Interconnection of Power Systems with Different Under-Frequency Load Shedding Schemes

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Abstract—**Development of power systems leads to new interconnections that can join power systems with different approaches regarding under-frequency load shedding (UFLS). Parallel operation of different UFLS schemes is analyzed in this paper considering possible UCTE / NORDEL and IPS / UPS interconnection. It is shown that due to differences between UFLS schemes the interconnection's stability can be endangered.**

Keywords-interconnected power systems; UCTE; NORDEL; IPS/UPS; under-frequency load shedding; power system modeling; EUROSTAG

I. INTRODUCTION

When a power system is in stable operation at normal frequency, the total mechanical power input from prime movers to generators is equal to the sum of all the connected loads, plus all real power losses in the system. Any deviation from this balance causes a frequency change.

UFLS is a common practice of electric power utilities for preventing frequency drop in power systems after disturbances causing dangerous imbalance between generation and load. The main goal of it is to gradually shed portions of load until frequency reaches admissible values. UFLS should be reliable, simple, and efficient as it is one of the key options in protecting electric power systems from blackouts and severe damages [1].

UFLS is affected by a worldwide trend of building interconnections with the goal to achieve significant technical and economical benefits. The liberalization in the power industry also supports more interconnections to enable the exchange of power among the regions or countries and to transport cheaper energy over long distances to the load centers [2].

Frequency variations can affect large areas and activate UFLS throughout the interconnection. As every power system usually has its own UFLS scheme, prior to new interconnections it is essential to carry out thorough research work to ascertain the possible problems that may arise due to diversity of the number of steps, the frequency levels and the amount of load to be shed at each step. Due to differences between UFLS schemes their joint operation can lead to unpredictable results.

Initial period of newly interconnected operation is characterized by relatively weak intersystem ties therefore unnecessary power oscillations due to un-coordinated UFLS schemes can endanger interconnected system's stability.

In the paper consideration is given to possible joint operation of UCTE / NORDEL and IPS / UPS synchronous transmission grids. Considered problem is a part of research work done by authors in the framework of international project No.227122 ICOEUR (intelligent coordination of operation and emergency control of EU and Russian power grids).

Mathematical models have been developed for different UFLS schemes to perform dynamic simulations using fictitious network configurations as well as ones for repetition of real accidents in power systems. These models are not presented in the paper due to space constraints. Nevertheless, the considerations that were applied during model development process are given in Chapter II.

Possible problems of UFLS operation in interconnected systems are shown.

II. CONSIDERATIONS USED FOR MODEL DEVELOPMENT

For gradual increase in load, or for sudden but mild overloads, electric power system generating units' governors will sense speed change and increase power input to the generator. Here the so called primary and secondary frequency control is activated. Simple governor (IEEEG1) and excitation system (DC1A) is used in models as they are not the object of the research. IEEEG1 is the IEEE recommended general model for steam turbine speed governing systems. By the appropriate choice of parameters, this model can be used to represent a variety of steam turbine systems including non-reheat, tandem compound, and cross-compound types. IEEEG1 can also approximate the behavior of hydro turbine-governors [3]. DC1A model has been widely implemented by the industry and is sometimes used to represent other types of systems when detailed data for them are not available or when a simplified model is required [4].

Severe system disturbances can result in a frequency decrease that is too fast for conventional governors to respond and UFLS takes place. Active power deficiency that leads to

UFLS operation can be simulated by disconnection of large generating units or by rapid and substantial load increase. The latter is chosen by the authors.

Simple two-machine system, such as shown in Fig. 1, is appropriate for most study cases. This scheme permits comparison of different UFLS schemes, simulation of weak transmission line, splitting and joining of two power systems etc. Equivalent generators in Fig. 1 can represent any system or interconnection up to joint operation of UCTE / NORDEL and IPS / UPS synchronous transmission grids.

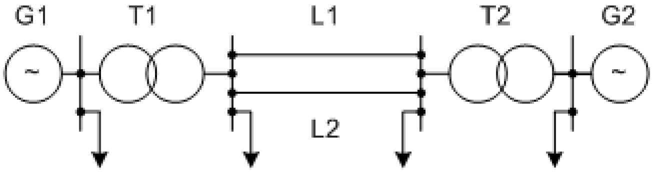

Figure 1. Model of interconnected power system

Dynamics of under-frequency during the deficiency of generation in the power system can have very different character. It depends on the value of disturbance, response of protection, automation, and governor systems, network topology, initial loading etc. The relatively simple network model as well as the same governor and excitation system at G1 and G2 (see Fig. 1) allows explicitly focus on UFLS operation and comparison.

