Hydrogenerator Reliability Assessment

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Abstract – **In order to decide whether an equipment upgrade, the rehabilitation or the refurbishment of any component of a hydroelectric facility is economically feasible it is essential to consider not only capital costs and benefits, but take into account the risk exposure associated with the aging equipment. Quantifying this risk exposure in terms of a cost stream hinges on a good understanding of the probability of failure as it varies over time and the consequence costs of a failure.**

Keywords – **Generator, availability, Hydro power plant, failure mode.**

I. Introduction

Reliability analyses are significant part of the economic justification for funding of submissions. They should be consulted for the most rehabilitation and major maintenance projects. There are some basic reliability concepts which arise from statistics and are utilized in evaluating certainty. The definitions of the terms used to produce represent these concepts and the definitions of terms more specific to hydropower equipment reliability analyses follow [2].

a. *Risk*. Expressions of risk are composed of the following: The existence of unwanted consequences. The occurrence of each consequence expressed in the form of a probability.
b. *Certainty*. A condition where determinacy exists in the elements that characterize a situation.
c. *Uncertainty*. A condition where indeterminacy exists in some of the elements that characterize a situation.
d. *Variability*. The existence of differences in the numerical quantities within the same population.
e. *Reliability of power plants*. There are risks associated with the possible failure of operating power plant. The risks include repair costs and higher power generating costs.
f. *Equipment reliability*. The overall engineering reliability analysis consists of four independent analyses to determine the following reliability factors: forced outage experience and reliability, efficiency and capacity, availability and dependability.

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II. Reliability study process

A reliability analysis of hydropower plant equipment requires the following three basic steps:

(a) data collection and investigations; This step should include historical unit availability and operation, any equipment derating, accident reports, operation and maintenance records, equipment performance tests, periodic inspection reports, design and construction reports, the operation and maintenance manual.
(b) identification of specific reliability issues; Experience and historical data of like equipment should be utilized in the determination of the equipment condition and future reliability.
(c) calculations and evaluation; Once the condition of the equipment has been identified, the calculations and evaluation should be performed. For equipment with extensive life databases, such as generators and turbines, standard time-dependent reliability and hazard functions should be used [1].

III. Failure modes and effects analysis (FMEA)

The failure modes and effects analysis (FMEA) is one of the most efficient low-risk tools for prevention of problems and for identification of more efficacious solutions, in cost terms, in order to prevent such problems.
FMEA is a deductive technique that consists on failure identification in each component, its causes and consequences on the equipment and on the whole system.

The FMEA process entails asking seven questions about the asset or system under review, as follows:

- what are the functions and associated performance standards of the asset in its present operating context?
- in what ways does it fail to fulfill its functions?
- what causes each functional failure?
- what happens when each failure occurs?
- in what way does each failure matter?
- what can be done to predict or prevent each failure?
- what should be done if a suitable proactive task cannot be found?

A fault tree analysis can be described as an analytical technique, whereby an undesired state of the system is specified. The fault tree is a graphical model of the various parallel and sequential combinations of faults that will result in the occurrence of the predefined undesired event. The fault tree depicts the logical interrelationships of the basic events that lead to the undesired event – which is the top event of the fault tree.

The fault tree is not a model of all the possible system failures or all possible causes for system failure. A fault tree is tailored to its top event which corresponds to some particular system failure mode.

IV. HYDROGENERATOR RELIABILITY MODEL

The logical interaction of the elements in the hydro power plant, failures and failures modes are modeled using network diagram and fault tree available in the Isograph software, Availability Workbench (AWB) module. Availability Workbench is a powerful availability and reliability simulator capable for analyzing complex and dependent systems. The diagrams are used to model failure modes, consequences and effect of failures. The software then analyse the sustem using efficient Monte Carlo simulation algorithms to provide availability and reliability parameters and optimize planned maintenance intervals [3]
In this paper only Generator fault tree (fig.1) is examined.

