COMPARISON OF DECENTRALISED AND CENTRALISED UNDER-FREQUENCY LOAD SHEDDING

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ABSTRACT
The paper deals with two concepts of the under-frequency load shedding. The first one is a conventional scheme based on frequency deviation measurement and no intentional delay and the second one is based on the measurement of frequency derivation with variable intentional time delay. The case studies of system wide and local disturbances proved that these concepts can coexist and solve frequency stability issues in transmission and distribution systems.

INTRODUCTION
The under-frequency load shedding (UFLS) is an important part of defense plans. These defense plans shall be designed by each TSO according to the EU regulation [1] to prevent power system from spreading of disturbances and to avoid blackout condition. The regulation introduced a new term the automatic low frequency demand disconnection, but we will keep the established term UFLS, which is commonly used in the literature - see the titles of existing publications [2] - [16]. The mentioned regulation prescribes for UFLS a minimum of 6 stages, maximum demand disconnection for each stage is 10 % and cumulative demand to be disconnected 48 % (on the control area level) for the Continental Europe (CE) synchronous area. But other UFLS schemes are proposed in other publications. These schemes or algorithms are trying to optimize the volume of disconnected load and they are usually based on measurement of power unbalance by the frequency derivation (RoCoF).

This paper compares the application of these two concepts (a standard UFLS scheme and a RoCoF-based scheme) for the case of the CE synchronous area together with a part of distribution network in the Czech Republic. The simulation on dynamic model is used as a method and the MODES network simulator is used as a tool (see e.g. [17] or [18] for more information about it).

POWER SYSTEM MODEL
The system model was derived from central-east part of the CE synchronous zone, which corresponds to the observable area in ČEPS (TSO in the Czech Republic) SCADA system. This area consists of the whole Czech Republic (CZ) and large parts of neighbouring transmission systems (50Hertz and Tenet depict areas operated by two German TSOs) completed by part of Balkan area (SH) – see Fig. 1. (see [19] for more info about this observable area).

Fig. 1 Simplified scheme of the ČEPS observable area

Detailed model (which is used in ČEPS for rotor angle stability calculations and in the dispatcher training simulator) was simplified for the frequency stability simulations. Each control area was reduced to one equivalent node with an aggregated generation and load. Part of the Czech distribution system was modelled to simulate the dynamic behaviour of distributed generation and an alternative UFLS scheme. This part is depicted in Fig. 2 in two operational states.

Fig. 2 Single-line diagram of the distribution system

The model of the distribution system consists of a transformer and three 110 kV nodes. It represents (in a simple manner) a real part of 110 kV network that is fed from the transmission system 220 kV. There is only one synchronous generator in the first operational state on the left side of the Fig. 2. The whole load is divided into two parts. One part is equipped by so called System UFLS (according to ENTSO-E requirements). The second part is equipped by a Local UFLS, which would represent an
additional load shedding contributing to maintaining the frequency stability of this deficient part of the distribution network.

SIMULATION ON THE DYNAMIC MODEL

Two simulations were carried out on the dynamic model. The first one is a system wide disturbance similar to the UCTE separation into three islands in 2006 (see [20] or [21]) and the second one is a simple island operation of part of distribution system (local disturbance).

System wide disturbance

The Czech Republic was part of the North-east island during the UCTE separation on 4th November 2006. This island was roughly the same as the observable area in Fig. 1 and there was large power surplus of more than 10 GW. Since the power deficit is needed for the UFLS operation, we will simulate it by separation 50Hertz control area that exported 4.5 GW to the rest of the system. The installed UFLS for the first 49 Hz stage is in the following table.

<table>
<thead>
<tr>
<th>Area</th>
<th>PL</th>
<th>H</th>
<th>SH</th>
<th>SK</th>
<th>Tennet</th>
<th>AT</th>
<th>CZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load [%]</td>
<td>15</td>
<td>10</td>
<td>8</td>
<td>13</td>
<td>10</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Load [MW]</td>
<td>1441</td>
<td>305</td>
<td>67</td>
<td>365</td>
<td>420</td>
<td>667</td>
<td>884</td>
</tr>
</tbody>
</table>

Fig. 3 shows frequency deviations waveforms after separation of the 50Hertz area at t=1s.

