IMPACTS OF THE REHABILITATION OF DRIN RIVER CASCADE ON ALBANIAN POWER SYSTEM RELIABILITY

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Abstract: The subject of the paper is related with the effects of the implemented rehabilitation of the HPP's at Drin River Cascade on reliability indices of generation reliability. These Project concerns four of the country's hydropower stations, representing over half of the total installed capacity in Albania. The work presented in this paper concerns the revitalization of the generators at Fierza HPP. The intention is to assess the integrity of four hydrogenerators at Fierza and the impact of rehabilitation project to ensure acceptable reliability and availability of the plant. The successful implementation of the project has contributed directly for a better water management in terms of energy produced as well as for management of the big floods that threaten the safety of population and dams in the surrounding area of the project.

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Introduction

In the past (before 1990) Albania was a net exporter of power to neighboring Greece. However, with a policy of isolation during the late communist era, the reliability and quality of generation deteriorated to the extent of a substantial reduction in available, good quality generated energy, new investments and hence export income. Intervention on the existing generating facilities and the need for accelerated developing new electricity production facilities was essential.

Over 90% of Albanian electricity is produced by hydro power with a total installed power capacity of 1670 MW. HPPs, mainly located at the rivers Drin and Mat, supply 1446 MW. The Drin River cascade comprises Fierza, Komani and Vau i Dejes hydropower stations, in downstream descending order. The Mat River stations are Ulza and Shkopeti. All hydropower plants under rehabilitation were between 20 and 50 years old and the rehabilitation was crucial due to the extended deterioration and unsafe operation of the plants.

The difficulty to raise the large investments required to meet a strong and sustained demand growth. The situation forced the Governments to provide increasing opportunities for foreign investment. To carry out a necessary refurbishment of four of the main HPPs, producing approximately 55% of the total installed capacity, KESH (Albania Power Corporation) has received joint funding from the EBRD, the Japan Bank for International Co-operation (JBIC), the Swiss Government (State Secretary for Economic Affairs - SECO), the Austrian Government (Ministry for Foreign Affairs) and Mediocredito Centrale (Italy). Together with a substantial contribution of KESH the total investments made approximately 50 Million Euro.

The plants are now rehabilitated to a satisfactory technical standard which prolongs the lifetime and ensures a reliable production of electric energy of good quality. The successful implementation of the Project has contributed directly for a better water management in terms of energy produced as well as for management of the big floods that threaten the safety of population and dams in the surrounding area of the project. In combination with the sector reform and implementation of "The Strategy for the Development of the Electricity System in Albania", it contributes to the modernization of the power generation as a basis also for integration in the regional power supply market. Currently Albania Power Corporation is exporting energy to the neighboring countries.

In this paper we analyze reliability indexes of the power system generation system focused on the effects on the quality, reliability and cost of the supplied energy. One understands essential relationship of the energy and all economics, politics and social aspects of the country's development. It is worth to mention the dependence of the country's GDP with the produced, supplied and consumed energy. This index varies in different stages of development of a country. Furthermore due to all political and economic changes related with transition from a centralized socialist type of economy to private and free market economy, the structure of electricity consumption, losses, peak load, balance of exchanged energy, electricity production, profile of the voltage have completely changed. The collapse of industry caused a 35% drop in the industry consumption, and residential consumption grew up with 50% of the total electricity consumption. Increase of active load demand and rise of technical losses worsened transmission and distributions system.

The paper, based on analytical methods, well known probabilistic tools and different reliability evaluation criterion, suggests calculated key parameters in the evaluation of the generating system reliability with the aim of evaluation of the unserved energy and the total costs of the unserved energy.

General approach to the rehabilitation

The Drin River Cascade Rehabilitation Project concerns four of the main hydropower stations, representing more than 50 percent of the total installed capacity. The capacity of the production varies from 3.5 to 4.8 up to 7 billion kWh respectively in accordance with rainfall rates and hydrologic conditions. Table 2 shows the difference between the total installed capacities and effective generating capacities.

TABLE 1. MAIN DATA OF THE CONCERNED HPPS

Power station	River	Installed capacity (MW)	Number of units	End of first commissioning
Fierza	Drin	500	4	1978
Vau i Dejes	Drin	250	5	1971
Ulza	Mat	25	4	1957
Shkopeti	Mat	24	2	1960

Source: data from KESH
Note: Data published by the Albanian Power Corporation in Annual Reports.

TABLE 2. THE TOTAL INSTALLED CAPACITIES AND EFFECTIVE GENERATING CAPACITIES

Hydropower plants	Installed capacity [mw]	Effective capacity [mw]
Drin river	1350	470
Mat river	49	22

Source: data from KESH
Note: Data published by the Albanian Power Corporation in Annual Reports.

