Generator Assessment of Hydro Power Station Adequacy after Reconstruction from Classical to HIS SF6 Substation

Srete Nikolovski[1], Goran Slipac[2], Emir Alibašić[3]
[1]Faculty of Electrical Engineering, Computer Science and Information Technology, University of Osijek, Croatia
[2]Croatian National Grid Company- HEP Inc., Zagreb, Croatia
[3]ZZO Tuzla Kanton, Tuzla, Bosnia and Herzegovina

Article Info

ABSTRACT

Reliability analysis of substations and generator assessment of power plant stations are very important elements in a design and maintenance process. This paper presents a generator adequacy assessment of a classical "H" scheme for an open conventional substation, which is often used, and a new HIS - High Integrated Switchgear with SF6 gas isolation. Generator adequacy indices of both types of classical and HIS switchgear were compared and the results showed a high level of reliability and availability of the HIS presented substation. The input data were the annual reports of Croatian TSO-Transmission System Operator (HOPS) and statistics of operation events of Croatian National Electricity (HEP Inc.). For the HIS substation, the input reliability data were used from relevant international literature since only few of HIS substations are installed in Croatia. The generator is modelled with a three-state Markov state space model and Monte Carlo simulations were used for the generator assessment analysis. Adequacy indices LOLP and EDNS were obtained using DIgSILENT software.

Corresponding Author:

Srete Nikolovski,
Faculty of Electrical Engineering,
Computer Science and Information Technology Osijek,
J.J. Strossmayer University of Osijek,
K. Trpimira 2 B, 31000 Osijek, Croatia.
Email: srete.nikolovski@etfos.hr

1. INTRODUCTION

During the analysis of the composite transmission system network reliability, it is generally not enough to view the switchgears solely as network junction points, and thereby omit the influence of individual switchgear components on the reliability of the system as a whole. Every switchgear configuration has a significant impact on the occurrence of power line outages and consequently on the entire system reliability [1], [2]. This especially concerns the multiple power line failures which considerably depend on switchgear failures [3], [4]. The paper analyzes switchgear reliability using Mont Carlo, the loss of one consumer and generator adequacy assessment using Monte Carlo simulation [5]. The basic definitions related to modelling failures from a switchgear are as follows:

a. Switchgear components: transformers, circuit breakers, disconnectors and busbars; surge arresters, current and load measuring transformers are usually omitted. The protection system is generally not taken into the account;

b. Switchgear availability: the probability of presence of a corresponding electrical connection between switchgear busbars from a HV to LV side;

c. Passive failure: unavailability is reduced to the faulty component (it does not cause a triping of protection). It should be noted that the definitions of active and passive failures vary from an author to author;

d. Switching-off disabled: normally switched-on circuit breaker unable to switch-off upon demand;
e. Switching-on disabled: normally switched-off circuit breaker unable to switch-on upon demand;
f. Maintenance: a planned activity aiming at improving the condition of a component. It can be postponed if required by switchgear conditions.

Generator adequacy assessment is a part of dependability evaluation (reliability, availability, maintainability, and safety) [6]. The analysis is performed for the events of the first level of coincidence which is a forced failure or switching-off of one component. The paper deals with the generator adequacy assessment connected on a substation using a computer software. The load in a substation is modelled with a load duration curve which is then modelled with different load states considered in the generator assessment analysis using Monte Carlo simulation [7-8]. The paper includes the generator assessment analysis using a sequential Monte Carlo simulation module in DIgSILENT Power factory software [9].

2.   MARKOV STATE SPACE MODEL FOR BUSBARS AND TRANSFORMERS WITHIN THE SWITCHGEAR

Busbars and transformers, as renewable components, with regard to reliability of supply, can have two different states – they are either available or unavailable. A two-states component model is the most oftenly used model since it gives the best description of the continuous operation of a component. It is presented in Figure 1.
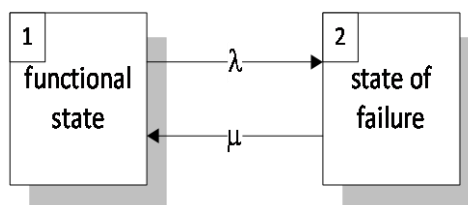

Figure 1. Model of a component with two states

Symbols:
1 - operation state of a component;
2 - component in a failure state;
λ - component failure intensity;
μ - component repair intensity.
Probability of being in a state 1 and 2 is:

$$P_1 = \frac{\mu}{\lambda + \mu} \qquad P_2 = \frac{\lambda}{\lambda + \mu} \tag{1}$$

Frequency of being in a state 1 and 2 is defined as follows:

$$f_1 = \lambda \cdot P_1 = \frac{\lambda \mu}{\lambda + \mu} \qquad f_2 = \mu \cdot P_2 = \frac{\lambda \mu}{\lambda + \mu} \tag{2}$$

