DISTURBANCES AND BLACKOUTS – LESSONS LEARNED TO MASTER THE ENERGY TURNAROUND

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Abstract

The "Energy Turnaround" is not a vision anymore - it is reality. With an analysis of blackouts and important disturbances in Europe since 2003 this paper describes the sequence of events and challenges restoring the grid. Since in most of the disturbances described renewables have been involved the paper describes concrete problems and impacts on protection and control.
After every blackout rules, transmission and distribution codes as well as national regulations have been adapted- sometimes causing new challenges and problems.
The paper sharpens the picture and shows concrete measures how to enhance the reliability of the grid penetrated more and more with distributed energy resources.
This publication does not just cover huge blackouts but also experiences in utilities and with system integrators.
The authors collected a huge amount of information and collect them in this paper to initiate and strengthen the discussion.
An outlook summarizing disturbance statistics is finalizing this paper.

1 Example Germany

This paper describes examples from all over Europe but is also focusing on some developments in Germany. Germany is one of the main drivers, especially after the decision to shut down nuclear power stations in March 2011 until the end of 2022 [1]. Already now the amount of energy from renewables is high- e.g. 67% of entire load on 3rd of October in 2013 [2].

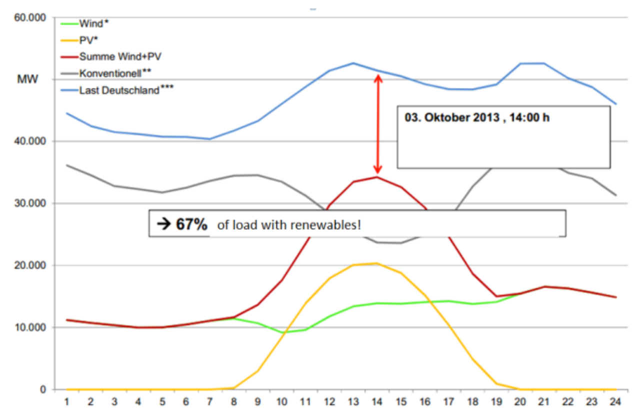

Fig. 1 Amount of renewables on 3rd of October 2013 [2]

2 The Year of Blackouts- 2003

In summer 2003 several blackouts occurred around the world

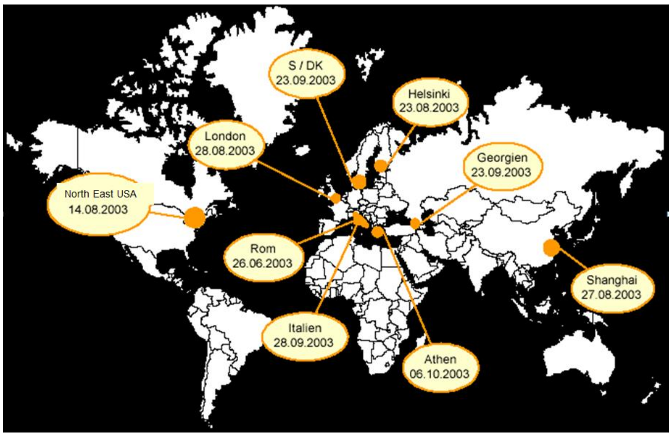

Fig. 2 Blackouts in summer 2003 [3]

Checking Fig. 2 it looks like a spiral coming closer to central Europe. The blackout in the US and in London became important events. It should take 3 years when it really reached Germany....on 4th of November in 2006. But this should be described later. Even some of the blackouts occurred are related to the "energy turnaround" and should be described more detailed.

3 Disturbances Caused by Energy Turnaround ("Energiewende")

3.1 Introduction

The term "energy turnaround" became very popular after the decision of the German government influenced by the Fukushima accident on 11th of March in 2011. The term in German language is "Energiewende".

3.2 Italian Blackout 2003

Already one of the 2003-blackouts was influenced by a change in energy- the Italian (2003-09-28, Fig. 3 [4]).

