are obtained by applying equations (1) to (2) [3].

$$\lambda_T = \sum_{i \in A} \lambda_i \quad [\text{fail/yr}],$$

$$U_T = \sum_{i \in A} \lambda_i r_i = \text{EDLC} \quad [\text{h/yr}],$$

$$r_T = \frac{U_T}{\lambda_T} \quad [\text{h}].$$

Now consider the equivalent elements, the 6 paths in the system are:
AHDG, AHCEG, BHDG, BHCEG, FICDG, FIEG.
Assume that the power plant bus bars (H and I buses) are reliable, then these paths can be modified as:
ADG, ACEG, BDG, BCEG, FCDG, FEG.



To find the paths and minimal cut-sets, the MATLAB software is used. The minimal paths are: G, DE, ABF, CDF, ABCE. The simulation flowchart is shown in Fig. 8. As mentioned earlier in this paper, the mean value of failure rate [failure/yr.], mean down time [h], expected duration of load curtailment (EDLC with h/yr.), expected energy not served, or loss of energy expectation index have been considered as reliability indices for the system.

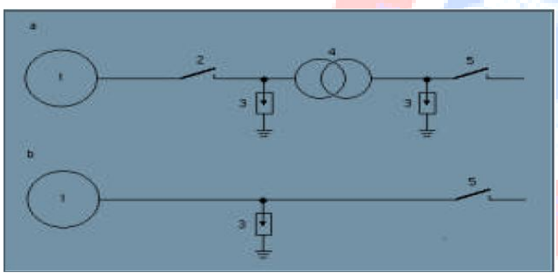
COMPARSION OVER EXISTING

The powerformer, although a new machine is a three phase synchronous generator with a rotor of a conventional type. The fundamental difference, compared with the conventional generator, is located in the Stator windings.

In Powerformers, the stator winding is made of high-voltage cables instead of the conventional rectangular cross-section windings. To increase the output power of an electric machine, either the output voltage level or the current in stator windings must be increased. Insulation technologies limited output generated voltage, so the solution now was to increase the current in the stator, instead of the output voltage.

However, in Powerformers, the output power is increased by increasing the output voltage by using XLPE cable in the stator winding. This design results in the omission of generator circuit breaker, the high power bus and the step-up transformer from the power plant, because Powerformer includes the features of both the generator and step-up transformer as shown in Figure (2a).

As a consequence there is an increase of up to 1.5% of the total electrical power efficiency in comparison with the today's best designs, without using superconductive materials. Reactive power output and overload capability are also improved in powerformer. There are also major changes in design, engineering, manufacturing and production of the complete plant. These give a total reduction in size andweight, which has a lesser impact on the environment. The technological basis of the new machine gives a promising future possibility for both water-and thermo-power stations and other electrical devices.



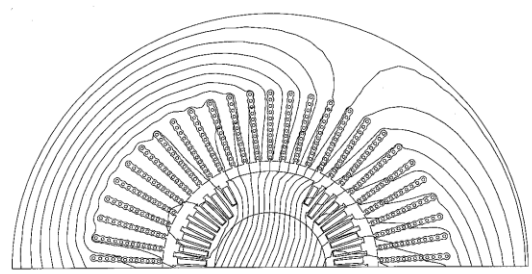
(2a.comparsion of existing Vs powerformer)

POWERFORMER USING XLPE CABLES

Almost all PEX is made from high density polyethylene (HDPE). PEX contains cross-linked bonds in the polymer structure, changing the thermoplastic to a thermo set. Cross-linking is accomplished during or after the extrusion of the tubing. The required degree of cross-linking, according to ASTM Standard F 876-93, is between 65 and 89%. A higher degree of cross-linking could result in brittleness and stress cracking of the material. The high-temperature properties of the polymer are improved. Adequate strength to 120–150 °C is maintained by reducing the tendency to flow. Chemical resistance is enhanced by resisting dissolution.

Low temperature properties are improved. Impact and tensile strength, scratch resistance, and resistance to brittle fracture are enhanced.PEX- or XLPE-insulated cables have a rated maximum conductor temperature of 90 °C and an emergency rating up to 140 °C, depending on the standard used. They have a conductor short-circuit rating of 250 °C.

