Dynamic Simulation of Black Start Capability

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***Abstract*—Paper deals dynamic calculations. It presents two cases for real black start tests and shows their dynamic simulation.**

Keywords — black start, dynamic simulation, prime mover models

I. Introduction

A black start is an important part of restoration plans, which TSOs shall design according to the new European legislative [1]. The black start consists of several processes, starting with the unit start up without support from external network, through building supply routes and finally loading the generator. Such a process does not belong to routine matters and it is appropriate to carry out the tests (see e.g. publications [2] and [3]).

Since these test are very complex, they have to be prepared carefully. Preparations are usually Dynamic simulations on a dynamic model are usually carried out in the preparation framework. This paper presents two examples of similar calculations, which were carried out after the field tests (ex-ante) in order to verify the credibility of used turbine dynamic models that play in these calculations crucial role. The preceding paper [4] showed some turbine models suitable for dynamic studies. We focus on special turbine control regime, when the unit supplies separated part of the network – so called island operation. The network simulator MODES is used as computation tool.

The paper is structured as follows. Two test cases are introduced in the section II. The section III describes used dynamic models for two types of prime mover – the hydro turbine and the supercharged diesel engine. The results of simulation are shown and compared with measurement during field tests in the section IV. Finally, the section V concludes the paper.

II. Test cases

The test cases demonstrate the dynamic behavior of different types of prime movers during theirs loading. These prime movers are:

1. hydro turbine and
2. diesel engine.

These prime movers drive synchronous generators, which supply through several transformers and 110 kV lines isolated variable resistive load (electric boiler).

This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences by the projects VEGA No. 1/0372/18.

The test cases correspond to the two real black start tests carried out on the 18th June 2014 in Slovakia (see [3] for more information). Fig. 1 and Fig. 2 show simplified scheme of both test systems.

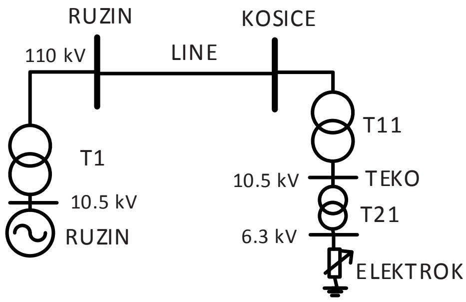

Fig. 1 Single line diagram for the first test case (simplified according to [3])

The electric boiler in heating plant (Tepláreň Košice) was supplied through the unit and step-up transformers (T21 and T11), 110 kV line and the step-up transformer T1 from one generator of the pumped storage hydro power plant Ružín.

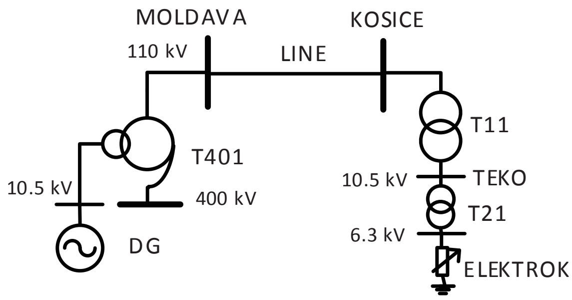

Fig. 2 Diagram for the second test case (simplified according to [3])

Diesel generators connected to the tertiary winding of the autotransformer T401 in 400 kV substation Moldava were used as sources. Rest of the test case is similar to the first one.

Since the power supply parameters were not exactly known, they had to be estimated as follows. Nominal power of the hydro turbine Ružín was 30 MW (according to the technical report [5]). The diesel generators were modeled as one equivalent with the same nominal power P_n=30 MW. The generators had nominal power factor $\cos\varphi_n$=0.9. Line reactance X was estimated 28 Ω and 13 Ω for the first and second test case. Estimated transformers parameters are in the following table.

TABLE I. Transformer parameters

	T1 121/10.5 kV	T11 121/10.5 kV	T21 10.5/6.3 kV	T401 121/10.5 kV
S_n	40 MVA	60 MVA	10 MVA	100 MVA
u_K	10 %	10 %	10 %	10 %

III. Dynamic Models

This section describes dynamic models of the prime movers.

A. Hydro turbine model

The hydro turbine model (marked HYDR in the MODES model library) is compatible to the IEEE recommendation [6]. The model block scheme is depicted in the following figure.