The main objective of the project is to rehabilitate and modernize the mechanical and electrical equipment with the intention to increase their efficiency, output, extension of lifetime and reliability. The operational availability of all units at these stations declined significantly during the last few years because of the lack of resources needed to purchase spare parts for repair and to carry out preventive maintenance measures.

The general objective of the electrical part of the project was to rehabilitate the electrical equipment of the power complexes, including powerhouse, intake, spillway and switchyard; such that the rehabilitated plant would be of the same standard as new plant in respect of safety, operational reliability and documentation. However, in the view of the limited budget, the object of the aim was the rehabilitation of equipment essential to plant safety; reliability and efficiency and other work of minor priority had to be left to a later program.

The project consists the following tasks:

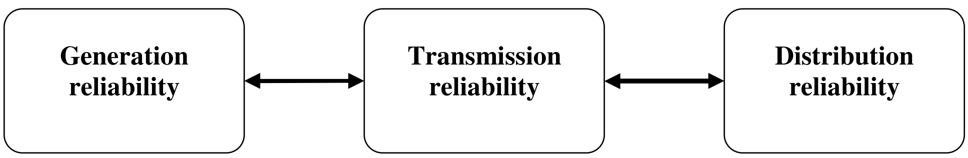
- increasing electricity production by using modern technology to replace or repair electrical and mechanical equipment;
- extending the life time of the mechanical and electrical equipment;
- enhancing the reliability and quality of electric supply throughout the installation of state-of-the-art control and automation technology, with the additional benefit of UCTE standards regarding frequency and voltage control;
- improving the safety conditions and reducing health risks faced by power station personnel.

Power system reliability

During the latest time period all the discussions were focused on energy market, less attention was paid to the reliability aspects in power systems. The power supply reliability directly affects the consumers and can cause tremendous economic and material losses due to reliability aspect. Under this framework, the Power System Reliability analysis and evaluation is very important.

The major question of power system reliability investigation is generation, transmission and distribution reliability.

FIGURE 1. THE COMPONENTS OF POWER SYSTEM RELIABILITY



Subject of the studies and evaluations are the generating units of the system. In the context of overall system, the supply of the reliable service to customers depends not only on the generating system but also on transmission and distribution systems. Customers may consider a utility system reliable only if it supplies them with the quantity and quality of electricity they need on the time they desire it. Consequently, generating, transmission and distribution systems which can fail for any number of reasons at any time are critical. The various reliability indices used in the power system can generally be grouped in two categories: deterministic indices and probabilistic indices.

Probabilistic indices permit the evaluation of system by taking into consideration the parameters and uncertain events that influence reliability such as the forced outage rate of each unit, periodical maintenance, capacities of generating units. While deterministic indices are more limited and they do not call for historical data, based in the established and acceptable value that came from the experience.

A more clear and meaningful index for hydro-dominated system is - “Expected Unserved Energy”, EUE**,** calculated in the paper.

Generating units availability

The main purpose is to state recommendations in regard of degree on intervention in the generating based in the conclusions of Power system reliability analyses for the studied time period.

Unit's availabilities are described by a combination of three factors that account outages, repair and maintenance. These calculated ones are given in the Table 3 for the units of Fierza hydropower plant.

Based in the historical data, extracted from the life story of the generation units at Fierza HPPs since the first moment of the commercial operation, as well as considering operation conditions, all data are elaborated and all factors contributing to availability of the unit generator are calculated.

The total period hours K_t (in hours) for the chosen time period consist of service hours K_p during which a generator supplies energy to the system, schedule outage hours for maintenance purpose K_m , forced outage hours K_o during which a unit is completely shut down, and hours K_r when the unit is available but not required by the dispatching center to generate in order to satisfied the system loads with low costs or to manage the level of the water in the reservoir of the lake. So the sum of those data equals the total period hours:

$$K_t = K_p + K_m + K_o + K_r, \qquad (1)$$

Service hours include the hours when the unit is synchronized with the network but without load. The relationships between outage and availability factors specified in "Generating system Costs" are calculated for the four generators at Fierza.

In the events when the unit is in operation but with a capacity reduction, equivalent forced outage hours K_{eo} are calculated (defined by a weighted sum of outage duration and magnitudes for each event of capacity reduction).

The equivalent forced outage hours K_{eo} are calculated separately for each units. Based in the statistic analyze for the four units at Fierza HPP the calculation shows that the units have been in operation with about 40% of the maximum capacity for an average of 3.61% of the total service hours K_p. So, with 60 % unit size capacity reduction and around 2.66% of the total service hours K_p , each of the units have generated around 50% of the maximum capacity.