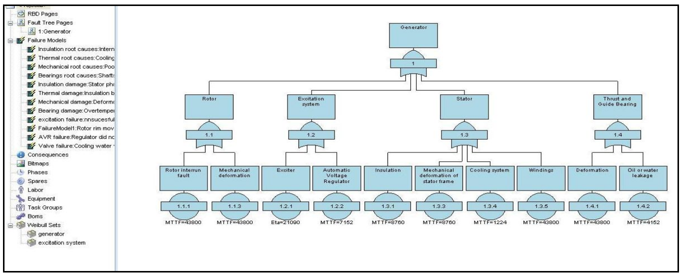

Fig.1. Generator fault tree

The root causes for hydrogenerators failures resulting in forced outages over 10 days duration are [8]:

- *Insulation root causes* **(**Internal partial discharges, Loosening of bars in the slot or in the overhangs, Defective corona protection, Contamination of winding, Overvoltages, etc);
- *Thermal root causes* **(**Cooling circuit failure, Shortcircuits and overload, Phase unbalance, etc);
- *Mechanical root causes* **(**Fatigue of materials, Faulty synchronisation, Poor rotor design to withstand centrifugal forces during runaway speed, Loosening of rotor parts, etc);
- *Bearings root causes* **(**Cooling circuit failure, Lubrication circuit failure, Oil or water leakage,Loss of bearing insulation and shaft current..)
- Excitation system is one of the most maintenance intensive equipment in hydro power plants. Efforts have been made to computerize its maintenance in recent years.

The most common type of damage in the machine produced by the failure are Insulation, thermal, mechanical and bearings damage (Stator and rotor phase to ground or phase to phase fault, stator and rotor interturn fault, Insulation burning, windings deformation, Deformation of coupling between shafts, rotor rim and poles, movement of end windings, mechanical deformation of stator frame, overtemperature, deformation of bearing and etc).

Failure properties may be accessed from the **Failure** tab of the **Cause Properties** dialog. We may link a failure model to a Weibull set created in the Weibull Analysis Module of (AWB). A cause that is linked to a Weibull set will obtain the distribution type and parameters directly from the Weibull set. This allows to analyze historical failure data and directly connect this data to the cause failure model. As historical data is updated, AWB will automatically update the distribution parameters for the associated causes. The exponential distribution represents the case where the failure rate is constant over time. The input value is the inverse of the failure rate in the **Mean time to failure** text box. The cumulative failure distribution at time *t* is given by Eq.(1):

$$F(t) = 1 - e^{-\lambda t} \quad (1)$$

where λ = constant failure rate.
The Weibull options relate to the number of three-parameter Weibull distributions to be used to sample the time to failure of the component [9]. We can choose to have one, two or three distributions, that will represent the three failure modes in the well-known bathtub curve for the failure rate of a component. The first mode represents early failures during the 'burn-in' period, the second mode is the 'useful-life' period when the failures are random and the final mode is the 'wear-out' mode
for which the failure rate rises. The cumulative failure distribution at time t for the three-parameter Weibull distribution is given by Eq.2:

$$F(t) = 1 - \exp[-(\frac{t-\gamma}{\eta})^{\beta}] \quad (2)$$

where η = characteristic life parameter, β = shape parameter, γ = location parameter.
The fixed distribution is intended for use when the time to failure is definitely known.

From the historical date, received for the generator in the hydro power plant in Macedonia, the most common failures are: relay protection failure, excitation system failure, cooling valve mechanical damage and thrust bearing failure. For the other components on the diagram we assumed only one failure in period of 5 years, and exponential distribution is used. Failure dates for electrical and mechanical part are taken from OREDA [7] and NRC Regulatory Guides (NRC 1987; NRC 1985), IEEE 500 (IEEE 1983) North American Electric Reliability Council (NERC), Generation Availability Data System (GADS) (Curley 1994).

In this model for the failure in generator protection and excitation system Weibull distributions are used [4].
Generator protection cumulative probability is shown on Fig.2.

