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Control of Steam-Turbine Regulators at Transition to an Island State

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Abstract - **The simple operating algorithm is presented for steam turbine regulators of type Simadin (Siemens) at emergency switching-off of the generator from system together with some, unknown in advance, load. The given situation is known as "a transition to an island state (regime)". Keeping of turbine speed and preservation of its rating value at a generator blackout when its own needs will be load only, is an easy problem. When the generator remains in its island it is necessary to solve "on-line" two additional problems: to reveal a situation "island" and to estimate the island load for translating a regulator on the new task and providing dynamic stability of transition. The algorithm was tried and entered successfully into practice on Varna TPP , CEZ GROUP (Prague), in 2008.**

I. INTRODUCTION

Experts in anti-failure automatics and power system stability are well familiar with the problem of preserving the functioning of the generators in the case of automated frequency decoupling. This automatic operates in the event of significant decline in frequency and usually entails several frequency-distinguished stages that are used to separate the power system into parts (islands) with the aim of preserving the synchronous functioning of the generators there. If this frequency continues falling, the next stages of the automated frequency decoupling are switched on, leading to the separation into even smaller islands with lower load (Fig. 1). The last stage in the automated frequency decoupling (normally with frequency 46.5 ÷ 47 Hz) leads to the complete decoupling of the generators from the system when each generator has to unload until reaching the power corresponding to its own needs that are provided by the transformer for own needs. The latter then remains the only load for the generator.

In practice the problem of providing dynamic stability in situations when the generator passes from the preceding steady state of normal load to the state of own needs is successfully resolved. Since the power corresponding to the own needs for each specific case is known in advance (5 ÷ 9% from the nominal power), by using the signal from the block-contacts of the generator voltage switch it is possible to immediately lower the input value of the turbine power regulator (setting the known power of own needs P_{ON}) and secure the mechanical and electrical moments equilibrium of the turbine rotor. The proportional turbine speed regulator then smoothes out the transition process. In consequence the unit maintains stability at some speed very close to the nominal one, functioning only to cover its own needs (Fig.1, Stage 4, 46.5 Hz), while the operating staff awaits the dispatcher's command to again synchronously connect the generator to the system (resynchronization).

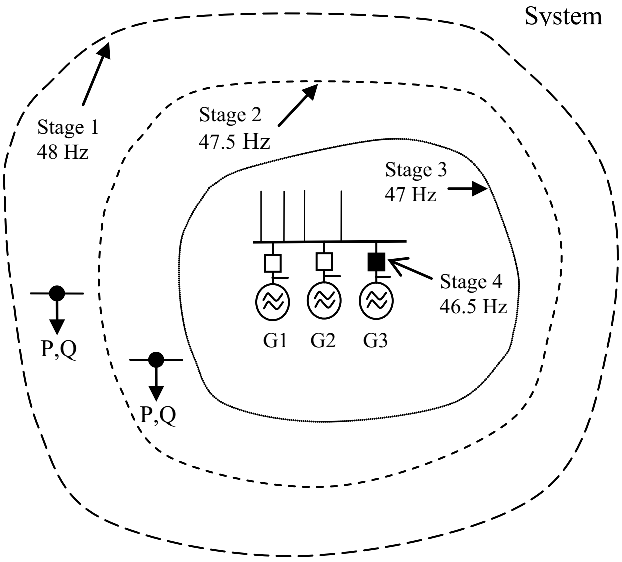

Fig. 1. General principle of automated frequency decoupling organization involving islands of gradually diminishing power related to the decline in frequency. The last stage in the automated frequency decoupling (stage 4) leaves each generator at its own needs' load.

The scenario specified above is not the only one concerning the development of system failures. It is possible that the described process might not reach its conclusion and at some stage there will be the "fortunate" situation when by chance the generation and load will happen to be in equilibrium; subsequently the frequency will stop falling. Then the given island will continue its independent functioning even if its frequency will not exactly equal the nominal one. Yet there is the opportunity to make the island parallel to the remaining part of the system (i.e. to "gather" the system together). Yet it is more plausible that at some stage of the automated frequency decoupling the next island's load will be lower than the generation which will immediately lead to the unit's acceleration and its speed will soon be above the nominal one. Note that the proportional turbine speed regulator cannot cope with such large frequency fluctuations and the technological high speed defense mechanisms will switch off the generator from the network. As a result, its own needs will remain without electricity, while the generated power cannot be started without the supply of power from without, i.e. from the failed system. An analogous situation may occur also as a result of ordinary failures (without the involvement of the automated frequency decoupling) when there is the simultaneous switching off of such electric lines which switches form some kind of an island. As we have seen in practice, such failures are possible in the event of cascade switching off as in severe winter conditions combined with iced cables, incorrect settings of the relays protection or in the event of its damage. The present paper focuses precisely on that case, namely when the generation in the island state exceeds the sum total of its load.

