

# The Special Features of Generators and Transformers of Upper Kotmale Hydropower Project

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**Abstract:** Upper Kotmale Hydropower Project is a recently concluded major hydropower project in Sri Lanka. The latest design concepts applicable to the hydropower industry are adopted in building this power plant. Some of these concepts were specified by the client at the time of bidding and others were adopted by the contractor. This paper briefly discuss few of the new features adopted in the design and implementation of the Upper Kotmale Hydropower Project.

**Keywords:** Design, Features, Power Plant, Upper Kotmale, Hydropower, Project

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## 1. Introduction

The design, manufacturing, installation and commissioning of hydro power plants involves many complex processes closely coordinated with each other. The selection of each components of the power plants depends on the layout, installation, operation and maintenance of the specific power plant. Standard equipment as well as newer practices which are growing popularity in the hydropower applications are used in the implementation of the Upper Kotmale Hydropower Project.

The following three new features, which were identified during the detail design and incorporated in the Upper Kotmale Hydropower Plant are discussed in this paper.

- 1) The Electric Braking system for the hydro generator
- 2) Special Three Phase Transformers for generator transformers
- 3) PEEK material for Generator Thrust bearing

## 2. Electrical Braking System

Traditionally hydro generators are provided with mechanical friction braking system. This system helps to stop the generator rotor rotation in a reasonable time during the shutdown.

The mechanical brakes will be activated around 20 percent of the rotating speed of the generator until the rotor comes to standstill. This system brings the generator to standstill quickly and avoids the wear of the thrust bearing.

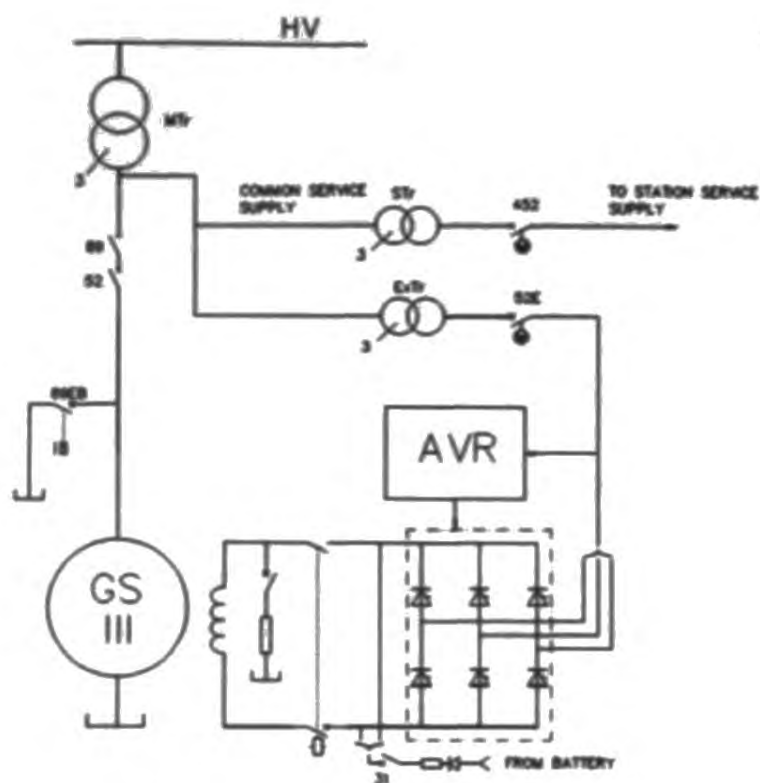
The modern hydro generators use electrical braking system in addition to the mechanical brakes. This concept is adopted in the Upper Kotmale Hydropower Project due to the following reasons:-

- This reduces the wear on the mechanical brakes and the amount of brake dust produced by the mechanical braking system
- Since the Upper Kotmale generators are of high speed type it is essential to have an electrical brake to reduce the stopping time and to reduce the load on the mechanical brakes [1]. This will minimize the wear on the brake rings and brake pads.