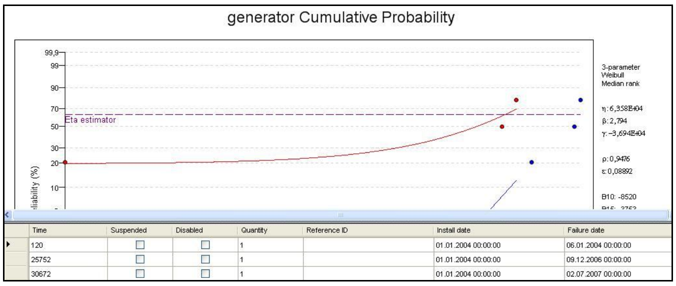

Fig.2. Generator protection cumulative probability

V. MAINTENANCE

The maintenance tasks assigned to a failure are categorized into one of three possible types – corrective tasks, planned maintenance tasks and inspection tasks. Corrective tasks are performed when a random failure takes place or when an inspection reveals a hidden failure. Planned maintenance tasks may be performed at fixed intervals or when the age of an equipment reaches a given value. Planned maintenance may involve the replacement of ageing equipment or minor tasks such as lubrication.
Inspection tasks may be performed at fixed intervals or when the age of an equipment reaches a given value. Inspection tasks are performed to detect an imminent failure (and hence allow a planned maintenance task to be scheduled to prevent the failure) or to detect a dormant (hidden) failure. Hidden failures are normally associated with standby equipment.
Monitoring equipment may be installed to automatically indicate a failure is about to occur without relying on an inspection by a maintenance crew.

VI. RESULTS

Individual cause prediction data is available once a system simulation has been completed. This data includes the down time due to corrective and scheduled maintenance as well as cost contributions due to the use of labor, equipment and spares. Benefit ratios are also displayed indicating the effectiveness of the assigned maintenance strategy. The parameters available at the simulation report are:**Mean unavailability -** the expected fractional time the component will be out-of-service over its lifetime; **Number of failures** - total number of failures of the component over the system lifetime; **Number of PMs -** total number of planned maintenance tasks performed on the component over the system lifetime; **Number of inspections -** total number of inspection tasks performed on the component over the system lifetime; **Total failure down time -** down time of the component due to failures; **Total PM down time -** total PM down time for a component is defined as the portion of the total down time for that component caused by planned maintenance actions; **Total inspection down time -** The total inspection down time for a component is defined as the portion of the total down time for that component caused by inspection tasks (Fig.3).