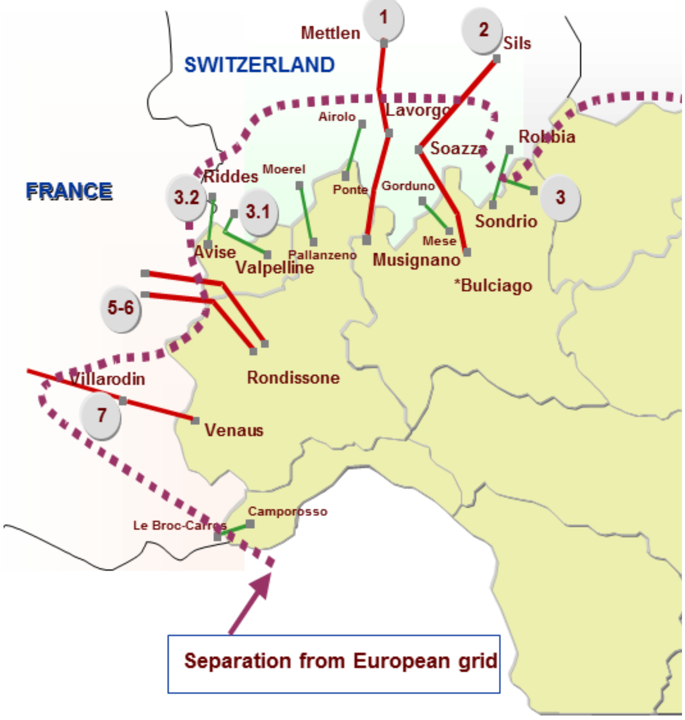

Fig. 3 Italy 2003-09-28 [4]

The initial situation was a high load in the network at night (28 GW, 6.5 GW have been imported from Switzerland) and a limited reserve. At 3:01 a.m. a 380-kV-high-load line touched a tree and tripped, no reclosing possible.
24 minutes later 2 overloaded 380-kV-lines tripped as well. The stability limit of the UCTE grid was reached.
Even with massive load shedding the frequency continued to decrease [4] because of further trips of frequency relays and loss of excitation.

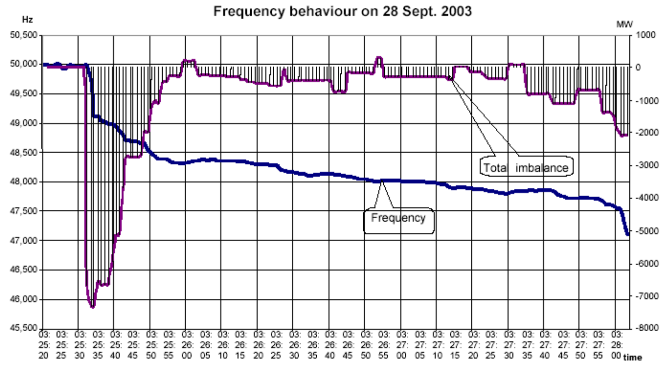

Fig. 4 Frequency Italy 2003-09-28 [4]

After 2.5 minutes the grid collapsed. 50 Mio people have been without power – 28 GW. It took almost 20 hours to restore the grid.
The reasons collected are as follows [4]:

- Overload
- Not possible to handle n-1 event
- No stability reserve
- Structure of Italian grid with long lines caused stability problems
- Too late communication between operators in Switzerland
- ....

Nevertheless as one of the main reasons the shutdown of 3 nuclear power stations and the resulting lack of reserve was described.
As a result UCTE reviewed the rules and guidelines [4], one of the 380-kV-lines (Luckmanier) in Switzerland was equipped with monitoring equipment to increase possible load [5].

3.3 Loss of Generation Wind 2004-01-29

A 3-phase line fault happened in the German region Oldenburg. The voltage collapsed. At this time 1.1 GW wind power have been switched off immediately according to utilities requirements at this time. [6]
As a result the grid codes have been adapted.