3.   MODEL OF A SYSTEM WITH TWO COMPONENTS

The model presented in Figure 2 shows the state of two different components - each component can be either ready to operate or not ready to operate (a coincidence of a transformer and busbar failure).
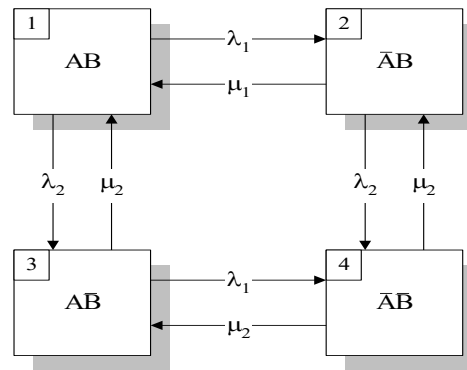
Figure 2. Model of two components with four states

This model is applied during the analysis of switchgear failures for transformer and busbar failure coincidence. The basic premise of all considerations is that the possibility that two or more events take place simultaneously is ruled out. Consequently, the possibilities of direct transitions between states 1 and 4, i.e. 2 and 3 within the model are ruled out.

Symbols:

A - first component; B – second component;

1 – components A and B in operation;

2 – component A faulty and B in operation;

3 – component A working and B faulty;

4 - components A and B faulty;

λ_1 and μ_1 - failure and repair intensity of component A;

λ_2 and μ_2 - failure and repair intensity of component B.

Stationary system solutions, i.e. stationary probabilities of the states are:

$$P_1 = \frac{\mu_1\mu_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad P_2 = \frac{\lambda_1\mu_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad P_3 = \frac{\mu_1\lambda_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad P_4 = \frac{\lambda_1\lambda_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \tag{3}$$

Since it had been shown earlier that the expressions: $A = \dfrac{\mu}{\lambda+\mu}; \ N = \dfrac{\lambda}{\lambda+\mu}$ present stationary availability, that is, unavailability of one component, the stationary probabilities of the states in the case of two-components system can be expressed as follows:

$$P_1 = A_1A_2; \ P_2 = N_1A_2; \ P_3 = A_1N_2; \ P_4 = N_1N_2 \tag{4}$$

According to the model of a system with two different components, the frequency of an individual state can be determined either as a product of the state probability and the sum of intensity of abandoning that identical state, or as a product of the sum of intensity of entering the state and the probability of a state that is being abandoned. Frequencies are equal regardless of being observed from a perspective of exits or from a perspective of entrances. According to that, frequencies of states are as follows:

$$
\begin{aligned}
f_1 &= P_1(\lambda_1+\lambda_2) = A_1A_2(\lambda_1+\lambda_2) = f_1A_2 + f_2A_1 \\
f_2 &= P_2(\mu_1+\lambda_2) = N_1A_2(\mu_1+\lambda_2) = f_1A_2 + f_2N_1 \\
f_3 &= P_3(\lambda_1+\mu_2) = A_1N_2(\lambda_1+\mu_2) = f_1N_2 + f_2A_1 \\
f_4 &= P_4(\mu_1+\mu_2) = N_1N_2(\mu_1+\mu_2) = f_1N_2 + f_2N_1
\end{aligned}
\tag{5}
$$

4.   MODEL OF COMPONENT WITH MAINTENANCE

Switchgear components count as renewable components and their maintenance (planned repair) is carried out periodically. Maintenance of switchgear components increases their reliability and availability

because the tendency of growth of failure intensity function is being reduced and maintained at a sufficiently low constant value. Figure 3 shows the Markov state space model of a component with maintenance. It is presumed that the planned repair of a component will not be performed when a component is not functional, and upon finishing the repair, a component is again ready for the operation.
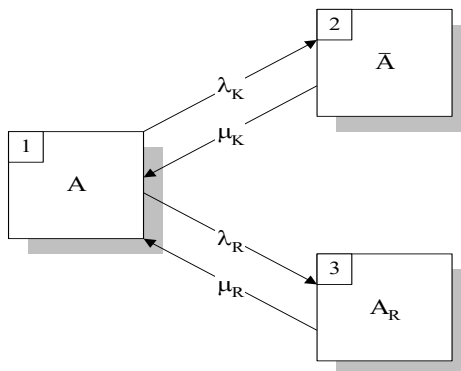

Figure 3. Model of component with maintenance

Symbols:
 1- component in operation;
 2- component A blocked;
 3- component A under repair;
λ_R and μ_R - intensity of repair and repair completion of component A;
λ_K and μ_K - intensity of malfunction and repair of component A.