Local disturbance

The local disturbance is initiated by disconnection of transformer feeding the part of distribution system depicted in Fig. 2. This part has power deficiency of about 88 MW. The generator is able to cover 23 MW (nominal active power is 55 MW) and rest should be covered by UFLS. Two UFLS types are modelled. The first one is system UFLS corresponding to the ENTSO-E scheme. It has 5 stages with total power of 57.6 MW – see TABLE II.

<table>
<thead>
<tr>
<th>Stage</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting [Hz]</td>
<td>49</td>
<td>48.7</td>
<td>48.4</td>
<td>48.1</td>
<td>48</td>
</tr>
<tr>
<td>Load [%]</td>
<td>16</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Load [MW]</td>
<td>9.6</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

As the sum of the reserve and the shed load is not enough to cover the deficit, the second load is equipped with a local UFLS.

The UFLS schemes proposed in different theoretical publications usually try to optimize the shed load according to power deficiency. Such schemes require measurement of RoCoF and knowledge of the system inertia. But the system inertia can change significantly during system operation and determinations of the power deficiency need not be sufficiently precise and robust. Therefore, another algorithm based on RoCoF measurement only (which does not require the knowledge of the system inertia) was designed. The local UFLS was implemented by an automaton model. The automaton has seven stages with the same RoCoF threshold of -2 Hz/s with staggered delays from 0.05 to 0.7 s and each stage disconnects 10 % of load. The value -2 Hz/s for the RoCoF threshold was chosen according to the report [22] as a value which grid users shall be able to withstand during system disturbance.

Fig. 4 shows frequency deviations and corresponding RoCoF waveforms after the transition to island at t=1s for the first operational state with only one source.
generator from being switched off by the under-frequency protection. After both UFLS operations the frequency recovered near to nominal value. It is important to note that the same local UFLS did not operate during the previous system wide disturbance. It means that the local UFLS is insensitive to system disturbances. Frequency deviations are explained by the difference between generation and consumption. Here it is necessary to specify that the generation means the power of the prime movers (most often the turbines). Consumption is (load and network losses) practically equal to the electrical power of the sources (most often the generators) connected to the grid. We will explain it on the example of our small island in the distribution system. Fig. 5 shows the waveforms of the generator and turbine powers ($P_{\text{EL}}$ and $P_{\text{MECH}}$) and the speed of turbo generator $\omega$.

![Fig. 5 Steam turbine dynamic behavior in the island](image)

A large step change in the generator power after the transition into island at $t=1\text{s}$ can be seen. Turbine power (specifically, the steam turbine is modelled) cannot change immediately and the speed governor increases power in dependency on the speed deviation. The steam turbine is able to increase power quickly even during load shedding process. It is not the case of a water turbine, which first reduces the power in reaction to a speed governor action and the dynamic response is slower - see Fig. 6.

![Fig. 6 Hydro turbine dynamic behavior in the island](image)

Worse dynamic behaviour of the hydro turbine is caused by a water hammer effect. Speed and frequency deviations are then greater. More information about turbine modelling can be found e.g. in [23].

Fig. 7 shows frequency deviations and RoCoF waveforms after the transition to island for the second operational state with two distributed sources – synchronous generator and photovoltaics (PV).

![Fig. 7 Frequency deviation and RoCoF in island with PV](image)

All five stages of the System UFLS was operated in time between 1.8 and 2.15 s together with four stages of the Local UFLS (they operated between 1.6 and 2 s) and they stopped the frequency drop and prevented the synchronous generator from being switched off by the under frequency protection. The photovoltaics source is switched off by the under frequency protection at $t=1.45\text{s}$. The under frequency protection has settings 49.5 Hz with delay 0.1 s. It used to be a common setting for distributed generation before 2010 (see [17] for explanation of this issue).

After both UFLS operations the frequency recovered near to nominal value.

### CONCLUSIONS

The paper introduces two concepts of the under-frequency load shedding (UFLS). The first one is a conventional scheme based on frequency deviation measurement and no intentional delay according to ENTSO-E rules defined in so called emergency and restoration network code. This system UFLS is designed specifically as a solution for system wide disturbances. The second concept is based on the measurement of frequency derivation (RoCoF) with variable intentional time delay. This concept can be used for solution of an island operation on distribution system level as a local UFLS. Simulations on a dynamic model proved that these concepts can coexist and solve frequency stability issues at both transmission and distribution levels.

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REFERENCES