3.4 Disturbance in Switzerland 2006 –Huge Amount of Data [7]

At the Swiss Rail (SBB) on 2006-05-22 2 of 3 lines have been out of service for maintenance. The 3rd line tripped.[7]
18 000 messages reached the control center within 1 hour. 3400 of them had been critical but at least 4 messages have been important to avoid the disturbance.
Lessons learned:

- Measures to handle messages necessary
- Filters necessary

Missing reactive Power in Poland 2006 [8] In case of significantly high demand in summer, during long high-temperature period, Polish system has too small margin for secure operation and so it crashed on 2006-06-26.
Very often only active power is paid for. On 2006-06-26 in Poland the systems crashed because also of a lack of reactive power. So the required margin can and should be restored through eliminating local reactive power deficits by installation of reactive power sources. Till the margin is restored the voltages and reactive power balances has to be monitored and proper actions undertook as

- Required reactive power reserve has to be kept even at the cost of lowering active power output (TSO)
- Higher reactive demand has to be immediately compensated (DSO)
- TSO should be informed about generated units states
- Temporary blocking of automatic transformer tap changer control was introduced

Some TSOs considered especially the last hint, but not all.

3.5 UCTE Disturbance 2006-11-04

The base for this event was a scheduled opening of a line to allow the move of a ship
An n-1 calculation for this event was done when the request was received in October 2006 but not directly before the operation.
So the line 380-kV-line Diele-Conneforde was switched off and the load shifted as expected. 25 minutes later the load increased unexpected (100 MW) and additional measures have been necessary (Fig. 5).

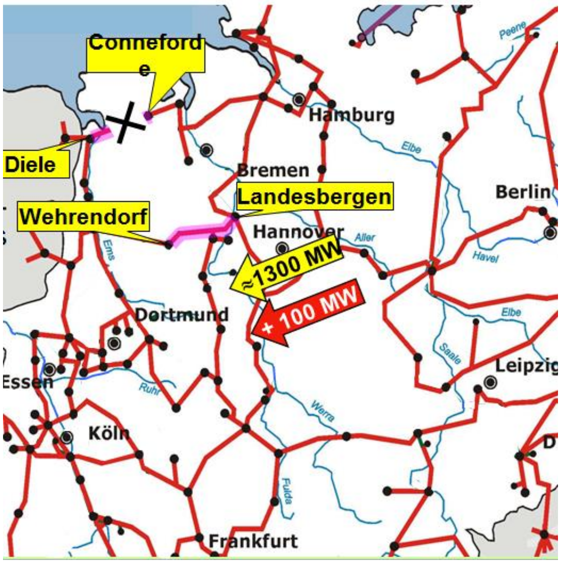

Fig. 5 Disturbance 2006-11-04 [9]

The coupling in Landesbergen was closed to decrease load. But the load increased further and so the lines Landesbergen-Wehrendorf and Bechterdissen-Elsen as well as Dipperz-Großkrotzenburg tripped within some seconds.
This caused a domino effect –like a zip from Germany to Austria (Fig. 6).

Fig. 6 Trips following [10]

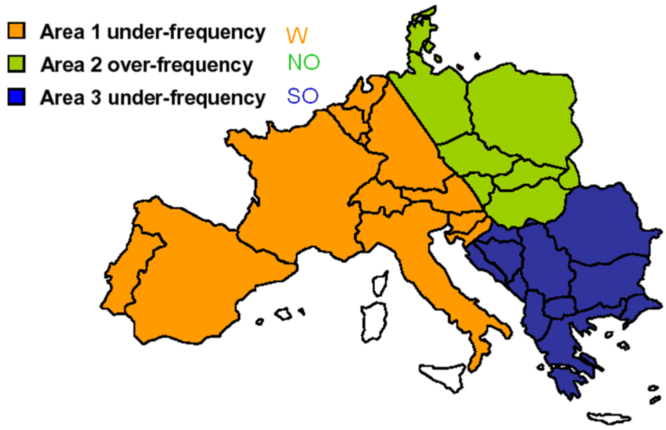

Fig. 7 Zones [9]

Finally the European grid was divided in three zones.
At first wind resources have been identified at reason but this could not be confirmed. In the north-east grid 3 GW wind have been taking from the grid. This was good because of overfrequency, nevertheless after 20 minutes the wind farms resynchronized what was too early.

