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*REVIEWS - LETTERS - REPORTS*

# OPERATOR'S MENTAL MODEL OF ISLAND POWER SYSTEM

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Operation of the electric power systems must fulfil economical demands while meeting the safety limits. Operating is influenced mainly by two factors — relation to safety and efficiency. Although they are contradictory, both aim to remove the unacceptable risk and determine the optimum of system output. The article describes the use of mental models for operating the process systems. A simple model of island operation is derived. With its help, an operator can perform adequate operational interventions and prevent a frequency collapse. Power plant behaviour analysis in $P-f$ state space allows verification of the power plant control circuit.

K e y w o r d s: power system, island mode, operator, mental model

## 1 MENTAL MODEL OF STABILITY ASSURING FOR ISLAND POWER SYSTEM

Mental models used by operators are very important for operating. If a mental model does not respect all current influences and restrictions, the system is transferred into the area of a higher error rate. For example a higher occurrence of emergency conditions of electric power systems is observed in economically advanced countries. [1]

Operation in an island power system is not a common situation. It is very important for all operators concerned to share the same simple model. Then their cooperation can be fast and effective because the main necessary information (frequency variation, power variation) is shared in parallel. From the transients of the basic controlled quantities, they can identify the basic state of the whole power system and estimate its progress without the need to check all the information with power system operator via telephone.

Lesson learned from blackouts should improve operator's mental model and ability to use it during major failures in the power system.

### 1.1 Model of turbogenerator in island operation

In the island mode, the system begins to behave differently. The loss of synchronism and the variations of power project mainly into frequency variations. The control system of the turbine generator (TG) has a decisive influence on keeping the isolated power system stable. The older electro-hydraulic controller keeps the principle of the Watt speed governor.

