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Journal of ELECTRICAL ENGINEERING, VOL. 66, NO. 2, 2015, 103–107

COMMUNICATIONS

INFLUENCE OF INTERCEPT VALVES ON CONTROL OF MULTIPLE STAGES STEAM TURBINES DURING THE SWITCHING INTO THE ISLAND OPERATION

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This paper presents control of a multiple stages steam turbine which is switched into the island operation. The frequency in an electrical grid is stated on nominal value which is in UCTE grid 50 Hz. When deviation of frequency is higher then 0.2 Hz, the switching of particular steam units into the island operation is only the chance how to maintain the supply of, at least, some small grids. The other possibility how to keep power units in operation, to be prepared for the next synchronization to the grid, is to switch them to operation status in which they supply only their self-consumption. This change of the operating state is the most dynamic load change for the control system of the unit. The multiple stages turbines are equipped with high pressure hydraulic valves for steam turbine governing. Influence of the intercept valve on steam turbine control during the switching process into the island operation is examined in Matlab Simuling software.

K e y w o r d s: island operation, steam turbine model, steam turbine control, control valve, intercept valve

1 INTRODUCTION

Electric energy in alternating electric power system with required quality parameters has to be delivered in any time to consumers. There is important to keep the quality criteria, primarily it is power value on nominal frequency, with voltage in required limits. In the case when the power system is without failures in operation, the quality can be kept without problems. The problems can occur during larger failures. One of those failures is for example disconnection of bigger power plants from electricity supply system. Higher requirements on control of particular units rise in this time. The frequency in the electrical grid is set in UCTE sytem on level 50 Hz and has to be kept in range 49.8–50.2 Hz. When the control in the grid is not able to keep this range and frequency exceeds it, then the grid operation is disturbed. The switching of particular electrical units into the island operation is only the chance how to keep at least parts of the grid under the supply. Other units are switched to be able to supply only their self-consumption, when it is possible. It is made for a reason to keep them in the stage for the next synchronization to the grid if it is possible. It means that the frequency is in limit scope.

Switching into the island operation especially into the supply of the unit self-consumption is the highest load change for the steam unit control which occurs during the unit operation. This maximal load change represents the best way how to check the control of the steam unit. It is useful to test unit control before it is prepared for test exams or if it is not manufactured yet. If we know the parameters of the unit, it is possible to create a model with the parameters of the tested steam turbine, the synchronous generator, the control system and the electrical grid. So we can simulate behaviour of the turbogenerator during switching into the island operation. From this simulation we can evaluate whether the control of the turbine control system is made properly to be able to fulfil dynamic requirements which can occur in the electrical grid during the operation.

In this paper the two cases steam turbine models which drive the synchronous generator connected to the grid are discussed. Further, the paper deals with switching process of the turbogenerator into the island operation with control which contains the intermediate pressure intercept valve. Then the same unit is switched into the island operation without the intermediate pressure intercept valve. Outputs from both cases are evaluated. From these simulations we can evaluate influence of this intercept valve on switching process into the island operation.

2 CONTROL OF MASS FLOW OF TURBINE ADMISSION STEAM

The mass steam turbine flow is controlled on base of the formula: $P = Mh\eta_{td}$, where P is active power (kW), M is mass flow rate (kg/s), h is adiabatic heat gradient (enthalpy difference) in the turbine (kJ/kg), η_{td} is thermodynamic efficiency of the turbine (–).

