Simulations of System Wide Disturbances in the Continental Europe Synchronous Area on a Simplified Model

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Abstract—The paper deals with frequency stability simulations for system wide disturbances in MODES network simulator. It describes a simplified model for Continental Europe separation from January, 8, 2021 and incident in Rogowiec substation from May, 17, 2021. It shows that the simplified model is suitable for different disturbances after minor modification. The simplified model is based on publicly available data.

Keywords—system wide disturbance, frequency stability, Continental Europe separation, dynamic simulation

1. INTRODUCTION

The Continental Europe Synchronous Area (CE) consists of 25 countries with 29 Transmission System Operators that are members of ENTSO-E. In addition, the Turkish transmission system is in synchronous parallel operation with CE, but it is not part of ENTSO-E. CE is very interconnected power system and the largest part of ENTSO-E, which leads to highly reliable operation. But even in such a resilient power system, certain aspects need to be evaluated. One of these aspects is frequency stability, which is the ability of the power system to maintain steady frequency after an imbalance between generation and load [1]. Maintaining the steady frequency is important for proper functioning of the power system components, because all devices in the power system are designed for a nominal frequency (50 Hz in this case). It is therefore necessary to assess frequency stability and dynamic simulation is one of the ways how this can be done.

After the occurrence of large active power imbalance in the interconnected power system, it is necessary to contain the emerging frequency deviation. For this purpose, Frequency Containment Process (FCP) is established. In first few seconds after the occurrence of active power imbalance, Frequency Containment Reserves (FCR) are activated on the units involved in the process. The total FCR capacity is determined from the Reference Incident, which is based on the N-2 criterion (outage of the two largest nuclear power units) with a total capacity of 3 000 MW for CE. This capacity must be fully activated for frequency deviation 200 mHz within 30 seconds. For the power deviation less than 1 500 MW, time is 15 seconds, and between 1 500 and 3 000 MW, time rise linearly to 30 seconds [2].

Incidents that exceed the Reference Incident are of interest, because it is not sure whether CE is able to withstand them. Several incidents of this type occurred in 2021. One of them was CE separation on January, 8, when busbar coupler in 400 kV Ernestinovo substation (in Croatia) was tripped by overload protection and it resulted into the separation of CE into two areas, North-West (NW), power deficient, and South-East (SE), power surplus. Power flow between these areas was approximately 5.8 GW before the incident. The disturbance is reported in [3]. Another incident occurred in 400 kV Rogowiec substation (Poland) on May, 17, when human error caused the outage of 10 units of Belchatów Power Plant with a generating capacity of 3 322 MW. The incident is reported in [4].

These incidents also show that it is important to assess frequency stability for different cases, but to do so, a model on which such incidents can be simulated is required. Therefore, this paper focuses specifically on the simulation of these disturbances in the MODES network simulator.

2. DYNAMIC MODEL FOR DISTURBANCES

To assess the frequency stability and behaviour of CE, a simplified model, referred to as SIME (Single Machine Equivalent), is sufficient for a simple analysis. In SIME model, the behaviour of the whole
system is replaced by a single machine – a synchronous machine with a steam turbine, an automatic voltage regulator and a governor. In general, the problem of the models is the estimation of their parameters as relevant data are not always available. The major advantage of SIME is that it is clear, but its disadvantage is that it is not suitable for advanced simulation, e.g., it cannot replicate interarea oscillations. Despite its drawbacks, the SIME model is indeed suitable for simulating the general system behaviour for these cases and is therefore used in this paper.

Single-line diagrams of the grid model for the incident from January, 8 for the NW area and for the incident from May, 17, hereinafter referred to as Rogowiec, are shown in Fig. 1. Units G1 and G3 represent SIME model, G2 represents loss of generation in NW area (import from SE area and outage of units in NW area) and G4 represents outage of 10 units of Belchatów Power Plant. Loads L1 and L3 represent the load on the power system and L2 represents the disconnected industrial loads, which occurred in France and Italy. Loads L1 and L3 are modelled as frequency dependent with an estimated load damping coefficient of 0.6 %/Hz (usually estimated between 1 and 2 %/Hz, but this estimation was modified to obtain better compliance between simulated and measured values).

