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Management of Operating Conditions and Emergency Control of Power Units

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KEYWORDS

Power system, interconnection tie, steady state, emergency control, monitoring of transients, WAMS.

1 INTRODUCTION

Modern digital measurement units are installed nowadays all over the IPS/UPS synchronous zone. These units are synchronized in time via satellite systems and are designed to register transients. The analog of WAMS (Wide Area Measurement System) - the Transient Monitoring System (SMPT) is being created in Russia. The control schemes based on the information obtained from WAMS are developed in many foreign countries.

Data on phasors in different points of the power system can be used to estimate how close the current electrical mode is to its stability margin and if stability is violated to provide the designed control actions and to alert the dispatcher. Implementation of such a control scheme operating in real time faces several difficulties, caused by the structure of IPS/UPS power system and WAMS peculiarities. So the study of the fundamental feasibility of such control is very important.

2 MANAGEMENT OF OPERATING CONDITIONS AND EMERGENCY CONTROL USING INFORMATION OBTAINED FROM WAMS.

Operating conditions of different interconnection ties of the UPS were studied. The results of the researches showed, that estimation of the locations for measurement units installation in the power system with the mesh structure is challenging. It is hard to find points in which phasors totally characterize how close an electrical mode is to its limits.

This situation can be illustrated in a simple three-node circuit shown in Figure 1.

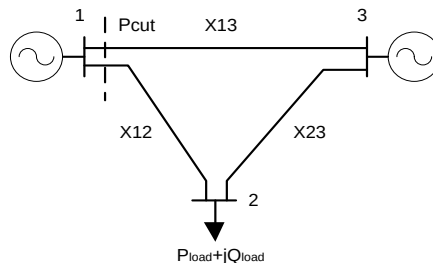


Fig. 1: Structure of the circuit

The power flow through the cut which separates node 1 from the system (P_{cut}) is studied. Let us consider the case when there is no load and the lines 1-2 and 2-3 are open. The scheme has the

following structure: two generators connected with line 1-3. The power flow in such schemes is determined using the well-known formula:

$$P_{cut} = \frac{U_1 U_3}{x_{13}} \sin \delta ,$$

δ - is the relative angle of the between voltages in nodes 1 and 3.

In the current scheme, the maximum steady state power can be transmitted between two machines when the angle value is 90°. The values of the maximum power flows through the cut were determined for various resistances of the line X13 (voltages in the nodes 1 and 3 are considered to be constant, $U_1 = U_3 = 1$ p.u.).

Xline (p.u.)	Angle (degrees)	P_{cut} (p.u.)
0.1	90	10
0.5	90	2
1	90	1

Table 1: Parameters of the scheme

If the value of the resistance of the line is 10 times changed the maximum power flow also 10 times changes, but the critical angle remains constant and equals 90°.

So, in the two-machine scheme, the relative angle between two constant voltages totally characterizes how close the electrical mode is to its angle stability limits. The angle is considered to be an informative parameter which helps to estimate the severity of the operating conditions. In the current scheme it is easier to control the relative angle than the power flow through the cut. If the interconnection tie 1 -3 consists of several transmission lines, the dispatcher should control several values of the power flows (which depend on the structure of the interconnection). Only one parameter should be controlled if we consider the relative angle.

But the relative angle becomes less informative even if lines 1-2, 2-3 are put into operation and the load is connected to the node 2. Indeed, in this scheme in the limiting operation conditions the relative angle between the voltage at nodes 1 and 3 will depend on the load and grid parameters. The parameters of 3 different test schemes are presented in Table 2. The maximum power flows and corresponding values of the relative angles between voltages in nodes 1 and 3 were determined for this schemes (Table 3).