Up-to-date automatic load shedding system practically in the most power systems foresees disconnection without time delay or with small delay part of the load on under-frequency. The numbers of load shedding steps and value of load to be shed vary for the different power systems. Some power systems use rate-of-change of frequency as additional factor to shed a load [1, 5]. Frequency and time delay settings of UFLS for European systems can be found in disturbance reports, such as [6]. UFLS of IPS / UPS systems is represented by the one used in Baltic states. It has the following characteristics:

- 49.2, 48.8, 48.6, 48.4, 48.2, 48.0, 47.8, 47.6, 47.4, 47.2 Hz (UFLS I) with tripping time delay 0.5 sec for each step.
- 49.1, 49.0, 48.9, 48.8, 48.7 Hz (UFLS II) and tripping time delay 10 - 80 sec.
- Total value of connected load to the UFLS is about 64%. The amount of load to be shed depends on a character of transient process (whether it is slow or fast) but in general each load shedding step disconnects on average several percent of load.

It differs from the UFLS schemes used in European power systems by additional stage (UFLS II) that is partly combined with UFLS I and makes load shedding somewhat adaptive to the character of the transient process. For fast transients all load connected to the corresponding steps of UFLS I and UFLS II is quickly disconnected. In case of slower frequency decline lesser amount of load in smaller portions and with larger time delay is shed.

All modeling tasks and simulations are performed in power system simulation software EUROSTAG. Models of governors, excitation systems, and UFLS are developed by the help of EUROSTAG'S "Model Editor" library elements.

III. SIMULATION RESULTS

Three simulation cases using the network configuration shown in Fig. 1 are selected and presented in this paper.

1) The same (Spain's) UFLS scheme applied in both systems

Table I presents the main parameters of UFLS system used in Spain [6], which is selected to be presented in the paper as it strongly comply with the recommendations set in the UCTE Operation Handbook [7].

TABLE I. TYPICAL STRUCTURE OF UFLS SYSTEM FOR SPAIN

UFLS step	**Frequency and time delay**	**Connected load, %**
1	49.5 Hz, 0.5 s	2.5% (50% of pumped-storage units)
2	49.3 Hz, 0.5 s	2.5% (50% of pumped-storage units)
3	49.0 Hz, 0.5 s	15%
4	48.7 Hz, 0.5 s	15%
5	48.4 Hz, 0.5 s	10%
6	48.0 Hz, 0.5 s	10%

Analysis of frequency behavior is made for different values of power deficiency.

Fig. 2 illustrates frequency behavior for 5%, 10%, 14% and 35% of active power deficiency. For 5% UFLS is not activated and frequency decline is stopped by governor system at 49.79 Hz. When deficiency is 10% the first step of load shedding is activated yet it is not enough to restore the frequency and it settles to 49.37 Hz.

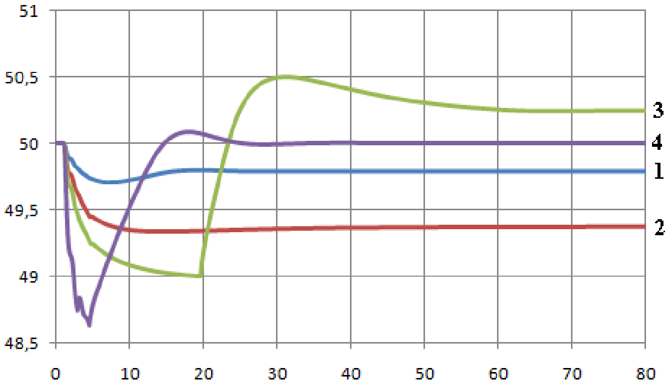

Figure 2. Frequency behavior for 5% (1), 10% (2), 14% (3), and 35% (4) active power deficiency

At 14% deficiency it can be seen that over-frequency situation takes place due to disconnection of extra load shedding step. The steady-state frequency in this case is 50.24 Hz. Eventually the fourth curve shows a perfect match between the magnitudes of disturbance and disconnected load and frequency restores to 50 Hz as a result. It can be concluded that depending on power system state and magnitude of disturbance, all kind of frequency deviation scenarios can take place.