II. PROLOGUE

All preliminary experiments, approbations and algorithm implementation of turbine regulator management were carried during 2008 and 2009 at the Varna Thermal Power Plant (Varna TPP), Bulgaria, part of the CEZ Group, Prague.

The Varna Thermal Power Plant is the second on the Balkan Peninsula regarding its power (the first one, “Maritza-Iztok”, is also in Bulgaria). The Varna TPP has six generators, the power of each equaling 210 MWT. Only 3 of those are connected to the network at voltage equal to 110 kV where islands are possible. The remaining three generators are connected at voltage equal to 220 kV and due to the circuit singularities they are not required to operate in island state.

The “Simadin” type of turbine regulators with microprocessor configuration and digital management are supplied by the “Siemens” company. They regulate the fast-functioning steam turbine valves. It is possible to set the step of the regulated process parameter registration with respect to time, yet it cannot be smaller than 0.1 sec. The regulation concerns the power and the speed on the basis of the proportional law with the possibility to set statism and insensitivity zone. As a supplier Siemens guarantees the regulators’ correct functioning of the regulators during the transition to the own needs state, which was checked many times in practice: everything went very well. Therefore, at some point those not well familiar with the subtleties of this field believed that the transition to an island with power exceeding the own needs had to be a simpler problem. Then in 2007, however, there was a failure in the area of the Varna TPP entailing the formation of an island. The turbine speed regulator did not cope with its task although the island’s power was sufficiently high. The rotor accelerated beyond the admissible values and the radically functioning automatics, preventing from excess speed, completely switched off the generator and unloaded the turbine. At that time there were no other generators at the station and it got into a blackout state with all accompanying undesirable consequences. Thus there emerged the problem of adding an algorithm of turbine regulation in an island state.

III. THEORETICAL JUSTIFICATION OF THE IDEA OF CONTROLING THE TURBINE REGULATORS IN AN ISLAND STATE

Studying the existing practice in Europe did not give us any result so we chose to test our own approach as described below according to the theory [1].

In an island state the turbine rotor is subject to only two opposing rotating moments: the mechanical P_{MECH} on the part of the turbine and the electromechanical P_{EL} on the part of the external load. Note that there will be no dampening moments due to the absence of parallel functioning between the generator and the system. In that case we can write down the rotor’s acceleration based on the second Newton’s law concerning rotating motion as a simple differential equation:

$$J_M \frac{d\omega}{dt\omega} = M_{MECH} - M_{EL} = \frac{1}{}\left(P_{MECH} - P_{EL}\right) \qquad (1)$$

where J_M is the inertia moment of the entire rotor (with the generator and the turbine); P_{MECH} and P_{EL} are the respective mechanical and electromechanical powers, while $\omega=2\pi f$ is the circular mechanical frequency, which in the given case coincides with the electrical one (single-pole turbo-generator), and f denotes the current frequency.

From this equation we can derive the unknown power of the island $P_{EL,}$ if we know the instantaneous mechanical power of the turbine P_{MECH}, the frequency f and its derivative:

$$P_{EL} = P_{MECH} - J_M \cdot \omega \frac{d\omega}{dt} =$$

$$= P_{MECH} - 4\pi^2 J_M \cdot f \frac{df}{dt} = P_{MECH} - k.f \frac{\Delta f}{\Delta t} \qquad (2)$$

Further on we can modify the set value of the turbine regulator to the already calculated one, P_{EL}. After equalizing in this fashion the two rotating moments of the unit’s rotor, we then leave the control of the transition process to the proportional speed regulator. The latter one based on its statism (usually 4%) will perform its task and will set a constant speed very close to the nominal one.

It is necessary to underscore that crucial circumstance that in the technical task of achieving control it was recommended to use only those signals and measurable variables that are appropriate for and present in the “Simadin” regulator. Therefore, we could not use the electric variables’ sensors, including the sensor of electric active power of the generator’s stator.