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DOI: 10.1515/jee-2015-0016, Print ISSN 1335-3632, On-line ISSN 1339-309X

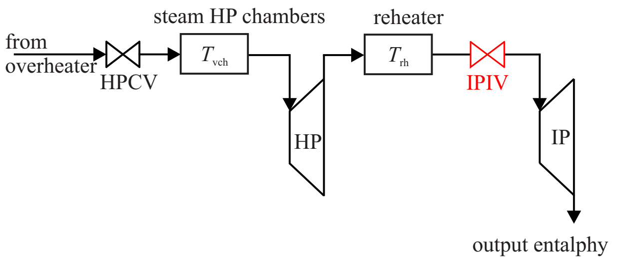

Fig. 1. The scheme of the two cases steam turbine with the intermediate pressure intercept valve

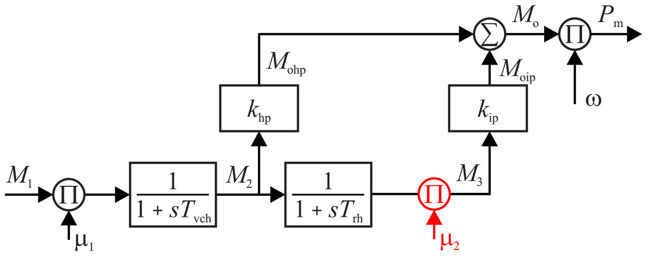

Fig. 2. The model of the two cases steam turbine with the intermediate pressure intercept valve

3 THE STEAM TURBINE MODEL

For simulation of the steam unit control behaviour, the model is necessary to create, where the exact amount of turbine cases should be kept. In presented example, two cases steam turbine, which consists of high pressure part (further HP) and intermediate pressure part (further IP) was created.

3.1 The turbine with the intermediate pressure intercept valve

Scheme of the turbine with the intermediate pressure intercept valve (IPIV) is in Fig. 1. Admission steam comes from steam generator overheater through high pressure control valves (HPCV) into HP turbine case, where the steam delay time in space of steam valve chambers is expressed by constant T_{vch}. Then steam comes through crossover pipes, reheater and IPIV into IP turbine case. In the reheater steam enthalpy is increasing. The IPIV is during the normal operation still opened. It closes only during the larger dynamic changes as, for example, switching into the island operation is. Constant T_{rh} expresses steam delay time in the reheater in the IPIV chamber and in the crossover pipes. This constant is due to the amount of steam always the largest one. Quick stop valves which are used for quick stop of the turbine are not taken into consideration. They have not influence on turbine control and during exact control they are not activated. Bypass stations which are used for quick diversion of redundant steam before control valves are not considered as well. We suppose their non problem action.

There is necessary to take into account that a steam delay occurs in steam vessels as are chambers and larger pipes. This delay represents differential equations. These equations have after Laplace transformation form

$$\frac{M_{out}}{M_{in}} = \frac{1}{1+sT_v}, \tag{1}$$

where M_{in} is steam mass flow rate (kg/s) incoming into the steam vessel and M_{out} steam mass flow rate (kg/s) from the vessel outcoming. T_V is the time constant of steam vessel expressing the delay in particular steam vessel. In this examine type of the turbine we take into consideration as steam vessels HP chambers and IP chamber together with crossover pipes and reheater. The time constant T_v is for HP part between 0.2–0.9 s and time constant for IP part is 9–12 s. For calculation of the time constant formula (2) was used. Where V is steam volume (m^3), $\partial\rho/\partial P$ is steam constant, which is deducted from steam tables. P_n is nominal pressure in the vessel (kPa) and M_n is nominal steam flow.

$$T_v = V\frac{\partial\rho}{\partial P}\frac{P_n}{M_n}\,. \tag{2}$$

By putting the parameters of examine turbine in (2), time constants are $T_{vch} = 0.32$ and $T_{rh} = 10.7$.

The model of the examine turbine is in Fig. 2. M_1 is mass flow rate from overheater which depends on control valves opening μ_1. Mass flow rate M_2 is output from HP case and M_3 is the flow on input into IP case. This flow depends on opening of the intercept valve μ_2. The mechanical moment of HP part is labeled as M_{ohp} and the mechanical moment of IP part is M_{oip}. The total mechanical turbine moment is M_0. For this type of turbine the moments allocation is $k_{hp} = 0.4$ for HP and $k_{ip} = 0.6$ for IP part. The total moment has to be 1. Mechanical power of the turbine P_m is then equal to multiply moment M_0 and rotating speed ω. From the model is clear that the mechanical power of the turbine depends only on steam mass flow rate M which is controlled by control valves on HP part and by intercept valve on IP part.