Stationary system solutions, i.e. stationary probabilities of the states are:

$$P_1 = \frac{\mu_K \mu_R}{\mu_K \mu_R + \lambda_K \mu_R + \lambda_R \mu_K} \quad P_2 = \frac{\lambda_K \mu_R}{\mu_K \mu_R + \lambda_K \mu_R + \lambda_R \mu_K} \quad P_3 = \frac{\lambda_R \mu_K}{\mu_K \mu_R + \lambda_K \mu_R + \lambda_R \mu_K} \tag{6}$$

Based on the earlier considerations, it follows that state "1"denotes component availability, state "2" denotes a failure-induced component unavailability, and state "3" component unavailability due to repair:

$$P_1 = A; \; P_2 = N_K; \; P_3 = N_R \tag{7}$$

Frequencies of failure and repair states are:

$$f_2 = P_1 \cdot \lambda_K = P_2 \cdot \mu_K = \frac{\lambda_K \mu_K \mu_R}{\mu_K \mu_R + \lambda_K \mu_R + \lambda_R \mu_K}$$

$$f_3 = P_1 \cdot \lambda_R = P_3 \cdot \mu_r = \frac{\lambda_R \mu_R \mu_K}{\mu_K \mu_R + \lambda_K \mu_R + \lambda_R \mu_K} \tag{8}$$

5. FAILURE COINCIDENCE MODEL WITH PLANNED MAINTENANCE

Preventive maintenance is conducted in order to keep the frequency of component failures at the lowest possible level. However, when these coincide with failures of other components in the system, the number of system failures may be increased. Thus, if possible, preventive maintenance and repairs should be conducted when they would not have negative effects on the system. It is generally considered that once the repair has been initiated, it has to be finished. Figure 4 shows a case of failure coincidence with the planned maintenance. If the possibility of a transition from state "3" into state "4" is removed, then the request that the repair cannot be initiated in state "3" is accepted, i.e. during the failure state of the other component. However, if state "4" does not represent the system failure state, that transition is allowed and the failure and repair processes are independent. The probabilities of being in certain states in case the transition from state

"3" into state "4" is allowed, since state "4" does not represent the system failure state are as follows:

$$P_1 = \frac{\mu_{AR}\mu_{BK}}{(\lambda_{AR}+\mu_{AR})(\lambda_{BK}+\mu_{BK})}; \quad P_2 = \frac{\lambda_{AR}\mu_{BK}}{(\lambda_{AR}+\mu_{AR})(\lambda_{BK}+\mu_{BK})}$$

$$(9)$$

$$P_3 = \frac{\lambda_{BK}\mu_{AR}}{(\lambda_{AR}+\mu_{AR})(\lambda_{BK}+\mu_{BK})}; \quad P_4 = \frac{\lambda_{AR}\lambda_{BK}}{(\lambda_{AR}+\mu_{AR})(\lambda_{BK}+\mu_{BK})}$$

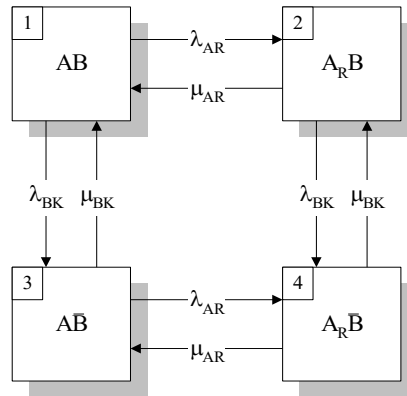Figure 4. Failure coincidence model of the planned maintenance and repair with failure

Symbols:
1 - components A and B in operation;
2 - component A in repair and B in operation;
3 - component A in operation and B in failure;
4 - component A in repair and B in failure;
λ_{AR} - component A repair intensity;
μ_{AR} - component A repair intensity;
λ_{BK} - component B failure intensity;
μ_{BK} - component B repair intensity;
μ_{R} - component repair intensity.

However, if state "4" also means system failure, the transition from state "3" into state "4" is not allowed, which means that the frequency of repair of the first component in the third and fourth system equation has a zero value ($\lambda_{AR}^{*} = 0$). In that case, the values are:

$$P_1 = \frac{\mu_{AR}\mu_{BK}(\lambda_{BK}+\mu_{AR}+\mu_{BK})}{(\lambda_{BK}+\mu_{BK})\left[\mu_{AR}(\lambda_{AR}+\lambda_{BK}+\mu_{AR}+\mu_{BK})+\lambda_{AR}\mu_{BK}\right]}$$

$$P_2 = \frac{\lambda_{AR}\mu_{BK}(\mu_{AR}+\mu_{BK})}{(\lambda_{BK}+\mu_{BK})\left[\mu_{AR}(\lambda_{AR}+\lambda_{BK}+\mu_{AR}+\mu_{BK})+\lambda_{AR}\mu_{BK}\right]}$$

