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Effect of Intermittent Power Supply on the German Power System

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Abstract—

It is expected that the operating modes of thermal generating units in Germany will be significantly impacted until at least 2020 as a result of the continued rapid growth of the intermittent power supply capabilities of wind turbines and solar systems. The current power system has a significant problem in attempting to accommodate this rising proportion of intermittent generation while keeping the same degree of supply security in place. The main issues stem from the fact that the intermittent generation does not always correspond with the power demand and is often situated distant from the load centres. Because of this, there are logistical constraints on how intermittent generation may be integrated into the current power grid. Therefore, it must be pointed out that certain traditional power plant generators with masses may be turned off and replaced by the intermittent generators, resulting in a reduction of the acceleration time constant while maintaining the same total nominal power value for the whole system. However, when traditional power plants are shut down, the acceleration power they provide by means of their turbine-generator-systems disappears due to a loss of inertia. As inertia is diminished, not only will frequency deviation following shocks get larger, but the system will also become more prone to oscillation, which will ultimately weaken its stability. To determine whether the system is stable or unstable, we will examine several scenarios including Renewable Energy Sources (RES) and demonstrate how to use simulation tools to schedule power plants.

Key words

The terms "wind," "photovoltaic," "inertia," "oscillation," "stability," "primary control," and "Eigenvalues"

Indrodution In theory, renewable energy sources (RES) have the capacity to provide much more energy than is now needed throughout the globe. Sustainably sourced energy services may be provided by renewable energy sources including biomass, wind, sun, hydropower, and geothermal, all of which make use of locally abundant and naturally occurring resources. Costs for solar and wind power systems have declined significantly over the last 30 years, and they are expected to continue falling [1, 2], making a switch to renewable energy sources more possible. In reality, the prices of fossil fuels and renewable energy sources, together with the associated social and environmental consequences, are moving in different directions. In addition, there has been significant development in the economic and regulatory processes essential to ensuring the continued proliferation of renewable energy systems and the creation of stable markets for them. It is becoming more apparent that the future of the energy industry lies not in traditional oil and coal sources, but in the new regime of renewable, and to some degree natural gas-based systems. The economic reality of genuinely competitive renewable energy

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systems [3] is likely to be foretold by the financial markets' recognition of the future growth potential of renewable and other new energy technologies. Roughly 15% - 20% of the world's energy demand is met by RES at now. Several scenario analyses have looked at the possible role of renewables in global energy supply, with promising results: with the proper policies in place, their share might rise from the current level of roughly 20% to more than 50% in the second half of the 21st century. Conditions in Europe vary from one nation to the next. The situation might vary depending on whether the systems are synchronised in terconnected or island systems. National circumstances determine both capacity goals and the RES portfolio of the future. However, wind power has the most room to expand. Forecasts from the European Wind Energy Association indicate a rise from

28.5 GW in 2003 to 180 GW in 2020 [4].

PROGRESS MADE IN GERMANY TOWARDS INDEPENDENTLY-OPERATED ENERGY CENTERS

The ever-increasing impact of intermittent renewable energy sources will have significant effects on Germany's current electricity generating system. Wind power (WP) has risen to prominence as the most significant renewable energy source in Germany [5] because to the rapid growth in the overall number of wind turbines, notably in the northern region of the country, during the last several years. Table 1 displays the growth in Germany's renewable energy capacity from 1990; at the end of 2012, the country had more than 31.315 GW of wind turbines installed. And the growth of photovoltaic (PV) capabilities is so rapid that by the end of 2012, more than 32.643 GW of PV capacity had been deployed. When compared to 2009, the solar industry had a rise of almost 209% [6]. Current predictions yield to about 50 GW of installed capacity for photovol taic systems and more than 51 GW of installed capacity for wind turbines in 2020, despite a gradual reduction in feed-in tariffs for the electrical energy produced by photovoltaic systems and wind turbines in Germany within the next 10 years. Consequently, by the end of the decade, Germany will have likely built more than 100 GW of wind and solar power generating. It is possible, therefore, that by 2020, these two renewable energy sources would account for more than 35% of Germany's total net electrical energy consumption, up from 12.6% in 2012.