2) The same (Baltic’s) UFLS scheme applied in both systems

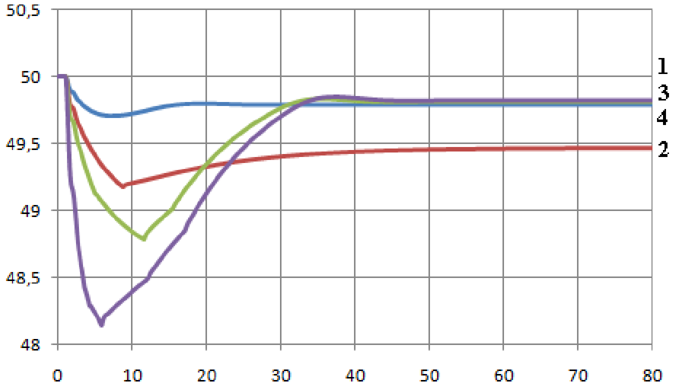

Figure 3. Frequency behavior for 5% (1), 10% (2), 14% (3), and 35% (4) active power deficiency

Characteristics in Fig. 3 are typical for UFLS with large number of steps and relatively small amount of load to be shed at each step. Frequency does not over-shoot 50 Hz, though it reaches lower values during the transient process in comparison with previous case (see Fig. 2) as the smaller amounts of disconnected load result in a slower frequency restoration and also due to the relatively low frequency setting of the first UFLS step. The steady state vales in Fig. 3 are as follows:

(1) deficiency $\Delta P = 5\%$, frequency $f = 49.79$ Hz;

(2) $\Delta P = 10\%$, $f = 49.47$ Hz;

(3) $\Delta P = 14\%$, $f = 49.81$ Hz;

(4) $\Delta P = 35\%$, $f = 49.82$ Hz.

Of course, different network configuration, different parameters of power system elements etc. result in a different frequency transients from the ones presented in Fig 1 and Fig 2. The general pattern, however, remains the same.

3) Different (Baltic’s and Spain’s) UFLS schemes jointly operating in the same interconnection

Let us examine the case when there are two different types of UFLS operating together. One of them is placed in the first system and the other - in second system. The systems are connected via strong intersystem ties.

Due to strong intersystem ties the simulation results do not depend on the placement of disturbance.

For the same active power deficiencies as studied in previous cases now we have the following steady state frequencies:

(1) $\Delta P = 5\%$, $f = 49.79$ Hz;

(2) $\Delta P = 10\%$, $f = 49.37$ Hz;

(3) $\Delta P = 14\%$, $f = 49.89$ Hz;

(4) $\Delta P = 35\%$, $f = 49.39$ Hz.

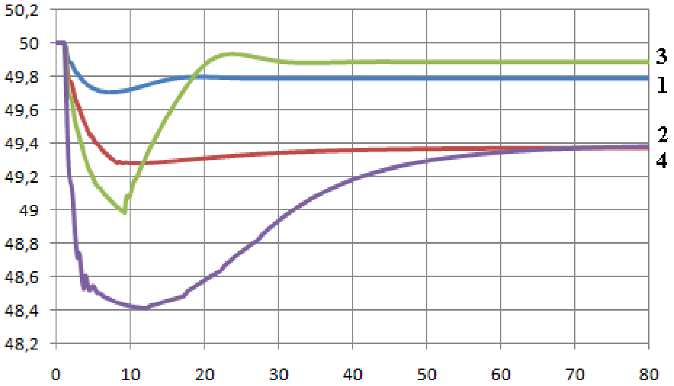

Figure 4. Frequency behavior for 5% (1), 10% (2), 14% (3), and 35% (4) active power deficiency

It can be observed that both UFLS schemes introduce their properties into the frequency transients. The frequency does not overshoot 50 Hz as it was in the first case and it does not decline as much as in the second case. On the negative side, 10% and 35% active power deficiencies result in a frequency hovering at inadmissibly low level.

With parallel operation of different UFLS schemes, additionally the existence of weak intersystem ties should be considered. Differences between frequency settings and load to be shed in both systems lead to unnecessary active power flows in intersystem ties that can become significant from the point of view of power system stability. Load shedding that is distant from the place of disturbance, increases transmission line and cable loading, and worsens voltage profiles.