$$P_m = M_0\omega\,. \tag{3}$$

The turbine power depends besides on adiabatic heat gradient h also on the thermodynamic efficiency η_{td}. Adiabatic heat gradient depends on parameters of steam which we consider during the quick dynamic changes constant. Thermodynamic efficiency depends on the turbine speed changes. These changes, during the switching into the island operation do not exceed 10 % deviation. In this range the thermo dynamical efficiency deviations are only a few percent and we can ignore them.

3.2 The turbine without the intermediate pressure intercept valve

To research influence of the IPIV, there is necessary to create the similar model without the IPIV in Fig. 1 marked by red colour. In Fig. 2 the constant μ_2 highlighted by red colour, is cancelled. The rest of the model is the same as in the case with the IPIV use.

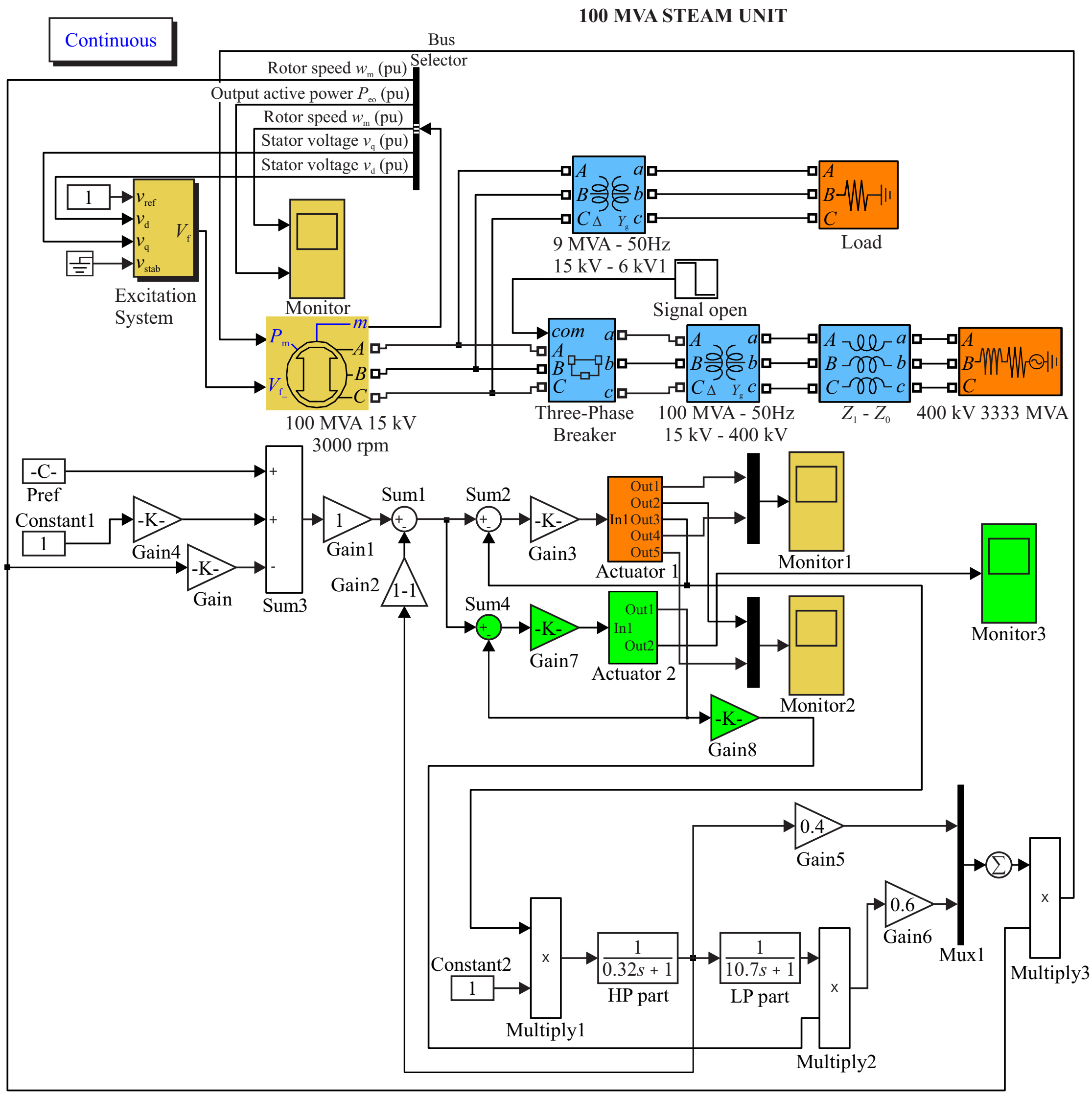

Fig. 3. The model of the turbogenerator connected to the grid

4 SWITCHING OF TURBOGENERATORS INTO THE ISLAND OPERATION

4.1 The turbogenerator with the intermediate pressure intercept valve

The two cases steam turbine with active power output 72 MW was realized by created model in Matab Simuling. The turbine model is based according to Fig. 2. Mass flow input to HP part is equipped with four control valves and input of IP part is equipped with one intercept valve.

To simulate the steam turbogenerator behaviour connected with the power electric grid, there is necessary to have model of the grid, as well. The model of the whole system is presented in Fig. 3.