TABLE 1 INSTALLED CAPACITY FOR RES IN GERMANY SINCE 1990

	Hydropower MW	Wind Energy MW	Bio-mass MW	Photo-voltaic MW	Geo-thermal MW	Total Power GW
1990	3429	55	584	1	0	4.069
1991	3394	106	595	2	0	4.097
1992	355	174	604	3	0	4.331
1993	3509	326	643	5	0	4.483
1994	3563	618	677	6	0	4.864
1995	3595	1121	740	8	0	5.464
1996	3510	1549	804	11	0	5.874
1997	3525	2089	845	18	0	6.477
1998	3601	2877	972	23	0	7.473
1999	3523	4435	1022	32	0	9.012
2000	3538	6097	1164	76	0	10.875
2001	3538	8750	1282	186	0	13.756
2002	3785	11989	1417	296	0	17.487
2003	3934	14604	1884	435	0	20.857
2004	3819	16623	2527	1105	0.2	24.074
2005	4115	18390	3561	2056	0.2	28.122
2006	4083	20579	4322	2899	0.2	31.883
2007	4169	22194	4943	4170	3.2	35.479
2008	4138	23826	5510	6120	3.2	39.597
2009	4151	25703	6156	10566	7.5	46.584
2010	4395	27191	6594	17554	7.5	55.742
2011	4401	29071	7324	25039	7.5	65.843
2012	4400	31315	7647	32643	12.1	76017

0 shows the expected growth of installed capacities of wind turbines (on and offshore) and photovoltaic systems in Germany; at the end of 2020, the installed capacity of wind turbines and photovoltaic systems amounted to more than 51 GW and 51.7 GW respectively

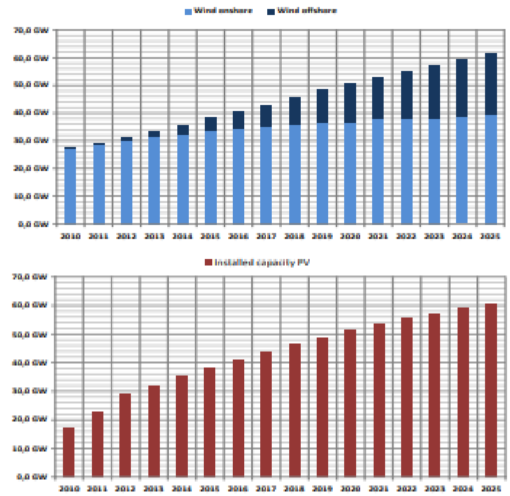

Fig. 1. Expected growth of installed capacities of WP and PV in Germany

CHALLENGES ON POWER BALANCE AND FREQUENCY CONTROL

Power generation and consumption within the model are shown in a simplified form at. This balancing equation relies heavily on the residual load in each time step that must be met by the dispatchable power production. The residual load at any given moment is determined by subtracting the total power used by customers from the total power generated by non-dispatchable generators (WP, PV). The residual load is positive as long as the non-dispatchable production is less than the used electricity. In the present day, this is typically the situation all the time due to the fact that the installed capacities and, by extension, the maximum concurrently generated power from various sources, are less than the network demand. The dispatchable generation, which includes fossil and nuclear facilities as well as pumped storage power stations, is responsible for meeting the re sidual demand. As a result, the dispatchable generation is adjusting the features of consumer demand in addition to the intermittent power production. Future heavy capacity increases, notably for wind turbines and solar systems, will cause the residual load to reach negative values over a number of time periods throughout the year. If the weather is favourable, a single nation may be able to generate more electricity than it needs. Only if the dispatchable generation becomes negative does the power balance improve, which indicates that the storage capabilities will be in use. However, future demands are likely to exceed current storage capacity. For this reason, in the future, if there are not enough transmission line capabilities available to convey the electricity to other areas, surplus power generated by renewable sources will have to be limited to retain the system stability.