№ of the variant of the scheme	X_{12} (p.u.)	X_{13} (p.u.)	X_{23} (p.u.)
1	0.5	1	0.5
2	0.1	1	0.9
3	0.9	1	0.1

Table 2: Parameters of the test circuits

№ of the variant of the scheme	Pload (p.u.)	Qload (p.u.)	Angle (degrees)	P_{cut} (p.u.)
1	0	0	90	2
	0.3	0.15	84.2	2.04
	0.6	0.3	74.3	2.01
2	0	0	90	2
	0.3	0.15	85	2.27
	0.6	0.3	86	2.55
3	0	0	90	2
	0.3	0.15	85	1.98
	0.6	0.3	82	1.8

Table 3: Relative angle between the voltages in nodes 1 and 3 and the an the maximum power flows for different variants of the scheme

The results of the analysis of the data presented in table 3 are the following: the relative angle between voltages becomes less informative in the complex schemes; the angle becomes a function of grid parameters and depends on the loads. The possibility of using the relative angle to determine the severity of the electric mode is limited by the parameters and characteristics of the studied power systems: Advantage of the relative angle comparing to the power flow can be found only in schemes of simple structure. In some cases the angle is as informative as the power flow, and sometimes control of power flow has obvious advantages.

The relative angle can be used to determine the severity of the operating conditions if the structure of the complex power system can be simplified - transformed into the following structure: transmission lines between two big complex interconnections, etc.

Comparative analysis of the behavior of the relative angle and active power flows in a typical for the UPS of Russia operating conditions showed that the structure of the 500 kV transit Surgut SAPP – Tyumen – Reftinskaya SAPP is similar to two-machine equivalent. The angle between voltages at 500 kV buses of Surgut SAPP2 and Reftinskaya SAPP was considered. The structure of the 500 kV network of this area of the UPS of Russia is shown on Figure 2 (the dotted line depicts the cut in which the power flow is controlled).