### 2.1 System Configuration

The main circuit arrangement for the electrical brakes is indicated in the Figure 1. The essential components for this system are as follows;

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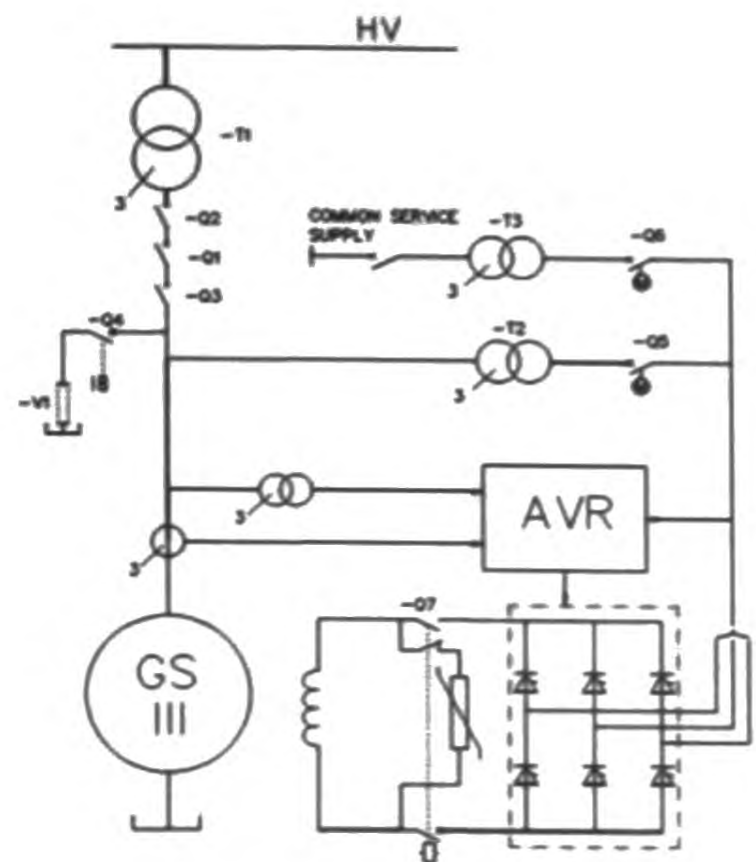
**Figure 1 - Component Arrangement for Electrical Brakes**

- Automatic Voltage Regulator (AVR) with electrical brake function
- Circuit Breaker (89EB) with the bus bar arrangement to short-circuit the generator terminals
- Excitation transformer connected to main transformer side of the generator circuit breaker (52).
- Control logics to discriminate between the electrical faults and mechanical faults and to block the electrical brakes accordingly.

The above scheme is adopted in the Upper Kotmale power plant. The significant difference between the conventional mechanical braking arrangement and the above electrical brakes arrangement is that the location of excitation transformer. In the case of electrical brakes the excitation transformer is located on the unit transformer side of the generator circuit breaker, while in the case of mechanical breaks this is not essential.

The electrical brake function in the AVR is activated and the excitation transformer is continuously energized throughout the operation of the plant.

An alternative arrangement for the above system is shown in Figure 2.



**Figure- 2 Alternative Arrangement for Electrical Brakes**

In this arrangement, the excitation transformer is placed on the generator side as in the conventional arrangement. However, an additional transformer is arranged separately for the purpose of electrical brakes. This in turn increases the number of auxiliary equipment and additional control steps in the sequence. This arrangement was not considered for the Upper Kotmale Power Station.

## 2.2 Sequence and the Principle of Electric Brakes.

The stop sequence of the generator starts with the opening of the generator circuit breaker. The AVR power supply is switched off by opening the exciter power supply breaker 52E. The generator rotor starts decelerating and at about 50 percent of the speed, the generator stator is short circuited by closing the breaker 89EB. At this stage breaker 52E is closed and the generator is excited with a constant field current. This field current induces a stator current equivalent to the rated current.

The interaction of field flux and the stator flux produce a braking torque and decelerates the rotor rapidly and reduce the speed. In this arrangement the energy stored in the rotor is dissipated as  $I^2R$  loss on the stator winding.

The application of electrical brakes above 50 percent speed is not useful as the value of the  $I^2R$  loss is much less than the other combined losses. At lower speeds the braking force is reduced. Hence the mechanical brakes are activated to bring down the speed from 5 percent to standstill.

The oscillogram[3] shows the total time taken to stop the generator rotation is 4 min and 44 sec. The stator current is set as 0.95pu and the field current during the electric brake operation is 525A. The stator current oscillogram is not clearly shown as the stator current frequency is of varying nature during this period. The total time to stop the generator without the electrical brakes is around 10 min for Upper Kotmale generator.