All calculated values are in *pu* form. In Fig. 3 proportional unit control consists of active power set point P_{ref} on value $0.72\,pu$. Therefore, the generator active power output is on value 72 MW. Further, the set point of turbogenerator speed 3000 rpm is equal 1 in p.u. adjusted by Constant 1. These signals go, together with real speed from generator Bus Selector to Sum 3. The speeds, before coming into Sum 3, are amplified with Gain and Gain 4. After counting up in Sum 3 the signal inputs to amplifier Gain 1 and then to Sum 1, where it is compared with the real value from Gain 2. The deviation is amplified and act on HP and IP control valves. These valves are presented in the model as Actuators 1 (for HP control valves) and as Actuator 2 (for IP intercept valve). Actuators 1 consist of four control valves and outputs are plotted by Monitor 1 and Monitor 2. Actuator 2 consists of one intercept valve and it is plotted by Monitor 3. The output control signal from Actuator 1 is Out 3 and from Actuator 2 is Out 1, they are inputs to steam turbine model according to Fig. 2. The output from HP valves is multiplied with Constant 2 which is equal 1 p.u. and it expresses pressure of the overheater which is considered constant.

Next the signal goes through HP part, where the steam mass flow delay occurs. After that the signal continues via IP part, where another steam delay occurs. This value is