XLPE has excellent dielectric properties, making it useful for medium voltage—10 to 50 kV AC, and high voltage cables—up to 380 kV AC-voltage, and several hundred kV DC.Numerous modifications in the basic polymer structure can be made to maximize productivity during the manufacturing process. For medium voltage applications, reactivity can be boosted significantly. This results in higher line speeds in cases where limitations in either the curing or cooling processes within the continuous vulcanization (CV) tubes used to cross-link the insulation.



(2b.armature flux distribution)

IMPLEMENTING IN THERMAL POWER PLANT

The implementation of thermal power plant simulation is already discussed earlier in this paper. By implementing powerformer instead of existing alternator, overall efficiency can be improved by (10to20) percent of power produced by existing alternators. The consumption of reactive power by the transformer is avoided and the reactive power produced in the generator may be used elsewhere in the network. Additionally, the cable winding technology stretches the limits of the short term overload capability of the generator such that more reactive power can be produced in Powerformer than in a conventional generator.

Other advantages resulting from the omission of the step-up transformer include a reduction of the number of components in the plant, such as medium-voltage busbars and generator breakers. Thus, maintenance costs are expected to be reduced and availability as well as reliability increased. Moreover, the layout can be made more compact for a plant equipped with Powerformer than for a conventional generator due to the exclusion of the step-up transformer and its auxiliaries.

PD: Partial Discharge.
The total plant comparison, which is more realistic since Powerformer also comprises a Transformer function

Conventional generator	Powerformer
Low voltage (<30kV)	High voltage (>>30kV)
High current	Low current
High temperature	Low temperature
Short teeth	Long teeth
Weight = 1	Weight = 1.2-4
PD accepted	PD minimized

Comparison over conventional generator

Advantages of Powerformer

- Savings in material costs as no mains transformer and no and low-voltage make / break switches are required.

- Savings in maintenance costs because no main transformer and no busbar cubicle and low-voltage make / break switch are required.

- Improving generator efficiency (equivalent to a 2% increase in efficiency in the Katsurazawa Power plant (Higher efficiency is the result of lower power loss due to the lower rated current value and reduced losses in the main transformer.)

- Improved reliability, since no main transformer and low-voltage make / break switch and busbas cubicles are required. Moreover, as the capacity of the generator increases, thus increasing their output power. As a result of the merits of the improved efficiency of the new high-voltage generator will be higher, the higher is the output voltage, and the higher is its capacity.

CONCLUSION

In this paper we are discussed about the implementation of thermal power plant using Powerformer . Nowadays in India power requirement is keep on increasing than the power production .By implementing powerformer in thermal power station able to increase the capacity and efficiency of the power delivered by the power plant .It can also replaces existing alternators. From this depletion in power production in India can be reduced considerably. Moreover cost of the power production per unit is also reduced. So power efficiency increased thereby cost also decreased.

REFERENCES

[1]C.A. Aumuller, T.K. Saha: Investigating the Impact of PowerformerTM on Large Scale System Voltage Stability, IEEE Power Engineering Society General Meeting, 12-16 June 2005, pp. 1283 – 1289.

[02] S. Lindhal, M. Leijon: Estimation of the Reliability of PowerformerTM, SECRC/ABB Corporate Research, Vasteras, SEGEN/DN HOG 9801, 1998, pp. 1 – 6

[3]R. Billinton and R. Allan: Reliability Assessment of Large Electric Power Systems, Kluwer Academic Publishers, Boston, 1988.

[4]M. Wahlen, B. Larsen, M. Lindgren, B. Hernas, P. Frost: Risk Assessment of a Highvoltage Generator with XLPE Insulated Stator Windings, CIGRE, Paris, Special Session, 2002.

[5]K Isaksson, U Wollstrom, "Breaking Conventions in Electrical Power Plants", Report 11/37-3, Proc CIGRE Session, Paris 1998, 8pp.

[6]M. Darveniza, T. K. Saha, B. Berggren, M. A. Leijon, and P. O. Wright, "A research project to investigate the impact of electricity system requirements on the design and optimal application of the PowerformerTM," in Proc. 2001 IEEE Power Engineering Society Transmission and Distribution Conf., vol. 1, pp. 504-509.

[7]J. McDonald and T. K. Saha, "Development of a technique for calculation of the influence of generator design on power system balanced fault behavior," in Proc. 2002 IEEE Power Engineering Society SummerMeeting, vol. 2, pp. 731-736

[8]R. Allan and R. Billinton, "Power system reliability and its assessment Part-I. Background and generating capacity," Power Engineering Journal, vol. 6, pp. 191-196, July 1992.