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ANALYSIS OF SYSTEM FAILURE WITH DISTURBANCE OF DYNAMIC STABILITY

Failure in power system causing the disturbance of dynamic stability is analyzed in order to prevent or minimize its consequences as a result of applying optimal strategy of operation in similar situations.

Key words: unified power system, system stability, power imbalance, transient process.

Problem set up

The problem of stability in electric power engineering became very important when electric stations and electric grids were united for parallel operation, i.e., since the time of creation of electric systems [1]. After a number of serious accidents in energy systems of the developed countries (USA, Germany, USSR), caused by the disturbance of stability, the investigation of this problem is considered to be of great importance. In [2] it is stressed that, for instance, in the systems of Mosenegro and Lenenergo in the period of 1932 -1934 38 accidents, caused by the disturbance of parallel operation, took place. The deficit of fuel energy resources, present nowadays at thermal power plants (TPP) of Ukraine and, as a consequence, rolling blackouts of the consumers greatly complicates the stability of unified electric energy system of Ukraine. Lack of fuel at electric power stations and active power shortage decreases the stability margine, it becomes impossible to maintain nominal frequency and may lead, under unfavourable conditions, to the disturbance of system stability by the criterion of mode parameters flow (drift) in the form of “frequency avalanche”.

In the literature, on this problem [1, 3] except statement of the facts of stability disturbance, it is not possible to find the analysis of the reasons, course and consequences of the accidents. Without such analysis improvement and increase of qualification level of operating and duty staff of electric stations and grids as well as training of the students in electrical power engineering is not possible.

Aim of the paper

--revealing and analysis of the reasons of the accident in the unified energy system;
--submition of the chronology of accident development;
--analysis of protective automatic devices reaction
--evaluation of the technology of stable after accident mode recovery.

Results of the study

The given accident (June 1997), that took place in energy system with the convectional name UE, led to the disturbance of power supply of the consumers for more than 10 hours and that is why, it is very instructive. Total generation power of UE energy system may reach 1655 MW, but at the moment of time prior to the start of the accident, actual generation was 339 MW. This is shown in Fig. 1, it is seen from this Fig. that total load of UE energy system P_l was covered by its own generation of power P_g and power P_t by transit over-head transmission line – 500 from UEU energy system . Links with other energy systems – NE and BE were disconnected.

It should be noted that normal mode, that was established, is possible in any energy system only when power balance and active power, “responsible” for the frequency in the system are provided. It is seen from Fig. 1, that in UE system in prefault state the balance of active power was strictly executed, imbalance power P_{im} was absent, $P_{\text{im}} = \boldsymbol{P_g} - P_{\text{t}} - P_{\text{t}} = 779 - 339 - 440 = 0$ (MW) that provided system frequency 50 Hz.

Total generation of power in OE system in prefault -mode was provided by three parallely operated power stations ES- 3, ES- 4 i ES- 5 (Fig. 2).

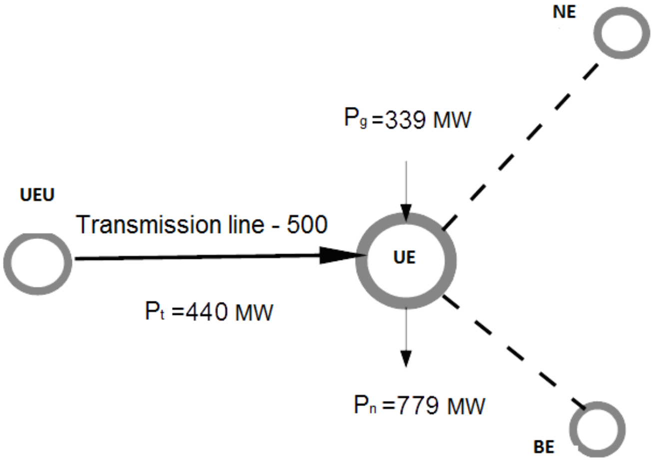

Fig. 1 Schematic diagram of UE connection with other systems

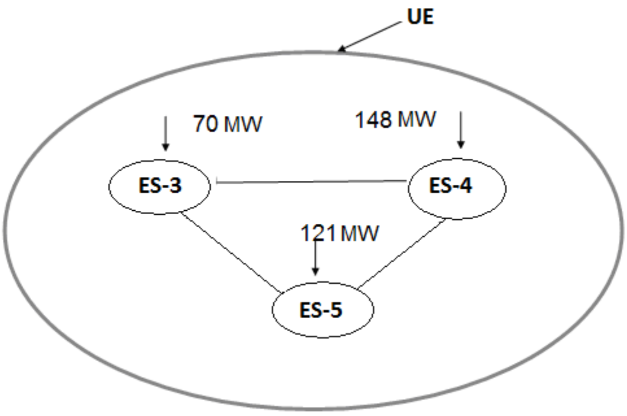

Fig. 2 Distribution of total generation of power in the system

We should note that loading on the buses of these power stations, taking into consideration their parallel operation, as a rule, does not correspond to their own generation . Start of the accident is referred to 11 hr. 56min. 40 sec. of local time, when disconnection of line – 500 took place on supplying end (Fig. 1) and energy system OE started to operate in isolated mode, the imbalance power equals

$P_{im} = P_n - P_g - P_t = 779 - 339 = 440$ (MW).