$$(10)$$

$$P_3 = \frac{\lambda_{BK}\mu_{AR}(\lambda_{AR}+\lambda_{BK}+\mu_{AR}+\mu_{BK})}{(\lambda_{BK}+\mu_{BK})\left[\mu_{AR}(\lambda_{AR}+\lambda_{BK}+\mu_{AR}+\mu_{BK})+\lambda_{AR}\mu_{BK}\right]}$$

$$P_4 = \frac{\lambda_{AR}\lambda_{BK}\mu_{BK}}{(\lambda_{BK}+\mu_{BK})\left[\mu_{AR}(\lambda_{AR}+\lambda_{BK}+\mu_{AR}+\mu_{BK})+\lambda_{AR}\mu_{BK}\right]}$$

Since the most common frequencies of the component repair and maintenance are significantly higher than the respective frequencies of entering into those states, i.e. the multiple products of very small values can be disregarded, the near solution values (10) are:

$$P_1 \approx 1; \ P_2 \approx \frac{\lambda_{AR}}{\mu_{AR}}; \ P_3 \approx \frac{\lambda_{BK}}{\mu_{BK}}; \ P_4 \approx \frac{\lambda_{AR}\lambda_{BK}}{\mu_{AR}(\mu_{AR}+\mu_{BK})} \tag{11}$$

The frequency of the system failure, (failure and repair coincidence state) which also means the failure of the system, is:

$$f_4 = P_4(\mu_{AR}+\mu_{BK}) \approx \frac{\lambda_{AR}\lambda_{BK}}{\mu_{AR}(\mu_{AR}+\mu_{BK})}(\mu_{AR}+\mu_{BK}) = \frac{\lambda_{AR}\lambda_{BK}}{\mu_{AR}} \tag{12}$$

The mean time of failure coincidence with the planned maintenance and repair is:

$$T_k = \frac{P_4}{f_4} \approx \frac{1}{\mu_{AR}+\mu_{BK}} \tag{13}$$

6. GENERATOR MODEL WITH A DERATED STATE

Figure 5 shows the model of the component with the derated state (reduced capacity). It is assumed that the transition of the component to the derated state from the forced outage is not allowed because it is believed that during its stay in the forced outage, the repair is performed and that component is ready for the operation with the rated capacity.
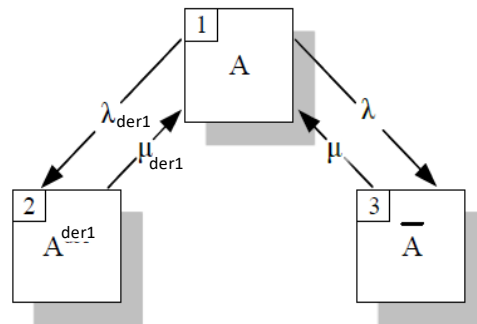

Figure 5. Generator model with one derated state

Symbols:
1   component A in operation;
2   component A^{der1} in operation with the derated state;
3   component A in failure;

λ_{der1} component A intensity of the derated state;

μ_{der1} component A intensity of departure from the derated state;

λ component A failure rate;
μ component A repair rate:
The probabilities of being in a certain state are:

$$P_1 = \frac{\mu\mu_{der1}}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu}$$

$$P_2 = \frac{\lambda_{der1}\mu}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu}, \ P_3 = \frac{\lambda\mu_{der1}}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu} \tag{14}$$

The frequencies of generator states are:

$$f_1 = P_1 \cdot (\lambda_{der1} + \lambda) = P_2 \cdot \mu_{der1} = P_3 \cdot \mu = \frac{\mu \mu_{der1}(\lambda_{der1} + \lambda)}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu} \tag{15}$$

$$f_2 = P_1 \cdot \lambda_{der1} = P_2 \cdot \mu_{der1} = \frac{\mu \lambda_{der1} \mu_{der1}}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu} \tag{16}$$

$$f_3 = P_1 \cdot \lambda = P_3 \cdot \mu = \frac{\lambda \mu_{der1} \mu}{\lambda_{der1}\mu + \mu_{der1}\lambda + \mu_{der1}\mu} \tag{17}$$

The mean time of generators states:

$$T_1 = \frac{P_1}{f_1} = \frac{1}{\lambda_{der1} + \lambda}, \quad T_2 = \frac{P_2}{f_2} = \frac{1}{\mu_{der1}}, \quad T_3 = \frac{P_3}{f_3} = \frac{1}{\mu} \tag{18}$$