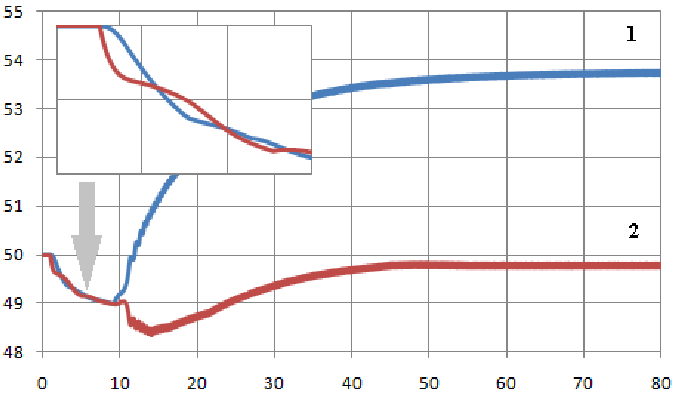

Figure 5. Frequency in both systems for 14% active power deficiency and weak intersystem ties (asynchronous operation). The first system here is equipped with the UFLS as in Spain, the second - as in Baltic region

Thus, for instance, the 14% active power deficiency that was successfully dealt with in all three previous cases leads to asynchronous operation of both systems with different UFLS types (as in third simulation case) due to weak intersystem ties (see Fig. 5). In this example transmission capability is set to 10% from the active power of joint power system.

It should be noted, that loss of generation or sudden and substantial increase of load in one area that has weak ties with its neighbor, results in a different rates of frequency reduction in each of the two areas. As a result generators in both systems oscillate against each other (see the zoomed region of Fig. 5).

Differences of UFLS schemes stem from the fact that there is no widely used method for calculating the settings of the UFLS, which determines the amount of the load to be shed, the stepping procedure and the timing. The electric power utilities adopt different approaches to this problem, which are mainly based on their experience and the robustness of their systems [8]. Due to new interconnections different UFLS that were previously designed for a specific power system find themselves jointly operating in a different environment (see Fig. 6). The settings of existing UFLS should be reconsidered in this case.

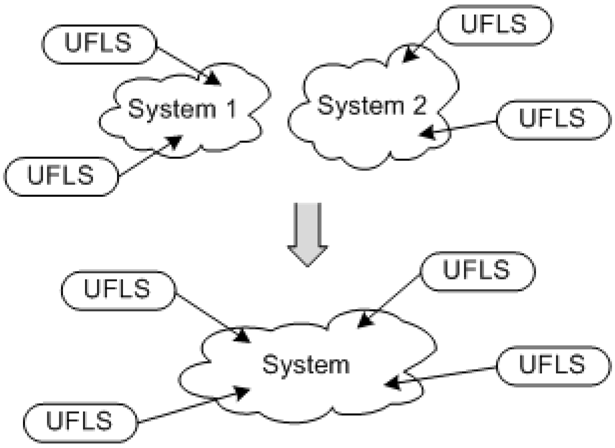

Figure 6. Multiple and possibly different UFLS schemes moving operating in parallel to achieve the same goal

According to the UCTE Operation Handbook the partners accept load shedding also if the failure occurs outside the control area of the respective TSO. As a result different UFLS schemes can be activated to achieve the same goal. Extensive simulation studies performed by authors and using different network configurations, different combinations of UFLS schemes etc. have shown that for the most effective operation of UFLS their schemes throughout the interconnection should be homogeneous.

Having weak intersystem ties it is better to coordinate the operation of UFLS so that it is activated only on that side of the weak tie where the disturbance has occurred to avoid system splitting.

IV. CONCLUSIONS

System interconnections offer technical and economical advantages. That leads to expansion of power systems changing their size and structure. Different protection and automation devices including UFLS that were intended for particular power systems due to new interconnections find themselves operating in a new environment.

Prior to interconnection of power systems it is essential to carry out thorough research work analyzing behavior of frequency transients during disturbances in power systems especially as the initial period of interconnected operation is characterized by relatively weak intersystem ties, that are vulnerable to any unpredicted power flows.

Larger number of UFLS steps with lesser load connected to each step can slightly decrease the impact on weak intersystem ties.

To provide selective UFLS operation, additional parameters can be used, for instance, direction and magnitude of active power in intersystem ties.

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