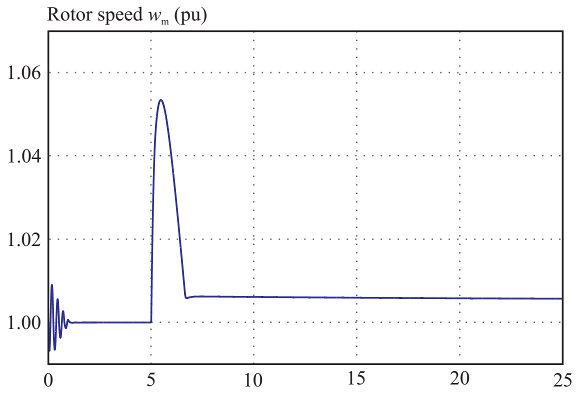

Fig. 4. Output speed with IPIV

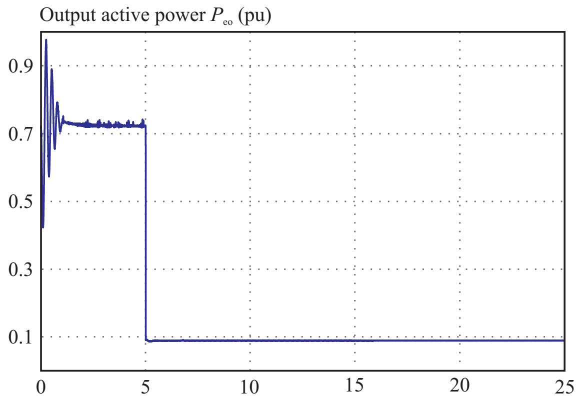

Fig. 5. Output active power with IPIV

else multiplied in Multiply 2 with valve opening Gain 8. The outputs from HP and IP parts come in Mux 1 where they are summed to supply mechanical power ratio from Gain 5 and Gain 6. This mechanical output is multiplied with the real turbogenerator speed in Multiply 3 and then the mechanical power is calculated. This value is input to 100 MVA synchronous generator, which is exited by Excitation system. Generator output voltage is 15 kV and it is input for 100 MVA three phases unit transformer which supply the 400 kV grid with short-circuit power 3333 MVA. From the generator the unit self-consumption Load is supplied as well. This consumption is 8 MW. Generator speed and active power are important values, therefore they are plotted from the Bus selector by Monitor.

4.2 The turbogenerator without the intermediate pressure intercept valve

For this simulation we use the model in Fig. 3 but without the branch which represents Actuator 2. It means without the blocks highlighted by green colour. Then we get the model controlled only by HP control valves on HP input into the turbine.

5 SIMULATION OUTPUT DIAGRAMS

5.1 Simulation with the intercept valve

After simulation is run speed starts to control to nominal value 3000 rpm it means $1\,pu$. and active power is controlled on required value 72 MW it is 0.72 p.u. This is made with control valves which control admission input into the turbine. In Fig. 4 rotor speed and in Fig. 5 active power are stable in 2 s. The Three-phase breaker is opened by Signal open in 5 s. The turbogenerator is disconnected from the grid and supplies only the smallest island operation. It is its self-consumption. From this switching the steam unit load rapidly decreases from 72 MW to 8 MW. The switching of the electrical unit into its self-consumption has the highest dynamic requirements to control valves control which can occur during the unit operation. Therefore, it is the best way how to check dynamic behaviour of control. After this unloading over speed occurs but it can not reach the value when the steam unit protections react and equipment is stopped. From the Rotor speed diagram in Fig. 4 is obvious that the over speed reached 1.0534 p.u. it is 3160.2 rpm. Electrical unit protection stops the machine on over speed 3300 rpm it is 55 Hz. The over speed is in limit and fit to work. In Output active power diagram in Fig. 5 the smooth active power reduction from 72 MW to 8 MW is seen. Active power 8 MW is 0.08 pu and it is unit self-consumption.

But the previous conclusion is not final result for all steam unit blocks that can be used for the electrical grid supply. In Czech Republic, to test the island control ability of the particular turbogenerator an unload test is performed. The turbogenerator is unloaded by switching into the island operation. The generator supplies only its self-consumption and the circuit breaker is disconnected from the grid. Power plants use this test for testing their control possibilities in order to know if they have possibilities to properly work in island operation. According to Codex transmission system ČEPS, part II temporary speed of the turbine after switching into the island operation, the turbine speed must not to exceed 8.5 % of the nominal speed. The nominal speed value is in Czech Republic 3000 rpm. The steady-state speed after transient performance has to be higher than the nominal value and the deviation must not to exceed 2.5 Hz. During the speed stabilizing, only very small oscillations are allowed.

From the simulation we obtained over speed 160.2 rpm from nominal value 3000 rpm, it is 5.34 %. The stable speed is 1.0057 p.u., it is 50.285 Hz. No higher oscillation occurred. All values, according to requirements, are in the limits. Therefore, the unit should be useful to work in the electrical grid in Czech Republic.