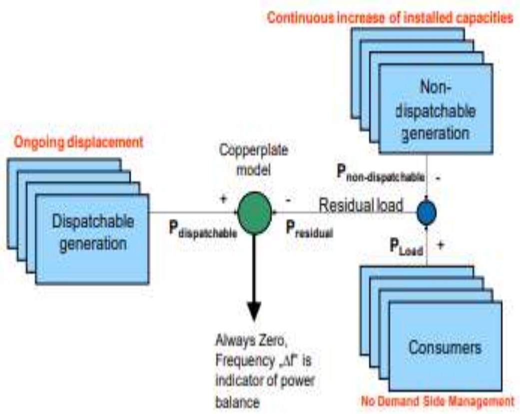

Fig. 2. A simplified scheme of the power balance of the generation system

DETAILED OVERVIEW OF THE POWER BALANCE OF GERMAN POWER SYSTEM

detailed non-linear dynamic model of the German power system was developed and 0 shows the overview of the power

balance of German system with all power plants (nuclear power plants (NPP), old and new lignite power plants, old and new hard coal power plants, gas power plants (GPP), old and new combined cycle power plants (CCPP), hydropower Plants (HPP), combined heat and power (CHP)…etc.). The conventional power plants (e.g. thermal, gas, nuclear and hydropower plants…etc.) have different transfer functions between frequency and mechanical output power of the turbines. All power plants with their primary controllers and loads of German power system are modelled completely in detail. The resulting frequency deviation depends on the power difference, load-damping constant D and the inertia constant (TN=2*HN). Where HN is the inertia constant of the system in seconds and TN is the acceleration time constant of the total network in seconds.

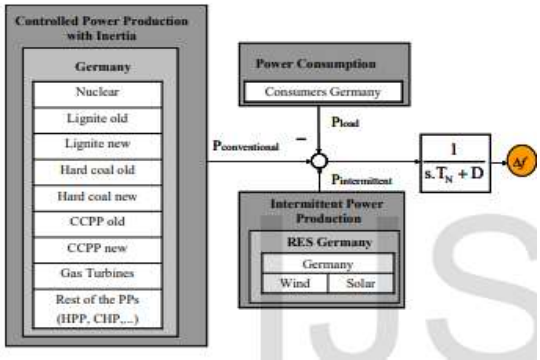

Fig. 3. Overview of the power balance of German power system

Any model consists of separate models for power controller, governor and turbine regulator as shown in 0. Where Psetpoint is the power setpoint, Δf is the frequency deviation, Ytref is the set point position governor guide vane, Yt is the position governor guide vane and Pm is the mechanical power.

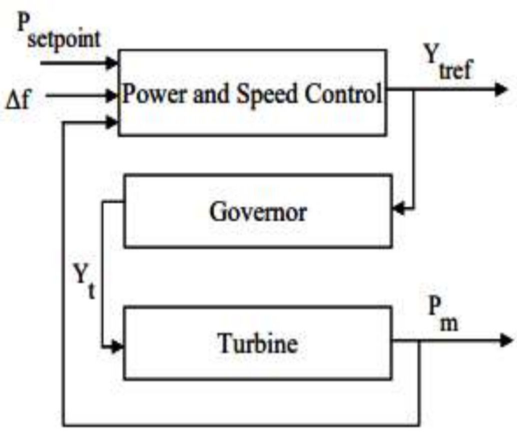

Fig. 4. General representation of sub-models

TN is calculated by the inertia of the generators and motors, commonly states how much time it takes from standstill to accelerate an inertia that is driven by its nominal torque or power until the nominal rotational speed is reached. Within the electrical energy system the inertia is of vital importance, since only the inertia is able to stabilize the network frequency at an acceptable value in the first moment after a disturbance of the power balance. Normally wind turbines are connected to the system via frequency inverters and photovoltaic systems are always connected via DC/AC converters, so they are mechanically and electrically decoupled from the system and cannot increase the acceleration time constant. Therefore, it has to be lined out that the acceleration time constant is reduced, if more renewable energy sources (WP and PV) are connected to the system when at the same time the number of conventional power plant generators with masses are displaced by these intermittent generators as shown in the 0 while the total nominal power value of the whole system remains constant.