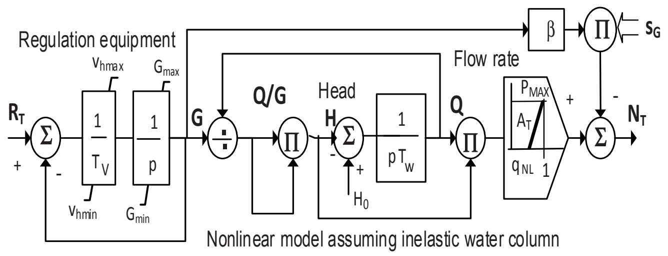

Fig. 3 Block scheme of the hydro turbine

Basic parameter, which determine dynamic performance of the hydro turbine, is water starting time constant T_W. This parameter and limits for gate opening and closing velocity were taken from the technical report [5]. Overview of the used parameters is in TABLE II.

TABLE II. Hydro turbine model parameters

T_V	T_W	β	v_{hmin}	v_{hmax}	G_{min}	G_{max}	q_{NL}	P_{max}
0.2 s	**2.18 s**	0	**-0.125 s^{-1}**	**0.066 s^{-1}**	0	1	0.1	1

The response of the turbine power N_T to the governor output R_T cannot be fast due to so called water hammer effect.

Block scheme of the used governor model is in Fig. 4

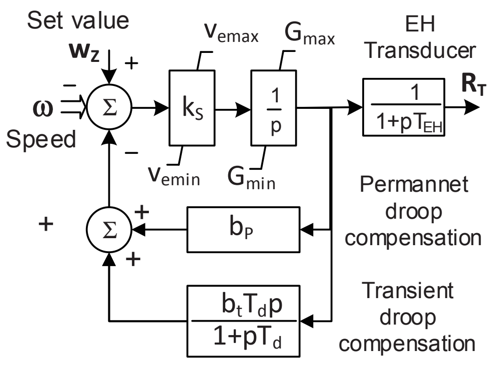

Fig. 4 Block scheme of the governor model for hydro turbine

This model was derived from the scheme of electro - hydraulic governor A-ROT published in the technical report [5] and it is compatible with a mechanical - hydraulic speed-governing system published in the IEEE report [7].

Values of transient droop b_t and dashpot time constant T_d depends on turbine parameter T_W and a inertia constant H of the hydro-generator set. In our case we used typical values from [7].

TABLE III. Governor parameters of the hydro turbine

k_S	T_{EH}	T_d	b_P	b_t
5 s^{-1}	0.2 s	**5 s**	**0.05**	**0.3**

Note that for $b_P \neq 0$ has governor proportional character and the governor transfer function is as follows (for k_S>>0):

$$\frac{(1+pT_d)}{b_p[1+(1+\frac{b_t}{b_p})pT_d]} \qquad (1)$$

B. Diesel engine model

The diesel engine model (marked DIES in the MODES model library) was developed especially in the MODES tool (details are described in [9]). It corresponds to a four stroke supercharged engine of large power, which is typically used in shipping and as beck-up source in nuclear power plants. The model block scheme is depicted in the following figure.

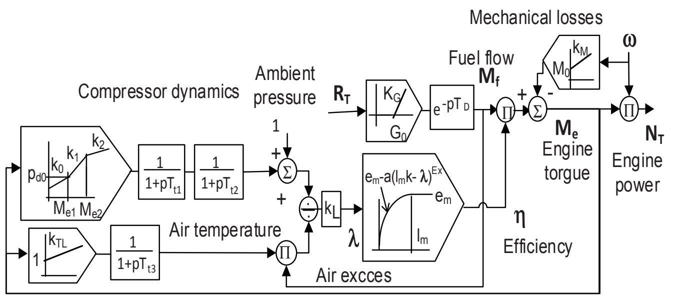

Fig. 5 Block scheme of the Diesel engine model

The engine dynamics is determined mainly by supercharging, otherwise, the power response to the fuel supply is virtually immediate. We have not any information about real engines, so that we used typical parameters for a twelve-cylinder engine with nominal power 6.6 MW from the following tables.