5.2 Simulation without the intercept valve

The same simulation, as in the previous case, is performed. After simulation start model is running and speed and active power get stable on levels 3000 rpm and 72 MW. The Three-phase breaker is opened by Signal open in 5 s. From the Rotor speed diagram in Fig. 6 is clear that the overspeed during the simulating time 25 s is

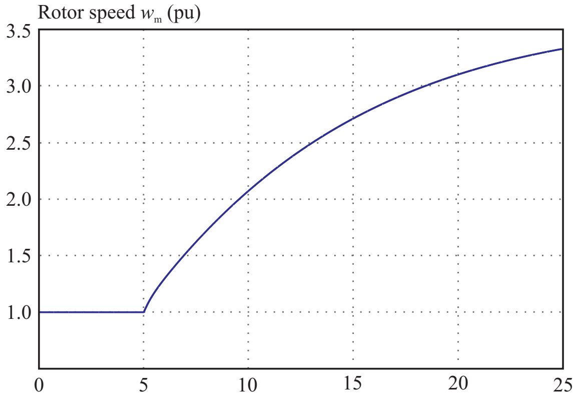

Fig. 6. Output speed without IPIV

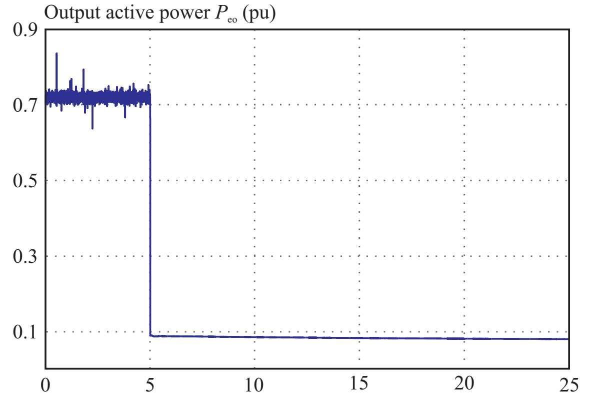

Fig. 7. Output active power without IPIV

still increasing. This state can occur only in a model, because in real situation the turbine protection would stop the turbine on level speed 3300 rpm, it is 1.1 in pu. Active power is controlled on required level in Output active power diagram in Fig. 7.

6 DISCUSION

In some multiple stages steam turbine models the intercept valves are ignored. In this paper the models with the intercept valve and without this valve were created. These simulations find out whether the intercept valves must be used in multiple stages turbine models or we can ignore them to simplify the models. The high dynamic unload, which is the switching into the island operation was performed. During this activity, the most important value for the unit is speed. From the model with the intercept valve we can see that speed is in limit scope, the turbine protections do not react and speed is as well in order according to Codex transmission system ČEPS, part II temporary speed of the turbine after switching into the island operation. From the simulation without the intercept valve is clear that turbine control is not able to control the turbine at all. Not only higher speed then is allowed over speed has occurred, but the proportional regulation is not able to control the turbine on required speed. The speed, during the 25 s testing time, is still increasing.

7 CONCLUSION

The check of the possibility to ignore the intermediate pressure intercept valve in the two cases steam turbine was performed here. It is possible if we do not simulate the high dynamic unload of the turbine. But when we need to find out if the turbine is able to operate properly in high dynamic situation as, for example switching into the island operation is, then the results from the model without intercept valve are very inaccurate. The turbine control which was set for this turbine is not able to control the over speed without the intercept valve, because big amount of steam is concentrated in crossover pipes and reheater. When the turbine has the intermediate pressure intercept valve it can close the input to IP part at a time, speed is decreasing, and control can continue in operation. Without this valve all amount of steam remaining in crossover pipes and reheater comes into IP turbine case and causes mechanical moment which steam turbine control is not able to control. The solution with only control valves on HP input is sufficient for the turbine models which have only one case. Then the control ability of the unit is in order and similar as in the real turbine operation.

Acknowledgements

This work was made under the support of student's project SGS 2012-047.

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Received 20 July 2014