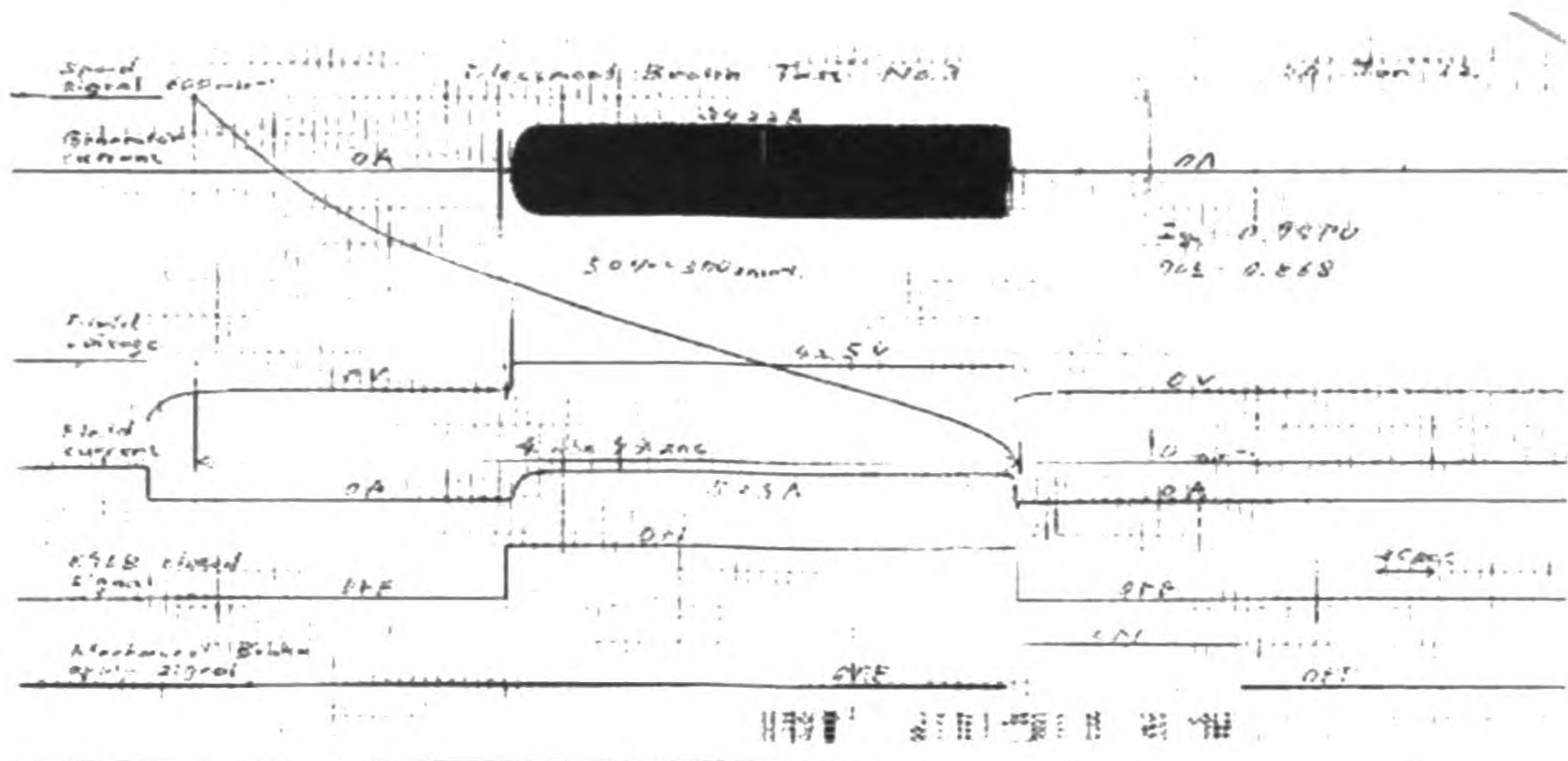


Figure 3- Oscillogram of Commissioning Data

The electrical brakes are activated at the normal stopping sequence of the generator. During electrical faults, the electrical brakes, cannot be activated. Hence it is blocked by the control sequence and the mechanical brakes are activated at around 20 percent of the speed. The mechanical fault of the generator does not disable the electrical brakes.