TABLE IV. Diesel engine model parameters

k_N	T_D	e_m	a	l_m	Ex	G_0	k_G	G_v	G_{min}	G_{max}	M_0	k_M	k_e
1.17	0.04	0.53	0.022	4	2	0.084	5.9	12	0.11	0.56	0.011	0.1	18

TABLE V. Compressor model parameters

T_{t1}	T_{t2}	T_{t3}	k_1	p_{d0}	m_{e1}	m_{e2}	k_0	k_1	k2	k_{tl}
2	1	6	1	0.06	0.55	1.	1.53	2.52	1.03	0.40

Block scheme of the used governor model is in Fig. 6.

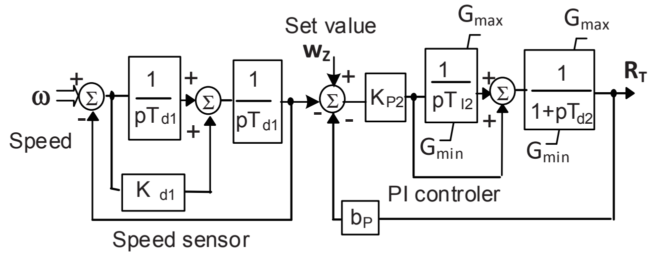

Fig. 6 Block scheme of the governor model for Diesel engine

This model was derived from the scheme real governor WOODWARD UG-40. Typical parameters from the following table were used for simulation.

TABLE VI. Governor parameters of the diesel engine

T_{d1}	T_{i2}	T_{d2}	k_{dl}	k_{p2}	b_P
2	1	6	1	0.06	0

Note that for $b_P = 0$ has governor proportional – integral character (astatic or isochronous regulation) and the speed sensor transfer function is as follows:

$$\frac{2\xi\omega_0 p + \omega_0^{2}}{p^2 + 2\xi\omega_0 p + \omega_0^{2}} \qquad (2)$$

where $\zeta = K_{d1}/2$ is a damping factor and $\omega_0 = 1/T_{d1}$ is a natural frequency.

IV. Simulation Results

Similar changes of the generator load were simulated according to Fig. 7.

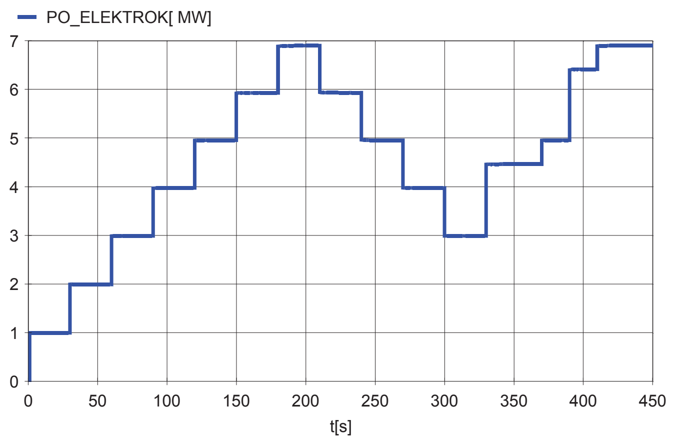

Fig. 7 Step changes of the load during simulation

The following figures show speed deviation waveforms for both cases (they correspond to the frequency deviation in the islands).