7. DESCRIPTION OF A HYDRO POWER PLANT SUBSTATION

7.1. Basic Characteristics of the Previous Switchgear

It is placed at the level of 183,5 m in the narrow area between the engine room facility and building entrance at the end of diversion channel [12]. The switchgear is in "H" scheme with five feeders, two block transformer feeders, each equipped with a circuit breaker, disconnectors, current measuring transformers and surge arresters, two outgoing feeders equipped with outgoing disconnectors only, section feeder with a diagonally placed disconnector for the connection between blocks, i.e. transmission lines. It is dimensioned for short circuit power of 3500 MVA. The switchgear is connected to the Nedeljanec substation by 110 kV double transmission line (Al/Fe 240/40 mm²). Considering that outgoing feeders do not have circuit breakers installed, distance protection in a hydro power plant works at the switching off of the circuit breaker in a block transformer feeder and the circuit breaker in the outgoing feeder of Nedeljanec substation which in this way represents distant busbars of this switchgear. Switchgear equipment is nearly 30 years old, except for the new SF$_6$ circuit breakers produced by "ABB" and installed four years ago in a place of the old pneumatic circuit breakers 3P 123 type, produced by "Končar d.d". The whole equipment is installed on the iron stands made from steel pipes and profile, coated with anticorrosive paint, fixed to a concrete base with anchor bolts. The connection of the devices is done by wires (Al/Fe 240/40 mm²), i.e. AlMg $\varnothing$ 70 mm pipes. A busbar system is carried out by wires attached above the devices by using double tension insulator strings with seven glass insulators, type U 160 BS, on each of them. Busbars are attached to "T" portals made from welded iron profiles. The classical 110 kV switchgear is designed for the outdoor use and shown in Figure 6.

Figure 6. Existing classical 110 kV switchgear

The 110 kV transmission line connections from Nedeljanec substation is carried out by the attachment to the southern busbar portal. Block transformers with transmission ratio of 10,5/121 kV, vector group Yd5, power 2×50 MVA, are placed at the level of 176 m, between the engine room facility and the dam. They are connected to generator terminals by copper profile busbars. Although rationally placed in

relation to the generator, due to an inadequately constructed oil pit, they are an ecological threat for the environment in case of disasters since there is a possibility of transformer oil spill into the Drava river. Also, in case of failure of a transformer with a tank crack, there is a possibility of flaming oil spreading onto the generator and other equipment. The analysis of the outage caused by failures at the hydro electrical power plant in the period from 2009 to 2013 shows the loss of supply of approximately 5 TWh of electrical energy, out of which 82% are block transformer failures due to lightning strikes. Considering the age of the equipment (about 30 years old), which is near the end of its life span, the stated manipulative possibilities and operating conditions of the network, as well as the work safety at the hydro electrical power plant which generates 100 MVA of electrical power, it is evident that it is necessary to reconstruct and modernize 110 kV switchgear by replacing the old equipment and expanding the switchgear to a scheme that would enable flexible manipulation without operation interruptions. Figure 7 shows single line scheme of the present classical and the new HIS switchgear
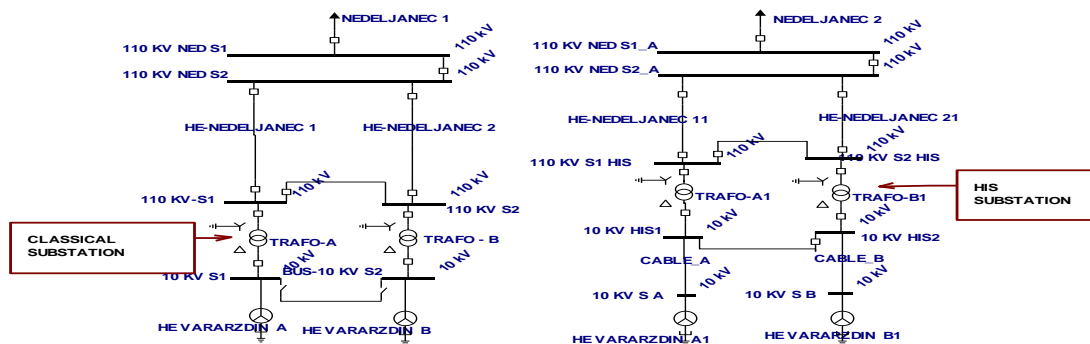