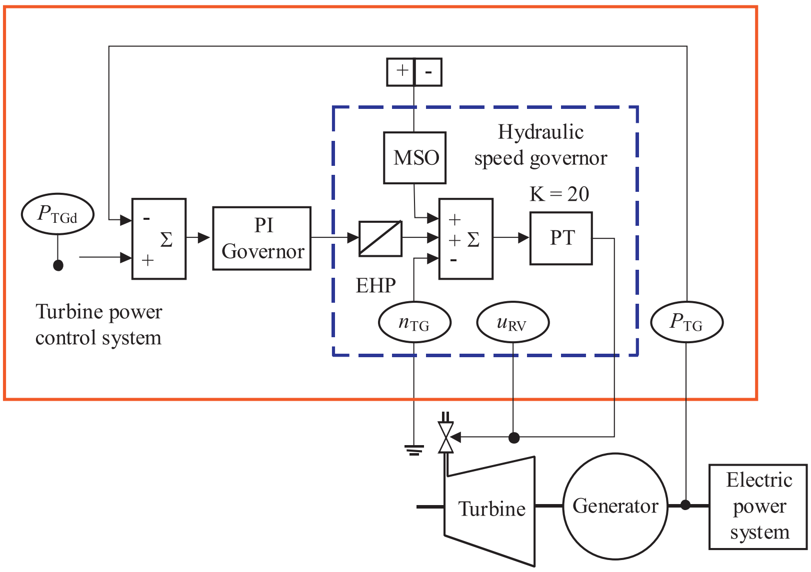


**Fig. 1.** Diagram of a hydraulic speed governor

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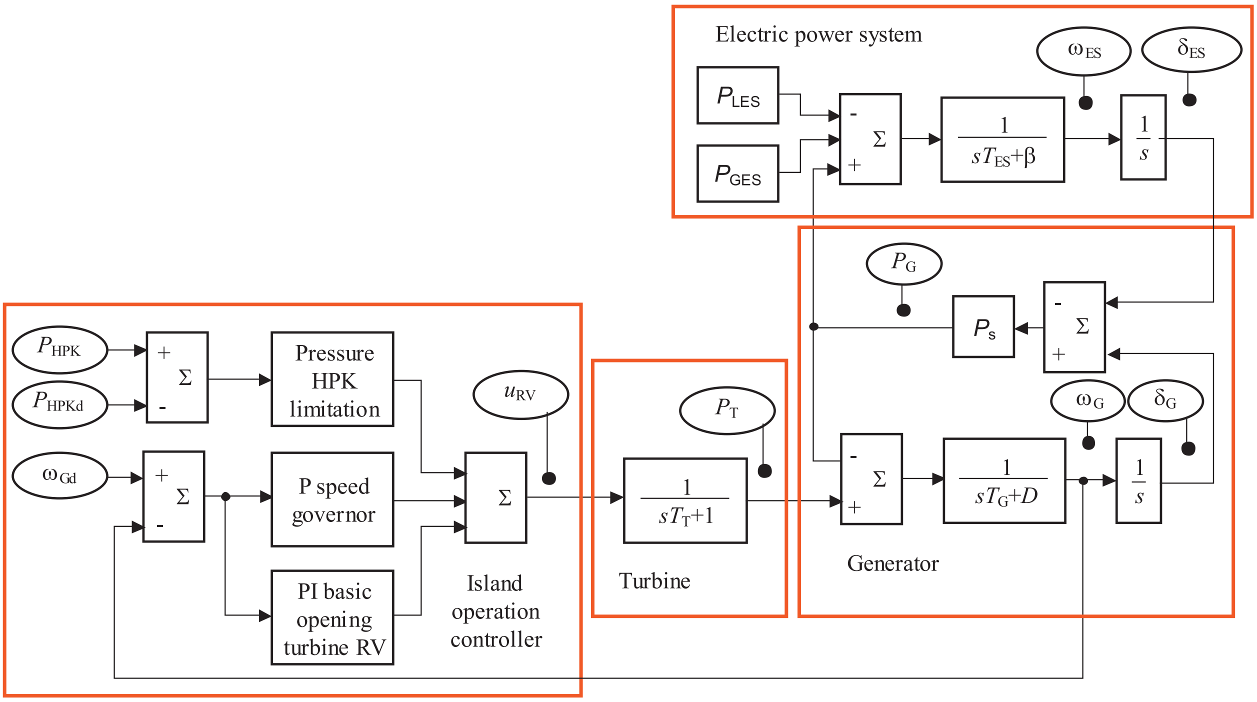


**Fig. 2.** Block diagram of a power plant in an island system

This control is schematically depicted in Fig. 1. Speed sensor ($n_{TG}$) is a centrifugal pump (impeller). The mean speed changer (MSO) together with the controller output define the desired speed value. The real value of the turbine generator speed is read from that and the resulting control error is brought to the input of the primary oil transformer. It is a proportional governor with adjustable gain. The output quantity is again the opening of control valves ($u_{RV}$) of the turbine, which determine its power $P_{TG}$.

A hydraulic governor has the same static characteristics as the Watt governor. MSO moves the static characteristics in the f-P plane.

### 1.2 Frequency control model in the island operation

In the case of power imbalance occurrence in the island system, an acceleration momentum occurs, which accelerates or decelerates the rotating mass in the power system until a new stable point is reached. With the help of a movement equation of the second order, a model of turbine generator and island power system can be created. The turbine is presented by a system of the first order where the power $P_{TG}$ depends on the opening of the control valves $u_{RV}$, (*ie* island operation regulator output).

That is formed by the superposition of outputs of basic opening governor and proportional speed governor. The maximum value of the island operation regulator output can be limited in the case of a low turbine steam pressure. The resulting power plant model in island operation is in Fig. 2.

### 1.3 Frequency variation in isolated power system

This model allows us to analyze the behaviour of a power plant in an island power system. Each change can be depicted with a trajectory in the state plane. New stable working points are determined by the static characteristics of the generation and load. Figure 3 shows the dynamic behaviour of frequency, turbine power and load power after a partial drop-out of generation $\Delta P$.

Before the drop-out, the system is situated in its balanced state $1_-$ (determined by intersection between $P_{V-}$ and $P_S$). The power generated equals the power consumed. After the drop-out the production jumps down (production characteristics changes from $P_{V-}$ to $P_{V+}$) and the system goes to point $1_+$ on the same frequency. Rotating masses are broken due to a lack of power and the system wants to reach a new working point 3, which is the intersection of lines $P_S$ and $P_{V+}$. Graph (c) shows a gradual increase of generation due to speed governors and the consumption power increases due to operation at a lower speed. Due to different time constants the process is balanced after a few periods.

The power of production equals the power of consumption in the new working point. The power system works on a frequency lowered by $\Delta f$. The increased generation $\Delta P_V$ on the remaining blocks of the power system is not the same as the drop-out, difference $\Delta P_S$ is covered by consumption decrease in operation at a lower speed.