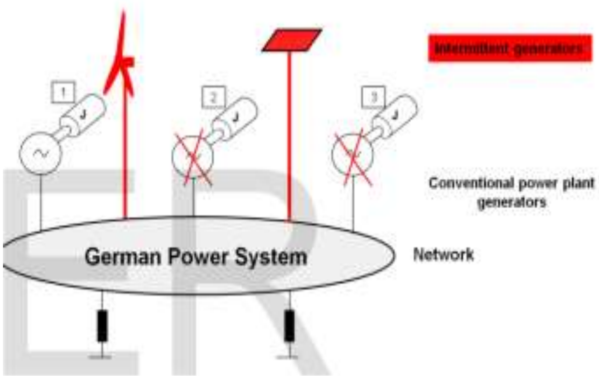

Fig. 5. German Power System

The acceleration time constant can be calculated by equation (1) [8]

$$T_N = \frac{\sum_{i=1}^{n} T_{G_i} . P_{G_i}}{\sum_{i=1}^{n} P_{G_i} + P_{RES}} \text{ and } T_{G_i} = \frac{J . \Omega_N^2}{P_{G_i}} \quad (1)$$

Where TGi is the acceleration time constant for individual units in seconds, PGi is the rated power of an individual Generator in MW, PREF is the intermittent rated power in MW, J is the moment of inertia of the rotor mass in kg-m2 and ΩN is the angular velocity of the mass J in radians per second. From the moment that a load imbalance is produced in the network to the moment where the grid frequency is fully stabilized, several mechanisms take place in the power system during different stages (but in this paper we took only the first two stages), which depend on the duration of the dynamics involved as shown in 0. These stages are: 1. Distribution of power impact and inertial response. 2. Primary frequency control or governor response starts within seconds. 3. Secondary frequency control replaces primary control after minutes by the responsible partner. 4. Tertiary control frees secondary control by re

scheduling generation by the responsible partner

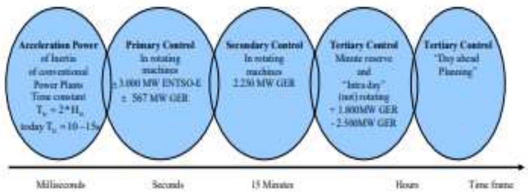

Fig. 6. Control scheme of electrical power systems

ANALYSIS OF DIFFERENT SCENARIOS FOR GERMAN SYSTEM

0 shows the description of the different scenarios for the German system when increasing the intermittent renewable energy in operation (wind and photovoltaic) for the second and third scenarios to 50% and 81% respectively compared to the first scenario with no intermittent renewable energy in operation (0% wind and photovoltaic).

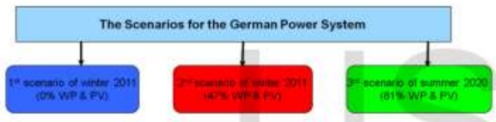

Fig. 7. The description of the different scenarios for the German power system

First Scenario of Winter 2011 (0% WP and PV) 0 shows the first scenario of winter 2011 with no intermittent renewable energy in operation (0% wind and photovoltaic). The power plants in operation are hard coal power plants, lignite power plants, gas power plants (GPPs) and combined cycle gas power plants (CCGPPs). Power plants which are in operation but do not contribute to the primary control are hydropower plants (HPPs), combined heat and power plants (CHP) and nuclear power plants (NNPs).

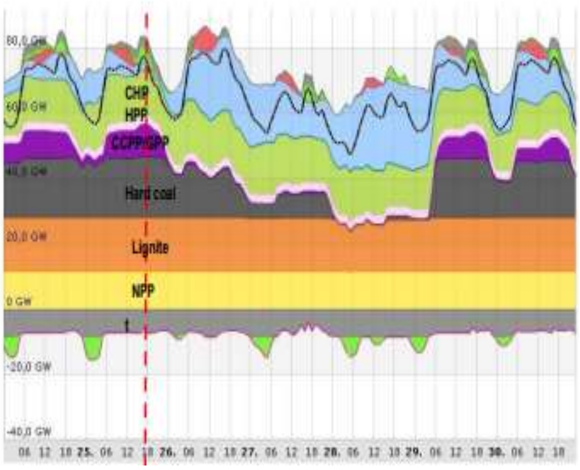

Fig. 8. First scenario of winter 2011

The total amount of the primary control reserve in German system is 700 MW. 0 shows that the contribution of the primary control reserve in the first scenario of winter 2011 is 25% allocated to hard coal power plants, 25% allocated to lignite power plants, 25% allocated to gas power plants and 25% allocated to combined cycle gas power plants.