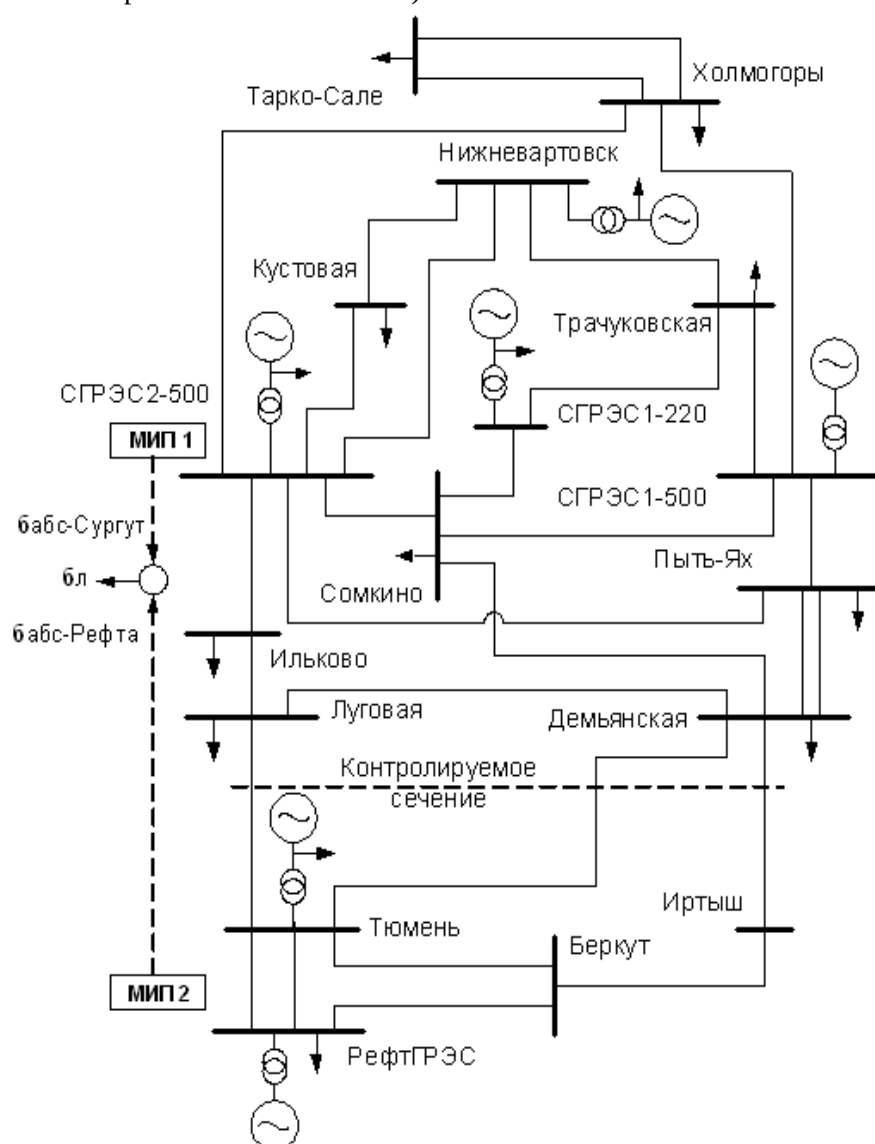


Fig. 2: Scheme of the physical model of the power system

The performed calculations showed that the structure of this interconnection tie can be considered as two-machine scheme. The limiting value changes in a small range from 80 to 90

degrees, depending on the method of increase of severity of operating conditions, topology of the network and the loads in the intermediate nodes.

Table 4 shows the results of the evaluation of post-emergency regimes for two types of control: the controlled cut is unloaded in the post-emergency mode - 1) the value of the angle equals the value in the mode previous to the emergency mode, 2) the value of the angle equals 92 % of the limiting value. The power referred to in the last column shows the redundancy of control compared to the option of reaching the 92% of the limiting value in the post-emergency operating conditions. However, in some cases if the system has technological limitations, the value of the angle in the prior to emergency mode can be taken as a reference.

Parameters Scheme	P _{20%} , MW	δ _{20%} , degree	P _{8%} , MW	δ _{8%} , degree	P _{δ=60,1°} , MW	ΔP, MW
initial scheme of the power system	2040	60,1	-	-	-	-
500 kV line - switched off Surgut SAPP-2 - Pyt-Yah	-	-	2150	75,5	1795	245
500 kV line - switched off Surgut SAPP-1 - Pyt-Yah	-	-	2190	71,8	1926	114
500 kV line - switched off Surgut SAPP-2 - Ilkovo	-	-	1670	63,8	1605	65
500 kV line - switched off Surgut SAPP-2 - Somkino	-	-	2290	75,6	1900	140
500 kV line - switched off Surgut SAPP-1 - Somkino	-	-	2275	70,0	2035	5

Table 4: Evaluation of control redundancy in the case of taking the value of the angle in the prior-to-emergency mode as a reference

The algorithm of power units control (developed in JSC «NIPT») can be applied to estimate the effectiveness of using the information about the angles between the vectors of the voltage (obtained from WAMS) . This algorithm of control of the turbines power [1] can be written as follows:

$$U_{\text{control}} = K_p \cdot (p_0 - p_{\text{current}}) + K_{\delta 0} \cdot \int_0^t (\delta_{\text{л}} - \delta_{\text{л.ref}}) dt + K_{\delta} (\delta_{\text{л}} - \delta_{\text{л.ref}}) + K_f \cdot \Delta f + K_f' (\Delta f)'.$$

where:

U_{control} – control signal from the turbines power regulator

p_0, p_{current} – power of the generator under control in the prior-to-emergency and emergency stage of the transient

$\delta_{\text{л}}$ – the current value of the relative angle;

$\delta_{\text{л.ref}}$ – reference value of the angle;

Δf – voltage frequency deviation (at the buses station);

$K_p, K_{\delta 0}, K_{\delta}, K_f, K_f'$ – setting of the regulator.

The turbine power regulator has five control channels.

The first channel controls the deviation of the power of the station (or each generator) and provides intensive control of the turbines power on the dynamic stage of the transient and stability in the first cycle of rotors oscillations.

The second channel controls the integral of relative angle deviation - integral control mode, by means of this mode the relative angle of the generator $\delta_{\text{л}}$ reaches its reference value $\delta_{\text{л.ref}}$.

The third channel regulation controls the deviation of the relative angle - provides active regulation in the starting period of the transient (when the integral is unavailable).

The fourth and fifth channels of regulation controls the frequency and frequency derivative at the buses of the station - provides the stabilization of the system (integral brings instability in the regulatory process).