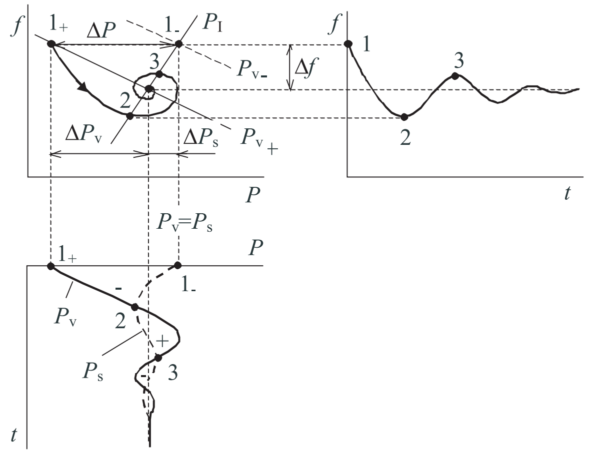


**Fig. 3.** Frequency variation after a drop-out of generation in isolated power system

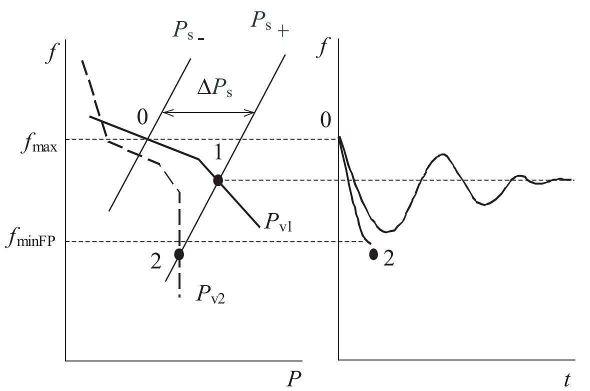


**Fig. 4.** Frequency collapse in case of a deficit island electric power system

## 2 FREQUENCY COLLAPSE

If the island power system has a small power reserve, the balance will not be restored with a high probability and a frequency collapse will happen. This could happen when some big power plant failed in the island mode, as it was during the Italy blackout 2003. This situation is shown in Fig. 4. With the occurrence of a deficit island, the load is increased by $\Delta P_S$ (*ie* the load characteristics changed from $P_{S-}$ to $P_{S+}$). In the first case (sufficient power reserves), the new balanced state is in point 1 (intersection of the lines $P_{S-}$ and $P_{V1}$). The frequency of the system becomes balanced after the transfer to the island. In the case of power plants trip, the static characteristics changes from $P_{V1}$ to $P_{V2}$ and the balanced state is now in point 2. Since this point lies under the limit value $f_{\min FP}$, the balanced state cannot be reached. When the frequency is reaching it, the power plants are disconnected from the power system by the protection and a frequency collapse happens.

The rules mentioned above always apply in the island operation and their knowledge is a necessary prerequisite of successful control. In the case of the island mode occurrence, the majority of interventions are performed automatically by the operating system. The operator comes across in the next phases. He must know the state of the system and the state where the system goes after performing a control intervention.

## 3 UTILIZATION OF THE MODEL FOR ANALYZING SYSTEM FAILURES

### 3.1 Behaviour of a power plant with an island operation regulator in the 2003 system failure

The behaviour of the regulated quantities of a power plant with a digital island controller in system failure is depicted in Fig. 5. Due to frequency increase to 50.2 Hz, the turbine controller is switched to the island operation mode and TG power decreased by $4\,\%\,P_{\mathrm{nom}}$. The expected value of the model power change is higher ($9\,\%\,P_{\mathrm{nom}}$ in the case of amplification of the branch of proportional regulation 20). At the time 03:32, the operator switched the primary source regulator into the manual mode to prevent its power to go low. Thus, the by-pass opened to the condenser and the steam pressure was lowered. That resulted in a TG power decrease to $98\,\%\,P_{\mathrm{nom}}$. After that, the TG power returns back to its initial value as a result of ES frequency return to 50 Hz. However the rated TG power is reached even at the increased frequency of 50.15 Hz. The operator had to stop the power plant island mode manually.