The followings parameters have been calculated based on the above mentioned data:

1. the planed outage rate in reference to the total period hour k_{mt};
2. the full forced outage rate K_{op}

Similarly, the Equivalent Forced Outage Rate - k_{eop} is calculated in reference to service hours and forced outage hours during the time period.

$$\begin{aligned} k_{eop} &= (K_o + K_{eo}) / (K_p + K_o) \\ k_{eot} &= (K_o + K_{eo}) / (K_t + K_m) \end{aligned}, \qquad (2)$$

Therefore, k_{eop} represents the probability that a unit will fail when called upon for service, while k_{eot} represents the probability that a unit will fail during a time period when it is not on maintenance schedule. The definition of the probability k_{eop}, is generally more appropriate for use in conventional production costs.

3. Equivalent average repair times K_{er} are used in calculation of outage frequency and duration

$$\begin{aligned} K_{er} &= K_o + K_{eo} / (\text{nr of full outages} + \\ &+ \sum \text{per unit capacity reduction}) \end{aligned}, \qquad (3)$$

Finally, the equivalent availability D_e for the time period is calculated based on the planned outage rate k_{mt} and the equivalent forced outage rate or the probability that a unit will fail when called upon for service k_{eop}

$$D_e = (1 - k_{mt}) \cdot (1 - k_{eop}), \qquad (4)$$

These factors, calculated for the units of Fierza HPPs, are important in estimating energy production for generating units. In the hydro dominated system the reliability of the generating system can be affected from other factors such as:

- the units can be mechanically and electrically available, but energy - limited due to the insufficient water during some periods;
- the generated energy varies upon the variable water inflow;
- the net power available can vary with head;
- the operational criteria for the reservoir can affect reliability and cost of the system;
- the constrains in the transmission system can also affect the reliability.

TABLE 3. FIERZA HPP AT TIME PERIOD: 20.05.1978 - 27.06.1996

Units	Date of commercial operation	Service hours Kp (hours)	Without load Kp0 (hours)	Forced outage Ko (hours)	Schedule outage Km (hours)	Available Kr (hours)	Keo (hours) Calcul.
Unit 1	31.08 .1982	38491	47	2915	15082	64832	1439.56
Unit 2	20.11.1979	64932	680	1885	16039	61790	2090.8
Unit 3	27.10.1978	68148	19	1053	21213	88692	2078.51
Unit 4	20.05.1978	73520	754	1166	15952	68965	2929.77
Total	27.06.1996	245091	1500	7019	68286	284279	8538.58

Source: Data from CELO AND BUALOTI (2006).

The conclusions of the analysis and calculations of the availability indices for generators at Fierza together with detailed analysis of other electrical and hydro mechanical equipment were very important to define the scope of the rehabilitation work the Drin River Cascade Rehabilitation Project, one of the most important projects on the generation system. Developed priority recommendations are the following:

- increasing electricity production by using modern technology to replace or repair electrical and mechanical equipment which is at the end of its useful life;
- increasing life expectancy of mechanical and electrical equipment;
- decreasing the unscheduled outages and minimizing the maintenance problems;
- establishing a modern, efficient electricity sector that operates according to sound economic, commercial and market prices;
- improving the safety conditions and reduce health risks faced by power station personnel;
- defining the priority of investments in accordance with the expected benefits on the supply and demand side based in the background of the power system;
- improving in the reliability and quality of electricity supply and reducing power cuts in the country, which affect the production capacity of local industry with the additional benefit of UCTE standards regarding frequency and voltage control;
- ensuring possibility for KESH to exchange electricity with neighboring countries.

The impact of rehabilitation in the reliability of Fierza HPP

The units were rehabilitated one by one, but the total rehabilitation including the auxiliary services, equipment on the substation, control and monitoring for all units and for the whole HPP was finished in 2007. The date of commissioning of each rehabilitated units according the acceptance certificate is presented in Table 4.

TABLE 4. THE DATE OF COMMISSIONING OF EACH REHABILITATED UNITS

1	Unit - 4	19 December 2004
2	Unit - 2	13 December 2005
3	Unit - 3	15 June 2006
4	Unit - 1	26 February 2007

Source: data from KESH
Note: Data published by the Albanian Power Corporation in Annual Reports.

TABLE 5. THE FORCED OUTAGES (IN HOURS) PER EACH UNIT AT FIERZA HPP BEFORE AND AFTER THE IMPLEMENTATION OF REHABILITATION PROJECT

Units	Forced outages on the year 2000 (hours)	Forced outages on the year 2001 (hours)	Forced outages on the year 2008 (hours)	Forced outages on the year 2009 (hours)
Unit - 1	510	-	0.5	1
Unit - 2	219	65	1	4
Unit - 3	577	7508	0.5	263
Unit - 4	15	1052	0.33	-

Source: data from KESH
Note: Data published by the Albanian Power Corporation in Annual Reports.