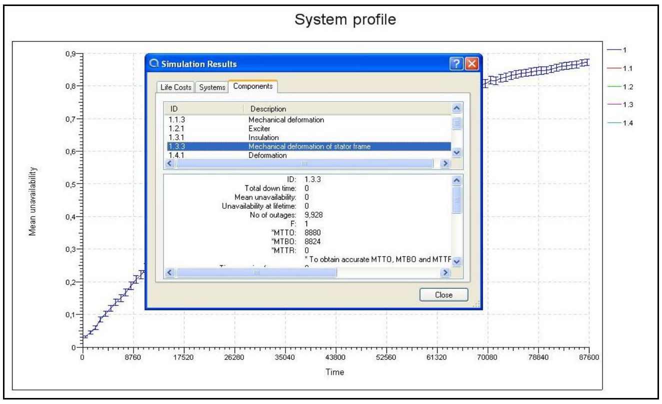

Fig.3. Simulation report for stator failure

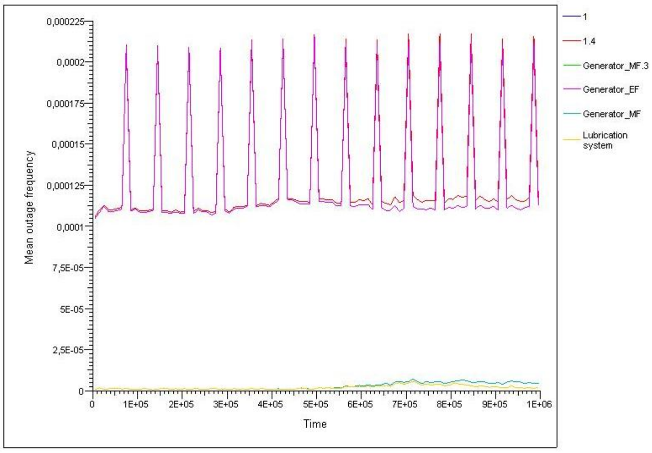

Fig 4. Generator's elements failure frequency

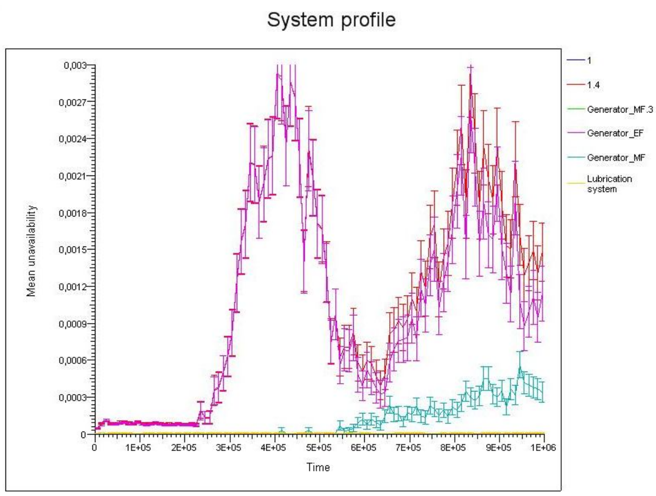

Fig 5. Generator's elements mean unavailabilty

System mean unavailability is shown on the fig.6.

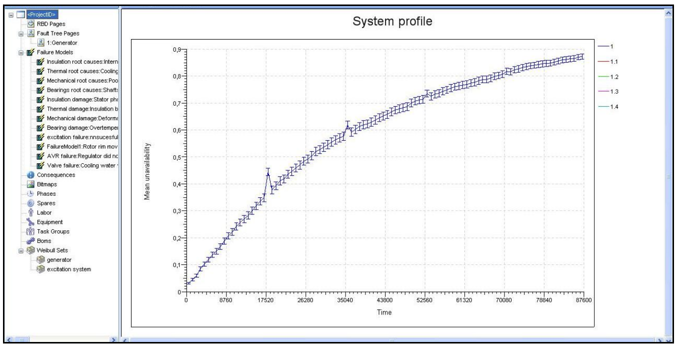

Fig.6. Hydrogenerator mean unavailability for 5 years period

The results from the analysis of this system are given at Fig.7:

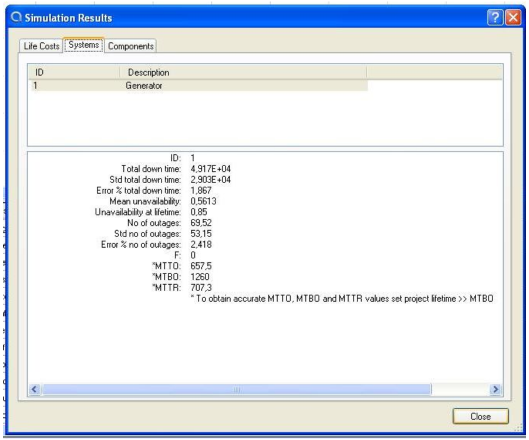

Fig.7. Hydrogenerator simulation parameters

VII. CONCLUSION

Reliability and availability of the power system and its components are the main topic for every company that manages them, like EVN and ELEM in Macedonia. The management role is to increase reliability of the plants and its equipment and continually to deliver power energy. That is the reason for performing risk analysis and for modernization of the plants and substation.

In this paper reliability analyze is performed only on the hydrogenerator in hydro power plant.

The reliability analysis conducted in this paper is performed by using Fault Tree+ from Isograph Software. First fault tree for generator failure is modeled using data from hydro power plant in Macedonia and data form OREDA Handbook. From the simulation results one minimal cut-set is obtain and elements unavailability is calculate for a period of five years. Depend of the failure one kind of maintenance is choosen. The chosen period is to help optimize maintenance and to see system performances. It also helps us to understand what kind of maintenance and inspections needs to be done to increase system reliability.

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