Figure 7. Single line scheme of the present classical and the new HIS switchgear

7.2. Description of the new SF6 High Integrated Switchgear

The new metal enclosed SF_6 gas insulated switchgear, high integrated for the outdoor installation (HIS) at the new location will be installed on the concrete laminated foundation. The switchgear will be constructed for the outdoor installation along with the appropriate treatment of the external surfaces, which enables the installation in open spaces exposed to the atmospheric conditions and solar radiation. The switchgear constructed in the "H" scheme form will consist of three-poled enclosed busbars, two busbar measuring feeders, one section/coupling feeder, two transformer feeders and two outgoing feeders. The switchgear will be connected to the network and transformers by the overhead connectors Al 300 mm^2. A block transformer is connected to the current measuring transformers by means of Cu pipes $\varnothing$ 32 × 2 mm. The designed switchgear satisfies the following minimum demands - modular performance of manufacture completed mounting groups with the possibility of subsequent extension by means of upgrade by additional fields, sections, busbars, circuit breakers, disconnectors and other components without unnecessary dismounting of the equipment's main parts. The switchgear should secure the highest possible security for the workers and others around the switchgear surrounding area under normal operating conditions and during failures (short circuit). In accordance with the conditions at the installation location, the switchgear will be sized for the insulation degree 123 Si 230/550 and will have the following rated values and technical characteristics shown in Table 1. Figure 9 presents the 110 kV SIEMENS SF6 switchgear.

Figure 9. SIEMENS HIS SF6 switchgear

Table 1. Technical characteristics of new HIS switchgear

Rated voltage	110 kV
Network maximum voltage	123 kV
Rated frequency	50 Hz
Rated withstand voltage of 50 Hz 1 min: between phases and toward ground	275 kV
110 kV neutral point earthing	Direct earthing
Rated withstand surge voltage of 1,2/50μs:	
between phases and toward ground	550 kV
between opened circuit breaker contacts	550 kV
between opened disconnector contacts	650 kV
Rated permanent current at 40°C:	
busbars	2500 A
outgoing and transformer feeders	1250 A
Rated short term withstand current 1 s	40 kA

8.   RESULTS OF THE GENERATOR ADEQUACY SIMULATION

The simulation was performed in the program package of DIgSILENT with the power flow calculation [12] for the period of 1 year. The load on the 110 kV side of the power transmission line Nedeljanec is displayed by the annual curve of duration presented in Figure 10. Also, 110 kV busbar outages were considered within the load Nedeljanec.
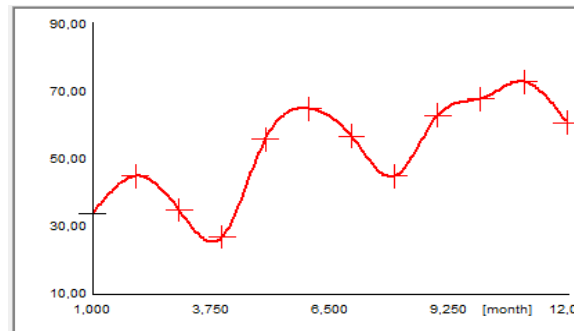

Figure 10. The curve of load duration Nedeljanec

The input data for HIS was used from [12], and for the existing switchgear from the statistics of the plant events HOPS from [13]. The input data for generators in the hydro power plant are given in Table 2. After the generator assessment analysis is performed using Monte Carlo simulation for 100 000 runs, the generator adequacy indices are shown in Figure 11.
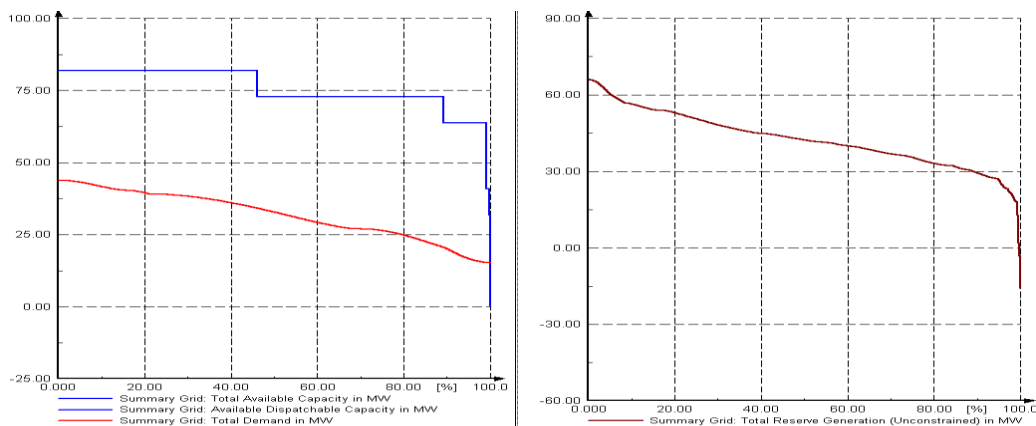

Figure 11. Total available capacity, available dispatch capacity, grid total demand and total reserve generation