**Figure 1**: Single-line diagram of the grid model for the NW area (A) and Rogowiec incident (B)

Modelling approach was inspired by [5]. For the equivalent synchronous machine (G1 and G3), 6th order Park machine model was used, and for steam turbine with speed governor, TGOV1 model (described in [7]) was used with zero frictional losses factor. Table I. shows important parameters of the model for NW area and for Rogowiec. Data for NW area model were basically taken from [5] (see [6] for more details). In case of Rogowiec, basic data from [5] was modified and its dynamics are based on models of NW and SE area (see [6]), where reheater time constant $T_3$ of TGOV1 was determined as the parallel sum of those parameters for both areas and the ratio $T_3/T_3$ is the same as in the NW area. Turbine-governor droop $R$ and inertia constant of synchronous machine is considered the same as in the NW area. The load of power system was determined from Transparency Platform [8] and rated power of the synchronous machine corresponds to approximately 70 % of the system load.

**Table I**: Parameters of the models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>NW</th>
<th>Rogowiec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>GVA</td>
<td>434</td>
<td>415.6</td>
</tr>
<tr>
<td>Max. turbine output</td>
<td>GW</td>
<td>412</td>
<td>394.7</td>
</tr>
<tr>
<td>Rated power factor</td>
<td>(-)</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Active power</td>
<td>GW</td>
<td>310.7</td>
<td>280</td>
</tr>
<tr>
<td>Inertia constant ($2H$)</td>
<td>s</td>
<td>14.8</td>
<td>14.8</td>
</tr>
<tr>
<td>Turbine-governor droop ($R$)*</td>
<td>(-)</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Reheater time constant ($T_3$) *</td>
<td>s</td>
<td>10.8</td>
<td>5.246</td>
</tr>
<tr>
<td>Ratio $T_3/T_3$ *</td>
<td>(-)</td>
<td>0.14</td>
<td>0.14</td>
</tr>
</tbody>
</table>

* MODES uses the constant $K_{P2}$, $T_R$, $K_{LP}$ and $K_{HP}$, where $K_{P2}=1/R$, $T_R=T_3$, $K_{HP}=T_2/T_3$ and $K_{LP}=1-K_{HP}$
3. SIMULATIONS AND RESULTS

Incidents were simulated in MODES on the dynamic models presented above. The simulation scenario for both system disturbances is similar and simplified (compared to the real disturbances). Disturbances are applied at time 1 second, after reaching the steady-state. In case of NW area, it is the outage of 6 300 MW of generation (G2 in Fig. 1) and 1 700 MW of consumption (L2 in Fig. 1). In case of Rogowice, it is the outage of 3 322 MW of generation (G4 in Fig. 1). The assessed variable was the frequency deviation waveform.

The simulation results are shown in Fig. 2, which shows the frequency deviation for both system disturbances, they are plotted together with measured data from the real CE power system. There are also added simulation results for NW taken from [5], which were, however, simulated on advanced grid model, not only on a SIME equivalent as presented in this paper.

![Figure 2: Frequency deviation in NW area (A) and in CE for Rogowice substation incident (B)](image)

Based on the results, it can be concluded that the dynamic model represents the behaviour of the power system very well. Simulation of CE separation of NW area shows the dynamic model has almost identical results as in [5], and therefore the model can be considered as validated with respect to the system behaviour as well. Further, the results show that after modification, the dynamic model can also be used to simulate other incidents, an example is the presented Rogowice incident, where the results obtained from simulation clearly correspond to the real system behaviour. Curves obtained from simulation are smoother because, as was explained, interarea oscillations present in measured data are not replicable on the simplified model and further regulation processes latter following the disturbance were not considered in the scenario.

4. CONCLUSION

This paper describes the basic behaviour of the interconnected power system of CE after the occurrence of active power imbalance and focuses on 2 system disturbances, which were the object of simulations – CE separation from January, 8, 2021, and Belchatów Power Plant outage due to failure in Rogowice substation from May, 17, 2021. The Single Machine Equivalent models for both disturbances were described and simulations of these events were done on them using MODES network simulator. Simulation results show good compliance between the model and the real system behaviour, indicating that the model can be further used for other system disturbances or for assessments of fictitious scenarios. It is worth mentioning that the models were created from publicly available data compared to the other published models (e.g. [5]).

This model is currently being extended to a single-bus model, in which aggregated units are modelled based on the power source (gas units, photovoltaics and so on) and HVDC interconnections between synchronous zones. The model is being prepared for the CE separation on January, 8, 2021, and it is expected to be suitable for other disturbances that are less severe than this one, or, eventually, to be extended for more severe disturbances.
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