### 3.2 Reasons of different behaviour of a power plant with a digital regulator of island operation

If the block behaviour in the state plane $P-f$ is analyzed, it is possible to see that the static characteristics moved and the desired speed value (frequency) changed (Fig. 6). Different behaviour of the TG (in comparison with the model) is in the circuit of basic opening. That one also provides for the fulfilment of the Power System Code demand "Block transfer to the island mode has to be steady (without a power bump if possible)" [2]. That is why the island operation controller output (the sum of its proportional branch and the base opening) is still being traced up to the current regulation valve opening value. The frequency in the moment of the transfer to the island mode is 50.2 Hz and the output of the proportional branch is $8\,\%$. To fulfil the demand on bumplessness, the basic ROP opening value must jump up by $8\,\%$.

From the point of view of the operation principle in an isolated system, it is a bad activity. Due to that, the said unit participates less on the island regulation. On the top of that, a quick return of the frequency to its rated value causes a TG power increase up to $106\,\%\,P_{\mathrm{nom}}$ and intervention of protection system.

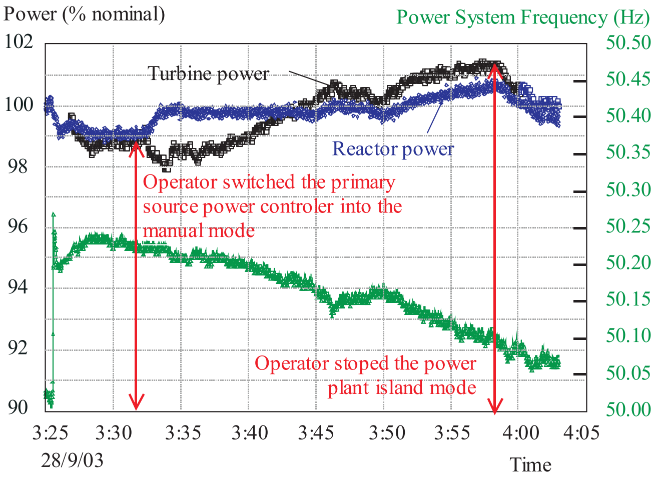


**Fig. 5.** Feedback of a unit with a digital controller of island operation while Italy being disconnected from UCTE (2003)

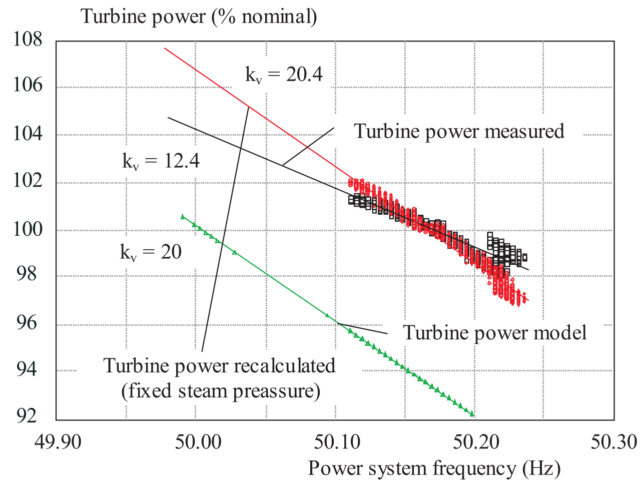


**Fig. 6.** Response analysis of a power plant with a digital island mode controller in the $P-f$ state plane

The operator correctly finished the island operation. However, from the power system view, the power reserve was decreased and the frequency collapse probability was increased.

## 7 CONCLUSION

An important element of operating in emergency states is the use of a correct mental model that can be shared among operators on various levels. In the exceptional states, the system behaves differently. With a proper mental model, the operator can derive the expected frequency, power of generation and load in the isolated power system.

Backward analysis of blackouts should improve operator's mental model and the ability to use it. He is able to identify the state of the system and the state where the system goes after performing control intervention

Another goal of the power plants behaviour analysis is grid codes verifying. The response analysis of a power plant with a digital island mode controller in the $P-f$ state plane confirms the ambiguous definition of the island operation regulator in the Czech national code. It should be modified in accordance with UCTE recommendation no. 5 [3]. National codes must contain a minimum number of requirements and be in accordance with UCTE so the generation units can be (even when considering their specifics) sufficiently robust in cases of frequency and voltage failures.

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[2] Codex of transmission system — Revision 2004,(Kodex přenosové soustavy — revize 2004), www.ceps.cz. (Czech)

[3] Final Report of the Investigation Committee on the 28 September 2003 Blackout in Italy, UCTE Report, April 2004.

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