To determine the relative angle the data obtained from WAMS is used.

To carry out all research related to the control of the power of turbines on Surgut SAPP-2, the detailed digital model of the turbine K-800-240 and its control system was designed and implemented for the generators (simulating the generators of Surgut SAPP-2) of the JSC «NIPT» physical model [2].

The algorithm of control of Surgut SAPP-2 turbines power (salvation of stability problems on the transit Surgut SAPP - PS Tyumen - Reftinskaya SAPP) has three phases of control:

1. If the emergency disturbance takes place at the first stage of the control algorithm the control action is formed. Its goal is to provide stability during the first swing of the rotors. To do this, the powerful off-loading signal is formed, aiming to quick discharge of the turbines power. The signal is formed on the basis of the difference between the power values in the prior-to-emergency and current modes measurements. This signal, after multiplication by the gain K_p is inputted the electrohydraulic converter of the turbine. With the chosen value of the gain K_p the system should provide transient stability responding to a largest possible disturbance. Its value lies in the range: $K_p = 2 \div 4 \text{ ne / p.u.}$. In the cases of smaller disturbances the control signal is proportionally decreases, providing the transient stability of the system in these cases. For the cases when the disturbance is remote, and the intensive control of the turbines power in the starting phase of the transient is not required, the channel of regulation has a deadband.

2. A continuous control action is formed on the second stage of the control algorithm. It aims to provide transient stability on the second and third and etc. swings of the rotors. Four parameters are under control: the integral and deviation of the relative angle between the voltage vectors at the ends of transmission lines, the frequency and frequency derivative of the voltage at the buses of the sending power station. The coefficients are chosen from the ranges:

$$K_{\delta 0} \approx 0,05 \div 0,1 \text{ ne/rad.s.},$$

$$K_{\delta} \approx 0,3 \div 0,4 \text{ ne/rad},$$

$$K_f \approx 0,1 \div 0,2 \text{ ne/Hz},$$

$$K_{\dot{f}} \approx 0,3 \div 0,4 \text{ ne.s/Hz}.$$

The selected values of the regulators settings provide stability in a wide range of schemes and regimes.

3. The value of the angle reaches the value of the angle in the prior - to -emergency mode in 15-20s after the beginning of the transient. Therefore, on the third stage of control the transmission capacity of the line should be fully utilized in the post-fault mode, so the angle reference is increased (taking into account 8% margin of steady-state stability in the post-fault mode). In this regard, in 25 ÷ 30 seconds after short-circuit elimination within 10 ÷ 15 s transition to the new set point is automatically carried out.

The effectiveness of the proposed algorithm of the power control was estimated during various emergency disturbances in full and remedial schemes.

Figure 3 shows the starting stage of the transient (first phase of the control).

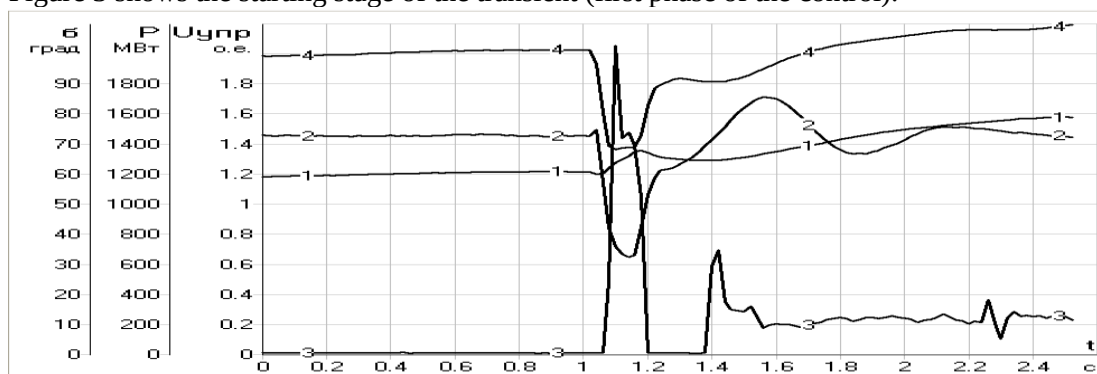


Fig. 3: Double phase ground to short-circuit with duration of 0.12 with 500 kV line Surgut-2-PS Pyt-Yah disconnection. The starting stage of the transient (first phase of the control):

1 – relative angle, 2 – power of the Surgut SAPP-2 power unit, 3 – control action sent to the EHC, 4 – active power flow through the controlled cut

According to the proposed algorithm the first control signal (with magnitude about 2 p.u.) was formed almost without a delay. This provided unloading of the generators during the short-circuit and ensured transient stability during the first swing of the rotors.