### 2.3 Upper Kotmale Commissioning Data

The oscillograms which were obtained at the time of commissioning of the Unit number 01 is appended below Figure 3.

### 2.4 The Advantages of Electrical Brakes

- Stopping time of the generator is reduced
- Lifetime of Bearings are increased due to reduced friction and reduces heat generation
- During the stopping the mechanical strains and vibration is equalized
- The lifetime of the brake linings are increased and their strains and the failures are reduced to minimum.

### 3. Special Three Phase Transformers.

The important criteria which influence the generator transformer design are the high

voltage on high voltage (HV) side, high current on low voltage (LV) side, high impulse voltage levels, transport height and weight. In the case of the Upper Kotmale power station the installation space and power plant layout impose additional limitations in the design of the transformers

Although the transformer capacity at Upper Kotmale Hydropower Project is relatively small, the location of the power plant greatly influence the selection of the type of transformer. The height and the weight are considered to be the most influencing factor in selection of the generator transformers in a hydropower project. Further, Upper Kotmale Hydropower power station being an underground power plant imposes an additional constraint in the form of installation space.

The three possible options on the type of transformers were as follows:

- Three Phase Transformers
- Single Phase Transformer Banks
- Special three Phase Transformers

The option of one single three phase transformer couldn't be considered as it cannot be transported into the power cavern and moved into the installation location. In addition to this, the layout of the power plant and the orientation of the access tunnel prohibits the loading and unloading of the transformers.

The single phase transformer banks are common option for hydropower plants. The single phase units can be transported individually and assembled at the site to form into a three phase transformer. This arrangement is commonly used for hydropower plants at Ceylon Electricity Board. The generator transformers are generally delta connected on the LV side and Star connected on the HV side. This star - delta connection is accomplished with air insulated aluminium bus bars. Since the transformer voltages are high, the clearance necessary to obtain the insulation strength is high. Accordingly the installation space is larger than the three phase transformer.

Upper Kotmale power transformers are located at the underground power cavern. Hence, it is necessary to have a very large space to form the star delta connection with the sufficient clearance and safety margin. This will influence the excavation cost and the stability of the power cavern.

The special three phase transformer is an arrangement between three phase transformer and single phase transformer banks. In this arrangement the three single phase transformer tanks are separately transported and assembled at the site as in the case of single phase transformer banks. The star delta connection is formed inside an additional tank which is installed above the three transformer tanks, insulated with transformer oil. This reduces the installation space considerably and it has the same flexibility of the single phase transformer banks.

The cost and the other relevant factors are compared in the Table 1 as indicated below.

**Table 1. Comparison of Transformer Types**

	Special 3 phase	Single phase	Three phase
Total price	100 (%)	108 - 110 (%)	89 - 91(%)
Installation space (Approx)	100 (%)	110 (%)	90 (%)
Limit of Transportation	100 (%)	100 (%)	230 (%)
Efficiency	99.35 - 99.65(%)	99.35 - 99.65(%)	99.38 - 99.66(%)
Quantity of OLTC equip	One set	Three set	One set
% impedance	13 -15 (%)	13 -15 (%)	13 -15 (%)

Considering the above three option, the special three phase transformers were considered as the best option for the Upper Kotmale Hydropower Project. Therefore this type of transformers were specified in the specification.

### 3.1 Detail Arrangement of the Three Phase Transformers.

The generator transformer consists of three identical single phase units. All three units are



Due to the above reasons the hydro generator industry has developed bearings using the PEEK materials replacing the conventional babbitt materials.

The Upper Kotmale Hydropower Project, the specification requests the contractor to provide PEEK or Poly Tetra Floro Ethylene ( PTFE ) thrust bearings. Accordingly the manufacturer for the Upper Kotmale Hydropower Project has opted to use PEEK materials for the thrust bearing. The generator upper and lower guide bearings are babbitt bearings as in the other generators in Sri Lanka.

#### 4.1 Characteristics of PEEK Bearings

The PEEK material is superior in strength under high temperature and the comparison of tensile strength of the different types of bearing materials are indicated in Table 2.