The emerging power imbalance creates additional braking torque for the rotors of all generators of UE system. It depends on imbalance value and inertia characteristics of rotating masses. This leads to the decrease of generators rotors speed and, thus, to frequency drop. Potential danger of frequency drop in the system is that the operation of the station auxiliary needs mechanisms such as supply pumps, circulating pumps, flow fans, smoke exhausters, etc., drive of which is performed by electric motors may be violated.

Thus, in case of power imbalance the following series of events may occur: frequency drop – decrease of the moments of rotating electric drives – reduction of auxiliary mechanisms performance and, in worse case – changeover of electric motors – complete shut-down of electric stations and outage of energy supply.

To avoid this negative scenario, various automatic means are provided in energy systems, namely, automatic regulation of turbine speed (ARTS), automatic frequency off-loading (AFL) and others. For instance, AFL, according to preset algorithm, provides forced disconnection of the part of consumers to restore active power balance. Volume of disconnected load, order of priority, temporary of frequency AFL settings are determined apriori, proceeding from the key demand – maintaining of system stability. If AFL provides power balance we may speak about positive result of the accident. Otherwise, energy stability violation becomes inevitable ---it is the worst result of the accident.

From these positions we will consider the operation of AFL at power stations of UE system after the start of the accident that is, beginning from 11 h. 56 min. 40 sec. of local time. Let us study the telemetric information and present it in the form of the table 1, given below and graphs in Fig. 3 and

Fig. 4.

It is seen from the Table 1 and Figs. 3 and 4 that:

-AFL system started operation only several seconds after the start-up of the accident;

-during first 30 seconds of the accident AFLS worked almost 80 % of the total resource of load sheding;

-further AFL operation is characterized by less intensity of load sheding;

-from the beginning of the accident and to the depletion of AFL resource, frequency in the system first dropped rapidly, then stabilized at low level, and further monotonously worsened;

-total AFL resource being shedded, is 280 MW, that was approximately 36 % of the system load in 779 MW, in the given accident turned out to be small.

Table 1

Telemetering information about the state of electric power system

Hr, hr. month..	Frequency, Hz	P shed., MW
11.56.4	50.00	0.00
11.56.5	47.52	52.80
11.57.0	48.44	76.00
11.57.1	48.28	92.6
11.57.2	47.96	32.4
11.57.3	47.88	14.00
11.57.4	47.80	0.00
11.57.5	47.80	0.00
11.58.0	47.80	0.00
11.58.1	47.80	0.00
11.58.2	47.80	0.00
11.58.3	47.52	5.10
11.58.4	47.20	1.20
11.58.5	47.08	0.00
11.59.0	47.00	6.00
Total $P_{shed.}$, MW		280.1

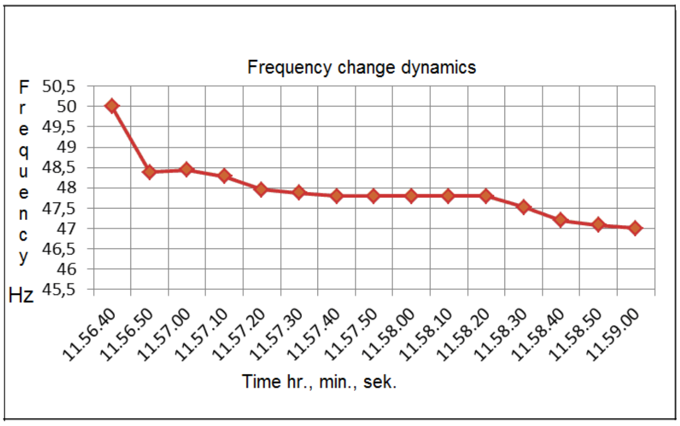

Fig. 3. Transient process of frequency change in UE system

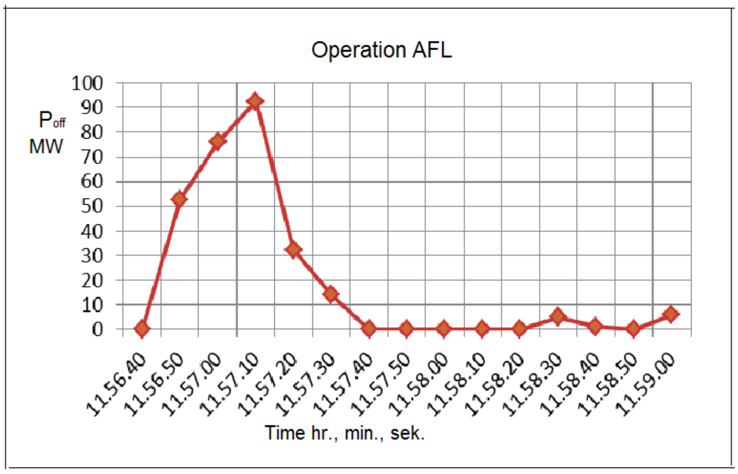

Fig. 4. Dynamics of loading, shedded by AFL

Taking into account the fact that the possibilities of AFL turned out to be exhausted and the frequency continued to decrease, system OE became to be divided into asynchronous parts by means of automation facilities and actions taken by dispatching staff. The events took place in the following sequence:

at 11.59.29 EC- 3 automatically allocated for isolated operation;

at 12.01.06 EC- 4 completely shedded the load (in professional slang – “sat on 0”) as a result of auxiliary power losses;

at 12.00. 07 unit №2 of EC- 5 was disconnected, and was allocated for auxiliary power loading;

at 12.05.43 unit №5 of EC- 5 is disconnected due to low frequency.

As a result of such events loading of total power 711 MW was disconnected, that is, the complete disorganization of energy supply took place, as a result of violation of dynamic stability of the system. Below, in Fig. 5 and 6, fragments of recorder charts of EC- 5 power and frequency are shown. They record telemeterings in all time range of the accident in the system.

It is seen, that generation power (vertical axis), Fig. 5undergoes considerable change – from normal value of 121 MW (see Fig. 2) to sharp increase, drop and further stabilization on the level, that provides loading of auxiliary power. Such change of power must be considered together with frequency change in Fig. 6. How could such great surge of generation at the initial stage of transient process be explained?

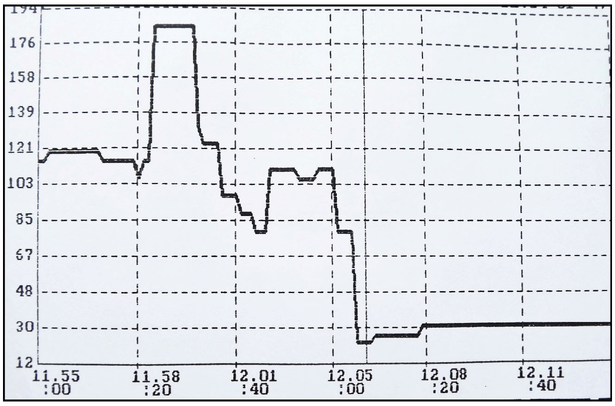

Fig. 5. Dynamics of EC- 5 power change (MW) during the accident

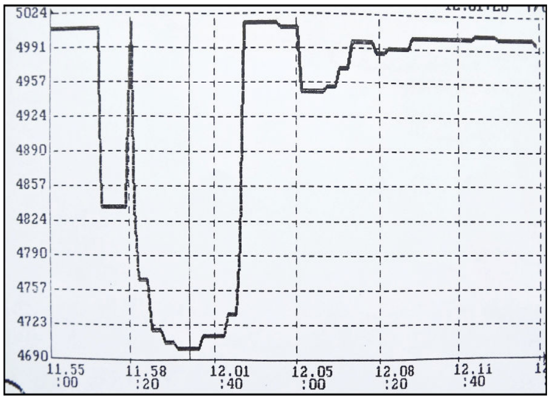

Fig. 6. Dynamics of EC- 5 frequency change during the accident

It should be noted, that systems of AFL and ARTS take part in restoration of power balance in the system. The first system performs force decrease of loading, and the second system performs the increase of generation power. As it was mentioned before, in parallel operation of power plants their real loading is not, as a rule, balanced with generation power. In case of transmission line-- 500 disconnection load surge on separate power station will not be the same. As a result of these two factors braking moments on the generators of parallely operating power station will be different (in professional language – they will get different "kicks"). Different braking moments along with various inertia characteristics of power stations create different changes of generators rotors speed and, hence, frequencies, that differ, at various power stations. In this case, ARTS system for generation power increase, starts to operate. In such a way the increase of generation power (Fig. 5) and frequency drop (Fig. 6) at the initial stage of transient process can be explained.

After the division of the system into nonsynchronous operating parts and EC- 4 disconnection transient emergency process was cover with very serious results. Further, the work, aimed at restoration of normal circuit of UE system started, it was performed in the following sequence:

at 12.48, local time, the voltage was supplied to buses of EC- 4 along communication line with system NE (see Fig. 1);

at 13.36transmission line-500 was connected and its loading began;

at 13.37 synchronization of ES- 3 with the system was performed ;

at 16.24 synchronization of ES- 5 with the system was performed;

at 17.30, unit №5 at ES- 5 was put into operation;

at 20.40 one of turbogenerators of ES- 4 was put into operation;

at 22.10 all the limitations from UE system were removed.

Conclusions

The analysis of reasons, course and consequences of the accident allows to make certain conclusions and assumptions that would help to avoid or soften similar phenomena in UE system.

It is necessary to increase auxiliary installed generating power.

It is necessary to increase the portion of the power, reserved for AFL systems, as compared with total volume of loading.

It is expedient to consider more complex algorithms of AFL control as companed with the existing rules of work; for instance, regarding deviation of power imbalance, its speed and even acceleration.

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