The transient on a longer time interval (the first and second phases of control) is shown on Figure 4.

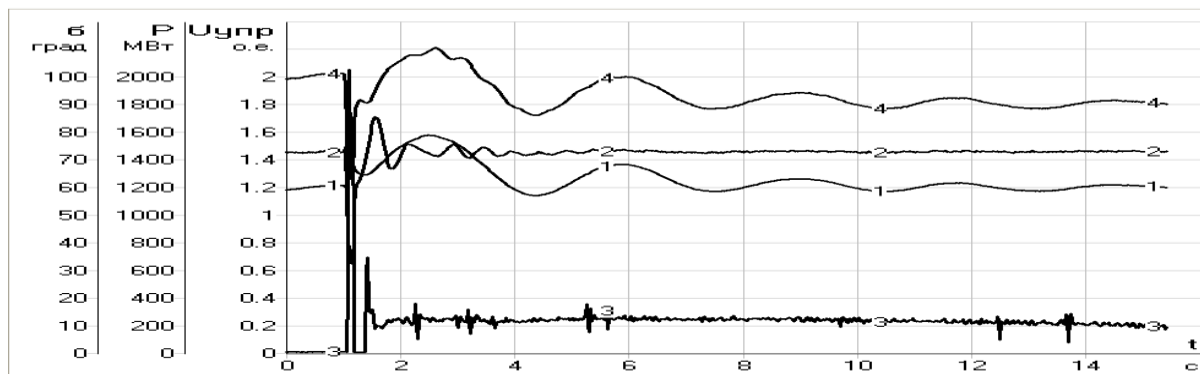


Fig. 4: Double phase to ground short-circuit with a duration of 0.12 with 500 kV line Surgut-PS Pyt-Yah disconnection. Transient (first and second phases of control):

1 –relative angle, 2 – power of the Surgut SAPP-2 power unit, 3 – control action sent to the EHC, 4 – active power flow through the controlled cut.

According to the algorithm of control of the turbines power, in 20 ÷ 25s the relative angle reached its set point value - value of the angle in the prior - to emergency mode (first and second stages of the control).

The transient on the interval covering the entire cycle of control (all three phases of control) is shown on figure 5.

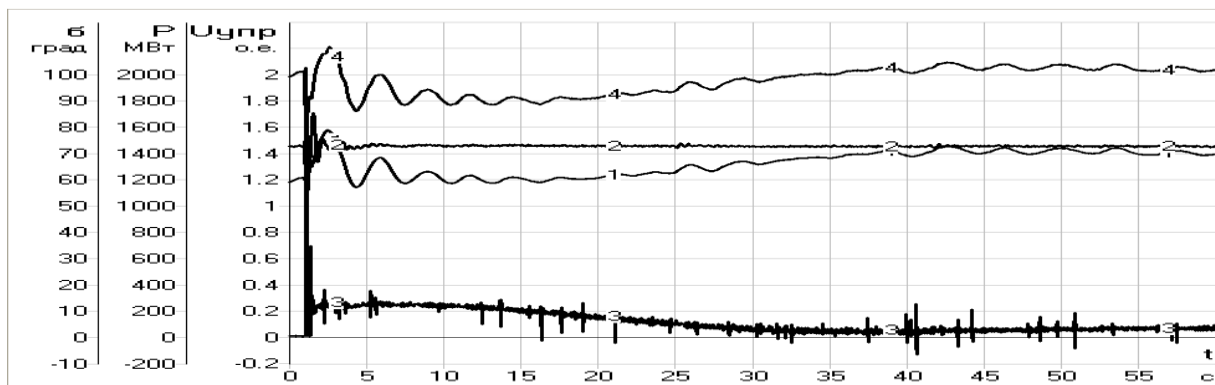


Fig. 5: Double phase to ground short-circuit with a duration of 0.12 with 500 kV line Surgut-PS Pyt-Yah disconnection. Transient (three phases of control).