We have selected two year before we started the rehabilitation (i.e. 2000 and 2001) and two years after the rehabilitation (2008 and 2009) to compare the impact of rehabilitation of the generations reliability.

The study shows that the total benefits from the additional energy sales might vary from 6.5% on the first year of Investment (2003), to 28% in the period under discussion (2015) in compliance with the forecast of the customer demand.

The Table 5 with the forced outages of the units, corresponds with the period of two years before start of the rehabilitation Project and two years after the rehabilitation. The difference in the table is self-explanatory. All the data for forced outages during 2003 and 2007 are excluded. During that period (2003 - 2007) the rehabilitation period was implemented and all the units were shut down one by one for about 8 to 11 or 13 months each one for rehabilitation purposes. So the units were completely dismantled in pieces, in order to be rehabilitated or replaced as needed. Furthermore, some of the interventions were done to the main auxiliary switchboard and control room, where all the units were connected, so we were forced to shut down units even for the purpose of the overhauling of these equipment. The only comparison that can be made in order to show the difference is the period before the rehabilitation and after the rehabilitation, excluding the rehabilitation period.

Referring to 263 hours for unit N.3 during 2009 (Table 5), it is important to explain that 260 hours and 30 minutes out of 263 hours are not related with the unit itself rehabilitated: the reason was the damage of one voltage transformer closed to the auxiliary transformer. It is worth to emphasize the fact that one of the key of the success in facing the difficult situation with the big floods at Fierza and Drin cascade during December 2009 and January 2010 was the fact that the units were rehabilitated and 100 % available, so they were working with full load during all this period consequently minimizing the spilling way of water from the spillway tunnels.

The positive impact of the rehabilitation of Fierza HPPs in the increase of safety and energy production is as follow:

- The rehabilitated hydropower plant is more efficient, far more reliable in operation and now meets the international standards in respect of quality of generation. It was possible to enhance the reliability and quality of electric supply throughout the installation of state-of-the-art control and automation technology, with the additional benefit of UCTE standards regarding frequency and voltage control. For the first time the load frequency control was implemented ensuring all the necessary interfaces between hydropower plants and transmission lines, substations and new Dispatching Center;

- There is an increase of energy production due to reduction of the repair time and for non-interruption of turbine running compared with the period prior the rehabilitation. The power generation is increased by about 4% per unit (8% for two units) mainly as a result of the two new turbines with a new profile. The result of the intervention is proved by the index tests carried out after the completion of the rehabilitation;
- The financial goal of exporting energy to neighboring countries to generate hard currency is achieved. Albania Power Corporation now is exporting energy. The total generation based on existing hydro resources in positive hydrologic conditions is 4.3 TWh. During Year 2009 which was considered as a positive hydrologic year the total hydrogenation was 5.14 TWh, while the export and exchanged energy (delivered out) was respectively 486 418 MWh and 131 881 MWh. The Table 5 covers all the data that prove the increase of energy as a result of elimination of unplanned stops;
- Extension of lifetime: With an adequate maintenance the rehabilitated engines should have a life time of 60 up to 80 years. As a result of rehabilitation Project, a new concept of maintenance is established;
- There is an increase of safety, reduction of health risks faced by power station personnel, decrease of environmental pollution, better utilization and optimization of water sources at Fierza lake and Drin Cascade. The difficult situation of December 2009 and beginning of January 2010 (due to influence of big inflows at Drin Cascade associated with heavy rainfall and increase of temperature which caused snow melting) has proved once more the positive impact of the rehabilitation Project in the water management at Drin and Mat cascade. It is worth to emphasize the fact that one of the key of the success in facing that difficult situation with the big floods was the fact that the units were rehabilitated and 100% available, so they were working with full load during all this period consequently minimizing the spilling way of water from the spillway tunnels.

Conclusion

The analysis of reliability indices has been directly related to the reliability of supply as well as to the total value of unserved energy due to failure. The rehabilitated hydropower plants are more efficient, far more reliable in operation and now meet the international standards in respect of generation quality. The life-time has been increased and safety operation is ensured through improving the safety conditions and reducing health risks faced by power station personnel.

In rehabilitation Project where the specification are prepared without knowing the exact status of dismantled equipment it is necessary to foresee a considerable amount of contingencies for additional work.

A new concept relating to operation and maintaining economical and sustained operation of the power plants is necessary to be implemented.

There increase of energy production has been achieved due to reduction of the repair time and for non-interruption of turbine running compared with the period prior the rehabilitation. The power generation has been increased by about 4% per unit (8 % for two units) mainly due to settling two new turbines with a new profile. The result of the intervention has been verified by the index tests carried out after the completion of the rehabilitation.

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