A certain ambiguity remains regarding the inertia moment J_M. For increased reliability it is best to determine the value J_M experimentally, without relying on the passport documentation. There are two ways of accomplishing that:

1) We can either use the unit’s acceleration at the time of its switching on from an immobile state. In this case, by setting a constant mechanical power for the rotor and

determining its acceleration as the difference between its speeds, we can find J_M as follows:

$$J_M = \frac{\Delta\omega}{\Delta t},$$

where Δt denotes the time passed.

2) Or, we can use the rotor's motion characteristics during test trials. We recommend first testing the algorithm in real-life conditions, yet it is necessary to start with a very small difference between the generator's preceding load and the island's electric power. In the algorithm, initially the value for J_M is taken from the technical documentation, but after the transition to an island state it is possible to determine the expected and the real rotor acceleration in the first time instances. Their difference will show how to correct the already set value for J_M. In this case the electric power P_{EL} has to be determined by electrically measuring the generator's voltage, while for the transition from power to mechanic moment it is necessary to also consider the change of frequency (speed), regardless how small its value.

In our work we used the second approach, conducting the first test experiment with a transition from 135 MWT in the preceding state (prior to the "island") to 130 MWT in the island state, i.e. with a difference of only 5 MWT. Thus, not only do we facilitate our subsequent calculations, but also increase the probability of completely avoiding the unpleasant "blackout" situation, all that owing to that insignificant process dynamics.

IV. TECHNICAL REALIZATION AND ALGORITHM TESTING

Our main problem here is setting adequate mechanical criteria that will help us determine the presence of an island. The mere change (acceleration) in the frequency or its deviation from its nominal value need not lead to the formation of an island. Although rarely, the frequency in a united system may fluctuate substantially around its nominal value, yet the system may remain un-separated. Our task is to enter such criteria into the algorithm, with which assistance we can exclude situations of that kind. For that purpose we used a simulator which allowed us, after reviewing a multitude of various scenarios, to settle on the following relatively simple relations:

Criterion "A":
$f > 51$ Hz;
Criterion "B":
$df/dt > 200$ mHz/sec AND $P_{set} - P_{meas} > 5$ MWT

The algorithm has to perform when at least one of the two criteria ("A" or "B") is fulfilled. The "A" criterion has been chosen to prevent from the switching on of the increased turbine speed automatics, while the "B" criterion consists of two conditions, connected with the "AND" logic operator. Both conditions are fulfilled simultaneously only in an island state: when there is a noticeable acceleration beyond 200 mHz/sec, the difference between the set power of the regulator and its measured real value has to exceed 5 MWT.

For the purpose of conducting experiments, the Bulgarian National Dispatch Centre (NDC) had in advance set aside an island formed by several substations in an area of mixed-type load, but without any important industrial consumers. A generator with a tested regulator was affixed to one out of the four bus-sections of a 110 kV. The connection between this section and the island was achieved with the help of a corridor formed by consequently connected electric lines. The transition to an island state was realized by switching off of that section from parallel work within the system. The island's power could be modified by changing the number of substations in the island, for the purpose of which the researchers were directly connected to the operational staff. Those on duty in these substations had been instructed in advance how to connect the substation directly to the system in case of an experiment failure and the occurrence of a blackout (complete switching off). In this fashion in the worst case we avoided a break in the electricity supply for the consumers for a period longer than one minute.

Since the highest significance during an island transition have not the powers themselves, but their difference, the majority of the experiments were conducted while maintaining constant power on the island, but with varying generator loads. There was no reason to simulate an island with power below 125 MWT, as such a turbine state is known to be unstable regarding the thermo-dynamic characteristics of the boiler-turbine system.

The experiments testing the algorithm of turbine regulation during a transition to an island state were conducted on a normal workday (Thursday) in the autumn of 2008. The resulting diagrams are shown in figures 2, 3 and 4.

V. CONCLUSION

1. Regardless of the obvious simplicity of the proposed algorithm of turbine regulation, based on Newton's second law, the experiments we conducted show that the generator maintains its dynamic stability and remains operating in a sufficiently broad scope of possible transitions to an island state.
2. The observed transition process smoothes out relatively fast and does not exceed 20 sec (unloading the generator by 80 MWT).