**Table - 2 Comparison of Different Types of Bearing Materials**

		PEEK -A	PEEK -B	PTFE	Babb it
Component		PEEK + CF	PEEK	PTFE +GF	Sn+C u+Sb
Tensile Strength	20°c	240 MPa	84 MPa	22 MPa	75 MPa
	100°c	150 MPa	60 MPa	15 MPa	50 MPa

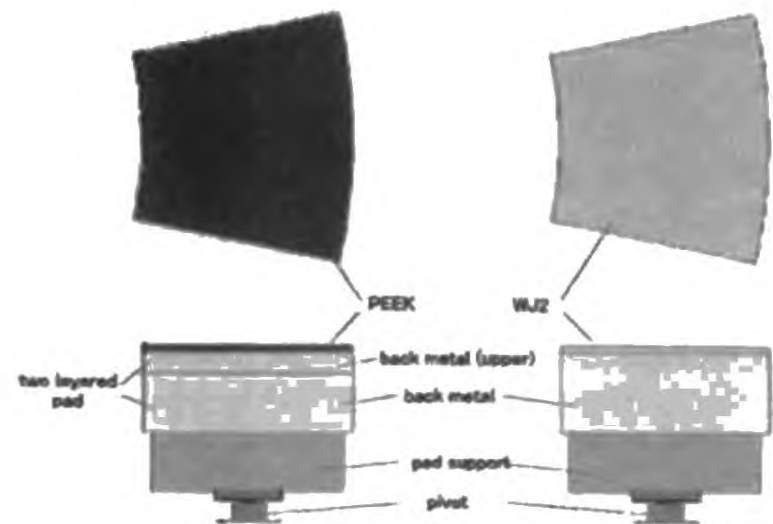
CF : Carbon Fiber GF : Glass fibre GF : other fillers

The manufacturer has two different types of PEEK materials namely PEEK -A and PEEK- B. PEEK A is filling in carbon fiber and is applied for large capacity generators. PEEK-B is applied for only small generators. In the case of Upper Kotmale generators PEEK-A is used for the manufacturing of the bearings.

#### 4.2 Construction of PEEK Bearings.

The construction of the PEEK bearings are same as the conventional babbitt metal bearings. The

Figure 6 shows a typical arrangement of various components of a bearing segment.



**Figure 6 - Various Components of a Bearing Segment**

It is difficult to joint plastic with steel. However, in this design, a porous layer is formed on top of the steel back metal and PEEK is impregnated to the porous layer, making a strong bond between the two materials.

#### 4.3 Advantages of PEEK Bearings

- Due to the low friction coefficient of PEEK material, high pressure oil injection system is not necessary
- PEEK B has electrical insulation, hence the electrical insulation is not necessary for thrust and upper bearings
- PEEK has good wear resistance and lower bearing loss. Due to these characteristic, the bearings can be designed to higher pressure than the babbitt bearings.
- PEEK has good heat resistance and high strength. This increases the reliability of the bearings.

### 5 Conclusion

The above discussed new features of the generators and the transformers are specified by the employer at the bidding stage of the project. These systems are already installed and they are in operation.

The electrical brakes are functioning well and during the regular inspection of the generators, it has been found that there are no brake dust around the lower bracket area.

The special three phase transformer arrangement has helped to overcome the transport limitations and the space constraints inside the power cavern. There was no significant problems encountered during the installation of the transformers.

The PEEK bearings were manufactured and assembled successfully. The performance of the bearings can be assessed only after reasonable period of operation of the power plant.

Many additional features incorporated by the contractor in the design of the power plant. Some of them are based on the contractor's design experience and some are industrial standards.

The power plant control is achieved by computer based numerical control system. Many software based schemes are adopted in the design of the control scheme. The power system stabilizers in the AVR, governor with deflective characteristics and water level control function, joint control of the power plants etc are some of the major software based functions incorporated in the design of the Upper Kotmale Hydropower Project.

These new concepts impose many challenges in the design, installation and commissioning of the power plant. In the Upper Kotmale Hydropower Project all these challenges were successfully resolved and the power plant is in commercial operation. Some of them are already showing their benefits and some of which the return will be realized only on a long run operation of the plant. The engineers who have involved in these works have gained lots of practical experience and exposure in implementing a complicated power project.

Many Sri Lankan engineers were actively involved in the design, installation and commissioning of the above works in par with the expatriate specialists, exposing their knowledge, skill and the commitment in executing a very complicated project demanding diverse engineering specialties.

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