1-relative angle, 2 - power of the Surgut SAPP-2 power unit, 3 - control action sent to the EHC, 4 - active power flow through the controlled cut.

The proposed control law not only provides transient stability during emergency disturbances but also can be used to limit the power flow through the controlled cut.

The mode of a slow increase of the power flow through the controlled cut is shown on Figure 6. According to the proposed control algorithm the limiter initiates the off-loading of the Surgut SAPP-2 generators and resists the increase of the power flow.

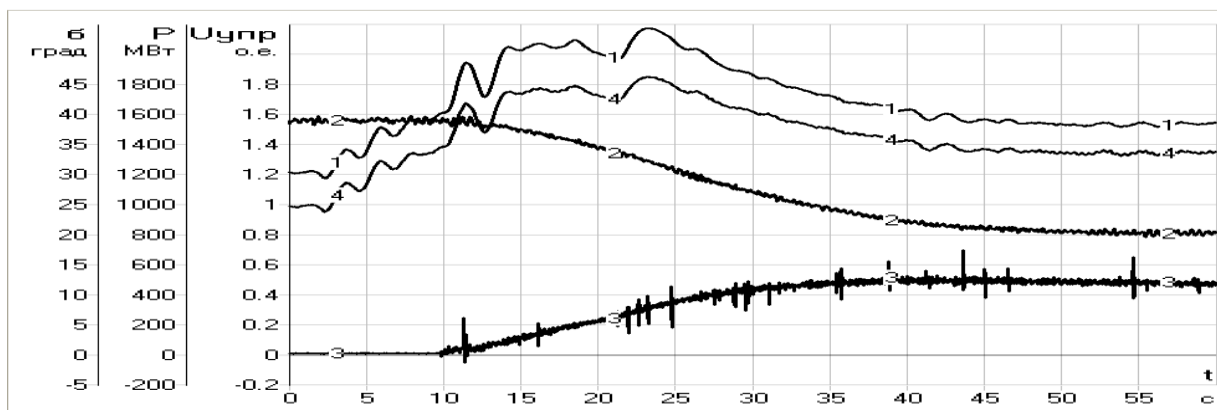


Fig. 6: Mode of the limitation of the power flow through the controlled cut: 1 – relative angle, 2 – power of the power unit, 3 – control action, 4 – active power flow through the controlled cut

3 CONCLUSION

The research has following results:

1. The proposed control law based on the data obtained from WAMS can be implemented in the schemes which has a structure of extended transit, similar to the structure of two-machine circuit. In these cases, the angle between the outer nodes of the considered transmission ties is more informative than the active power flow. In the considered scheme the angle between the voltages on the 500 kV buses Surgut SAPP-2 and Refinskaya SAPP is taking into account (the mode of power transmission from the Surgut SAPP to the IPS of Urals).
2. On the first stage of the electromechanical transient the implemented control law provides step-by-step (depending on the intensity of disturbance) impulse off-loading of the power units taking into account only local parameter (the value of active power imbalance).
3. The angle set point can be saved on the prior-to-emergency level or can be changed to the reference level which matches the maximum power flow in the post-emergency conditions.
4. The implemented control law can provide automatic control of the power flow and also can be used on transmission ties as a power flow limiter.
5. The proposed system can add specific features to the system of centralized emergency control (SCEC). The system requires smaller amount of control action than SCEC to provide stability during the starting phase of the transient. By means of the proposed system the limiting value of the angle is reached in the post emergency mode with smaller stability margins (in the cases when there are no additional requirements to off-loading of the controlled cut due to technological limitations) The control signal is formed taking into account only local parameters that is why there is no delay (required for the data transfer). In the case, when the angle in the post-fault mode remains the same as in the initial mode, the off-loading in the post-fault mode is redundant.

REFERENCES

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