VI. REFERENCES

[1] V.N.Veller. "Automatic control of steam turbines" (in Russian). *Moscow, Energia, 1977, p. 405.*

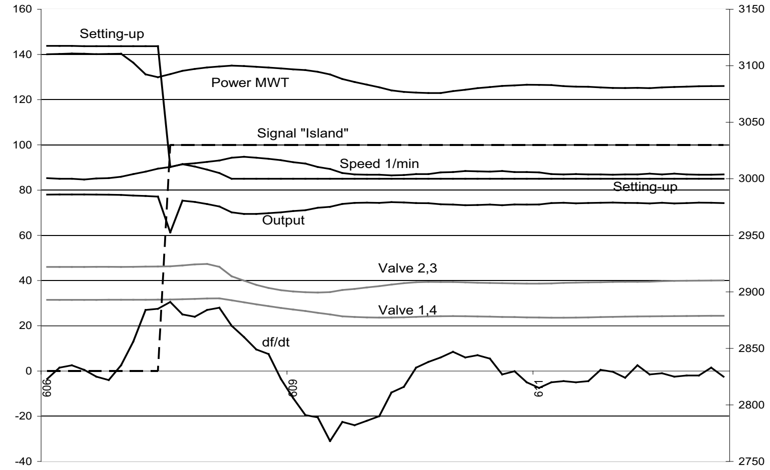

Fig. 2. Parameter diagram during the transition from 140 MWT to an island of 130 MWT (ΔP = 10 MWT). The transition process smoothes out after 5s.

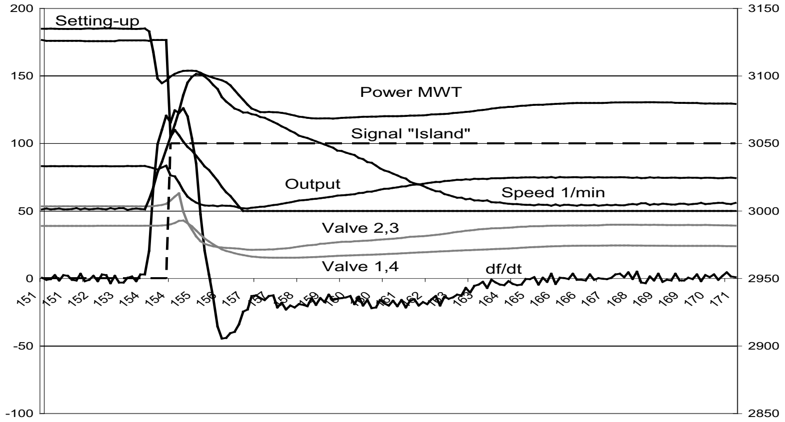

Fig. 3. Parameter diagram during the transition from 185 MWT to an island of 125 MWT (ΔP = 60 MWT). The transition process smoothes out after 12s.

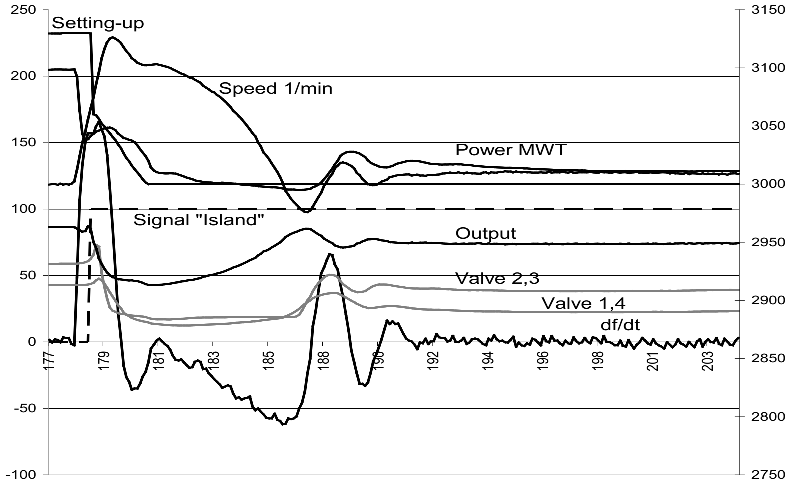

Fig. 4. Parameter diagram during the transition from 205 MWT to an island of 125 MWT (ΔP = 80 MWT). The transition process smoothes out after 20s.