Table 2. Input data for generators

Year	Working state (h)	Derated state (h)	Maintenance (h)	Failure state (h)	Sum of hours (h)
2010	5535	2418	793	14	8760
2011	5884	2024	850	2	8760
2012	5834	1980	946	0	8760
2013	6490	1481	651	138	8760
Average	6030,8	1823,6	862,8	42,8	8760

Figure 12 shows monte Carlo simulation process for Classical switchgear, minimal, average and maximum values of LOLP and EDNS indices
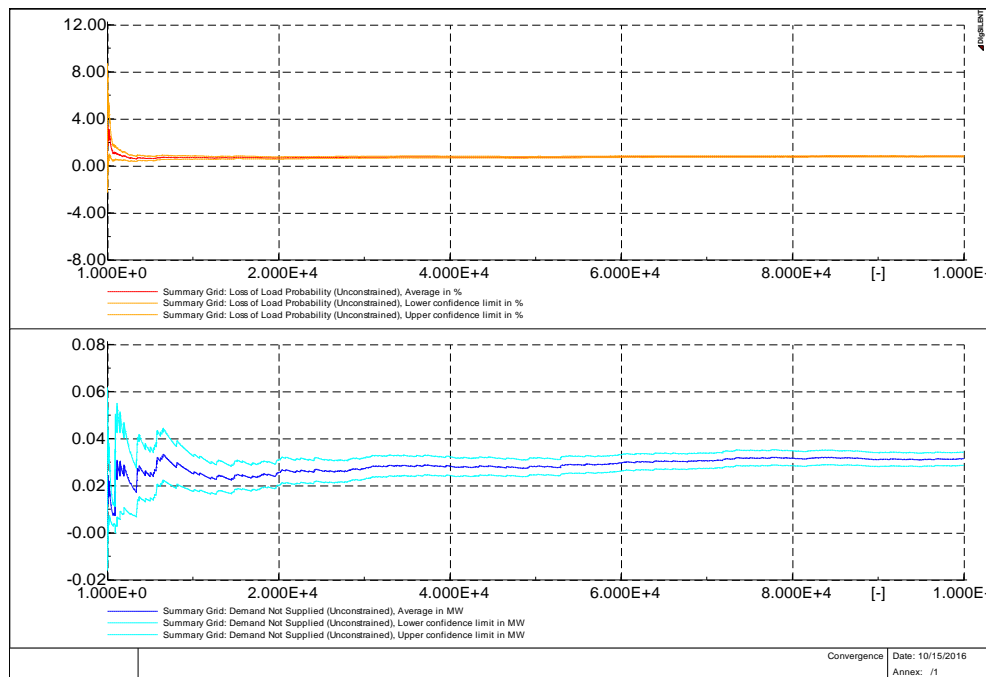

Figure 12. Monte Carlo simulation process for Classical switchgear, minimal, average and maximum values of LOLP and EDNS indices

In Tables 4 and 5, results for Monte Carlo simulations of generator adequacy indices for both cases, classical and HIS switchgear are presented.

Table 4. HIS switchgear generator adequacy indices

Loss of Load Probability			Expected Demand Not Supplied		
Average(LOLP) (%)	Confidence Levels Lower	Upper	Average (EDNS) (MW)	Confidence Levels	
0.21700	0.19279	0.24121	0.011	0.010	0.012

Table 5. Classical switchgear generator adequacy indices

Loss of Load Probability			Expected Demand Not Supplied		
Average (LOLP) (%)	Confidence Levels Lower	Upper	Average (EDNS) (MW)	Confidence Levels	
0.27300	0.24586	0.30014	0.015	0.013	0.016

The difference in adequacy indices of the new SF6 gas insulated High Integrated Switchgear in relation to the standard existing switchgear for the outdoor usage is obvious. This can only be one of the advantages and additional criteria for choosing the HIS and justifying the reconstruction.

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9.   CONCLUSION

This paper presents the generator adequacy assessment connected to 110 kV/10 kV switchgear in the hydro power plant, particularly of the present switchgear for the outdoor use, as well as the new SF6 HIS-High Integrated Switchgear. Markov space-state method was used, together with the generator assessment Monte Carlo simulation using DIgSILENT software. Monte Carlo generator assessment is also performed in consideration to the generator three states model (in work, derated state and in outage). All outage data are taken from the statistics of the plant events for the four years period of time, form 2009 to 2013 year, from HEP d.d.. The information on the equipment and switchgear elements outages has been statisticaly processed. For the new switchgear in the "H" scheme, which was conducted in the HIS SF6 technology, outage data are taken from the relevant literature statistics. All relevant adequacy generator assessment indices of the switchgear have been computed. The generator adequacy indices of the HIS are far better than the standard switchgear for the outdoor use, which of course, aside from other advantages, can be crucial in transition to the High Integrated Switchgears.