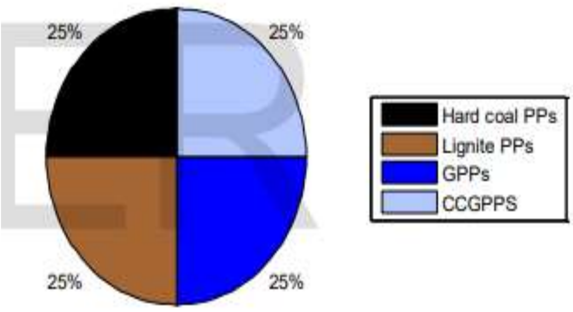

Fig. 9. Contribution of the primary control reserve in the first scenario

SIMULATION RESULTS

The simulation results have been performed for three scenarios as explained before. After 5 seconds 700 MW generation loss in German power system, 0 shows the frequency response and turbine power for the first scenario (blue line), second scenario (red line) and the third scenario (green line). Due to switching off power plants and replacement by RES to increase to 50% and 81% in German system, the existing inertia mass in the grid decreases and deeper frequency deviation (nadir) with more oscillation occurs and shorter oscillation period. With shorter oscillation period, the phase shift between input frequency deviation and output power deviation produce greater delay as shown in 0 (< φφ 23). As results, for the first scenario with no intermittent renewable energy in operation, TN is calculated to 9.9s and the frequency deviation will reach -290 mHz. For the second scenario, the intermittent renewable energy is increased to 50%, the existing inertia massin the grid will decrease, TN is decreased to 5s and the freequench deviation will reach -550 MHz with some oscillation occurs. For the third scenario, the intermittent renewable enderg is increased to 81%, the existing inertia mass in the grid is decreased more and TN is decreased to 2s and the frequency deviation is decreased to less than -800 MHz with more sociallotion occurs. Therefore, some protection devices will operate and switch off some consumers/customers.

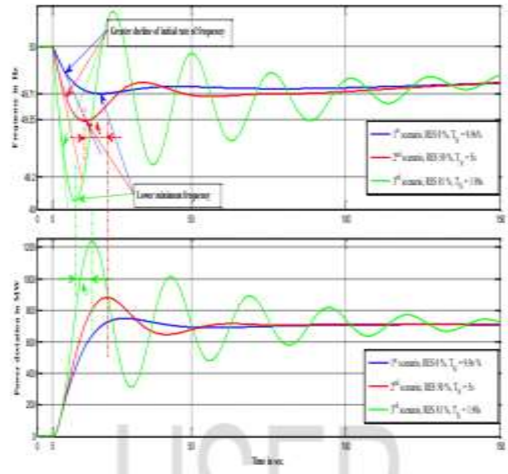

Fig .10. Comparison of all scenarios for frequency and turbine power deviation

Finally, we may infer that a decrease in the inertia of the grid will occur as a consequence of the increasing share of renewable energy sources in the overall energy mix. The first drop in frequency will become more apparent. Larger and more rapid frequency deviations will follow the occurrence of sudden fluctuations in generation and load if the system has lower inertia.

CONCLUSION

Several scenarios of intermittent generation were used to demonstrate the methodologies and tools given for simulating the scheduling of power plants. Reducing the number of conventional power plants at certain times will shorten the system's inertia time constant. This change will have a significant impact on the "Primary Control Oscillation" oscillation frequency and the frequency deviation following disturbances. The frequency of oscillation in Germany will rise from 24 MHz to 43 MHz, and the deviation following a 700 MW-disturbance will increase from 390 MHz to 900 MHz Since a consequence, the electrical grid is severely impacted, as customers and coupling lines might be simultaneously tripped, leading to system islanding. However, the lifespan of the associated power plants will decrease as the principal control oscillation frequency increases. Finally, we conclude that a critical mass of conventional generating capacity must always be present in the system to ensure its reliability.

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