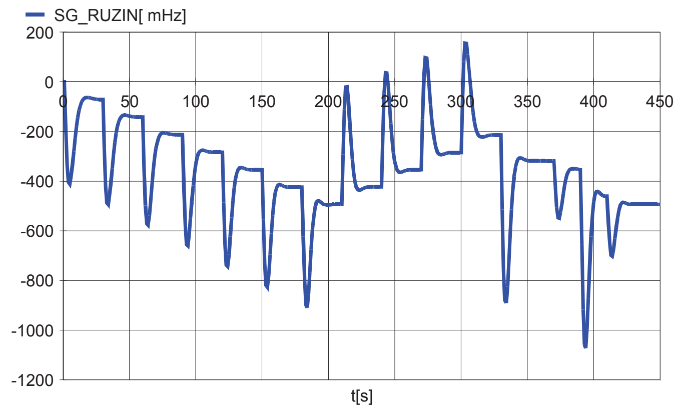

Fig. 8 Speed deviation of the Ruzin generator

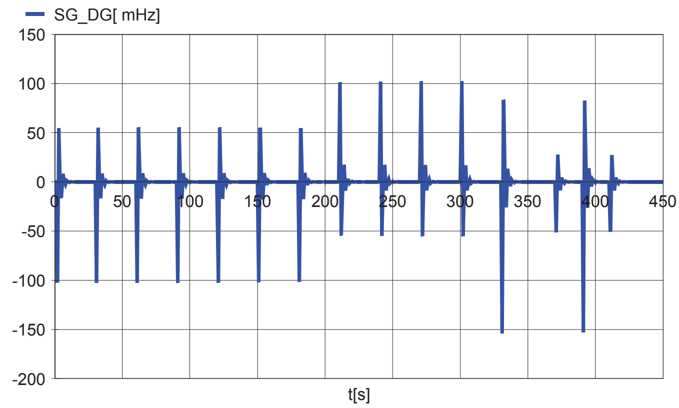

Fig. 9 Speed deviation of the DG generator

It is seen significant differences between these cases. While in the first case there is a permanent frequency deviation, in the latter case the regulator maintains a steady deviation of zero (isochronous regulation). The maximum steady state deviation is about -500 mHz, which corresponds to the deviation in the real test (the frequency at maximum load was around 49.5 Hz).

Transient frequency deviations are much greater for a water turbine than for a diesel engine. Unlike the hydro turbine, the engine is able to change power quickly without a delay. Maximal deviations were about -700 mHz in the simulation and about -650 mHz in the field test for the hydro turbine.

V. Conclusion

The paper presents computational capabilities of the network simulator MODES for dynamic calculations carried out during preparation phase of black start test eventually after its completion (for verification of used dynamic models).

Dynamic models are important in the context of obligation to provide simulation results and validated simulation model to demonstrate compliance of power generating module with requirements of the European network code [11].

ACKNOWLEDGEMENT

This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences under the contract No. VEGA 1/0372/18.

REFERENCES

[1] *Commission regulation (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration*

[2] O. Rychlý, T. Linhart, M.Pistora, "Black Start Test Of Pumped Storage Dlouhé Stráně, " in *Proc. 19th Int. scientific conference Electric Power Engineering (EPE 2018)*

[3] *M. Grega,* S. Prieložný, M. Kret, M. Jedinák, P. Gamboš, " The Slovak Power System Restoration after State of Blackout, ," in *Proc*. 13th International Scientific Conference Control of Power Systems (CPS 2018)

[4] K. Máslo and T. Hába, "Compatibility of Turbine Models for Stability Studies," in *Proc. 19th Int. scientific conference Electric Power Engineering (EPE 2018)*

[5] Invetarizace technických vlastností vodních a přečerpávacích vodních elektráren, Příloha C - Vodní elektrárny, Technická zpráva ČEZ – ORGREZ Brno, 1991

[6] IEEE Working Group Report, "Hydraulic Turbine and Turbine Control Models for System Dynamic Studies," Transactions on Power Systems, Vol. 7. No1, Feb. 1992, pp.167 - 178

[7] IEEE Committee Report, "Dynamic Models for Steam and Hydro Turbines in Power System Studies," IEEE Transactions in Power Apparatus & Systems, Vol. 92, No. 6, Nov./Dec. 1973, pp 1904-15

[8] Džmura, J., Petráš, J., Balogh, J., Kurimský, J., Cimbala, R., Kolcunová, I., Dolník, B., Kolcun, M.: Separation of solid particles from flowing gases by AC high voltage. JOURNAL OF ELECTROSTATICS, Vol: 88, AUG 2017, P. 158-164, ISSN: 0304-3886

[9] K. Máslo: Model dieselgenerátoru pro dynamické výpočty, časopis EE č.2/1999

[10] Džmura, J., Petráš, J., Balogh, J., Bernát, M.: Modeling and Computer Simulation of Electrical Separation. 17th International Scientific Conference on Electric Power Engineering (EPE), MAY 16-18, 2016, Prague, p. 537-542, ISBN:978-1-5090-0908-4

[11] *Commission regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators*

[12] Z. Čonka, M. Kolcun: Impact of TCSC on the Transient Stability In: Acta Electrotechnica et Informatica. Vol. 13, no. 2 (2013), p. 50-54. - ISSN 1335-8243

[13] *J.Pálfi, M. Tompa, P. Holcsik: Analysis of the Efficiency of the Recloser Function of LV Smart Switchboards ACTA POLYTECHNICA HUNGARICA 14 : 2 pp. 131-150. , 20 p. (2017)*