REFERENCES

[1] D. Koval, A. Chowdhury, Assessment of Transmission-Line Common-Mode, Station-Originated, and Fault-Type Forced-Outage Rates, *IEEE Transactions on Industry application*, Vol. 46, No. 1. Nov. 2001.
[2] R. Billinton, T.K.P. Medicherla, Station Originated Multiple Outages in the Reliability Analysis of a Composite Generation and Transmission System, *IEEE Transaction on PAS*, Vol. 100. No.8. Oct. 1981.
[3] R. Billinton, P.K. Vohra, S. Kumar, Effect of Station originated outages in a composite system adequacy evaluation of The IEEE Reliability test system, *IEEE Transaction on PAS*, Vol. 104. No.10. Oct. 1985.
[4] R. Billinton, R.N. Allan "*Reliability Evaluation of Power Systems*", 2nd Edition, Publisher Plenum Press, New York, USA, 1996.
[5] R. Billinton, W. Li, Reliability assessment of electric power systems using Monte Carlo methods, Publisher, Plenum Press, New York and London, 1994.
[6] M. B. Hamouda, M. N. Lakhoua, L. El Amraoui, Dependability Evaluation and Supervision in Thermal Power Plants, *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 5, No 5. Oct. 2015.
[7] J. Nahman, Modeling simultaneous outages for Bulk-power system reliability analysis, *IEEE Trans on Reliability*, Vol. R-34, No. 5. Nov. 1985.
[8] J. Nahman, M. Grahovac, *Load modeling for generating capacity reliability evaluation using frequency and duration method*, IEE Proceeding-C, Vol. 139, No. 6, Nov. 1992.
[9] DIgSILENT PowerFactory 15, User Manual, Gomaringen 2014.
[10] SIEMENS i EXOR "Electrical project of reconstruction of substation 110 kV i 35 kV in HE", 2005.
[11] T.M. Chan, F. Heil, D. Kopejkova "Report on the second international survey on high voltage gas isolated substation service experience", *CIGRE*, Paris, WG, 1998K. Karsai, D. Kerenyi, L. Kiss „Large Power Transformers", Oxford 1987.
[12] Croatian Transmission System Operator, HOPS d.o.o Zagreb "Operational Events Statistics for 2013", Zagreb, 2014 S. D. Bole, "Mitigation of Inrush Current in Transformer", *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, ISSN: 2278-3075, Volume-3, Issue-7, Dec. 2013.

BIOGRAPHIES OF AUTHORS

Srete Nikolovski, PhD.MSc.El.Eng.   (IEEE M'1995, SM'2005) was born in Belgrade on October 1, 1954. He obtained his BSc degree (1978) and MSc degree (1989), in electrical engineering at the Faculty of Electrical Engineering, University of Belgrade and his PhD degree from the Faculty of Electrical and Computing, University of Zagreb, Croatia in 1993. He is currently a Full Professor at the Department of Power Engineering at the Faculty of Electrical Engineering, Computer Science and Information Technology, J. J. Strossmayer University of Osijek, Croatia. His main interests are power system protection, power system analysis and reliability. He has published 200 technical papers in international journals and proceedings. He is a Senior Member of IEEE Reliability Society, PES Society and the Croatian CIGRE.
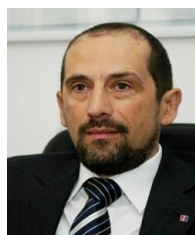
Goran Slipac, PhD.El.Eng, was born in Travnik, on February 25 1960. He obtained his diploma degree in 1983 in field of Electrical Power Engineering from the Faculty of Electrical Engineering and Computing, University of Zagreb and a master degree in the field of on the same Faculty. During 1994-2001 he attended training courses in Argonne, USA, in the field of Generation Expansion Planning and Energy Demand Analysis. He was a Manager of Corporate Development Department in HEP Inc. (Croatian Electricity Utility) and a Director of HEP Renewables company. He is currently employed as an Advisor of HEP Inc. Management Board. He is the former chairman of the Study Committee C1 Croatian CIGRE. His main interests are power system analysis and generation expansion planning.

Emir Alibašić, Dipl.El.Ing., was born in Tuzla on March 12, 1982. He obtained his BCs degree (2007) in Tuzla in field of Electrical engineering at the Faculty of Electrical Engineering, University of Tuzla. Currently he is a PhD student at Faculty of Electrical Engineering, J.J. Strossmayer University of Osijek, Croatia. His main interests are power transmission lines and optimization of electrical energy transmission. He wass employed at UMEL-DALEKOVODMONTAZA Tuzla on the position of design and maintenance of objects up to 400 kV and currently is owner INFORM Agency for the development of software applications. Currently he works as ITC manager at ZZO TK.