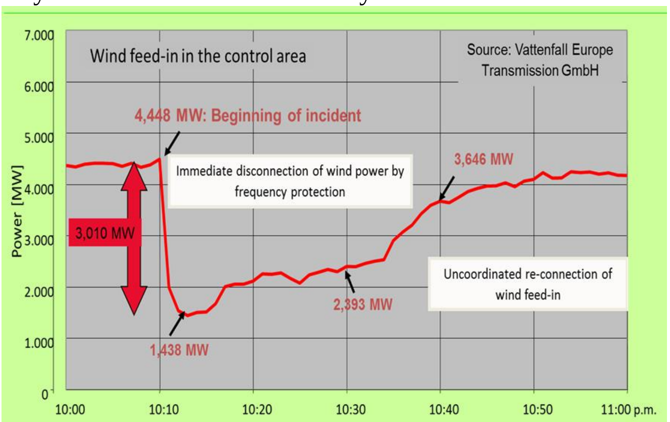

Fig. 8 Wind feed-in [10]

From the author's perspective one of the main reasons was a different protection setting in the substations Landesbergen and Wehrendorf (different utilities). In addition the distance protection used is not proper overload detection.
Lessons learned:

- Need for better energy forecast
- Additional guidelines for TSOs and DSOs needed
- Usage of WAMS would help
- Load shedding with direction of power detection
- Check of frequency in case of switching on distributed energy resources
- Q-U-protection
- Monitoring of lines

3.6 What can be wrong

When wind farms are connected to the grid this is very often done at a later stage. Fig. 9 shows an example from Germany.

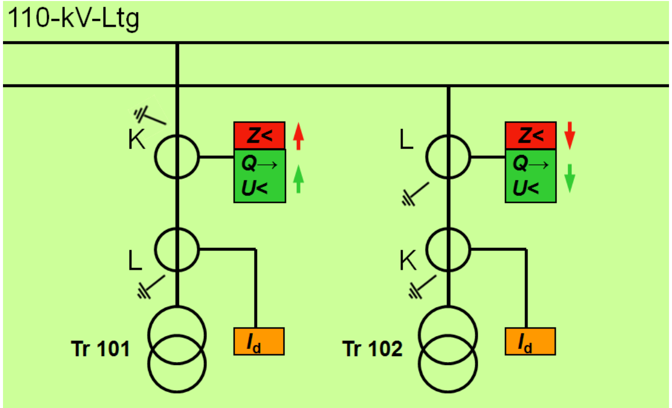

Fig. 9 Extension for wind

Everything what could be wrong was wrong- different earthing of CTs, wrong direction of protection etc. This example shows the need for testing- especially primary testing.

3.7 Generally recognized codes of practice are valid

Relaxation oscillations caused the disturbance shown in Fig. 10.

Fig. 10 Burning VT in Germany

The damping resistance (Fig. 11) was mounted in the wrong manner- the codes of practice have not been considered.

Fig. 11 Damping Resistance

3.8 DER stabilizes the grid

Fig. 12 Damaged tower

Fig. 12 shows one of 5 towers damaged by whirlwind in Germany in 2012. The connected medium voltage grid shows almost no reaction – because of the huge amount of connected wind farms (Fig. 13).

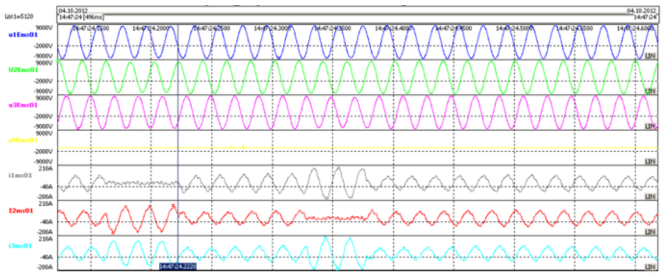

Fig. 13 Medium voltage grid connected

3.9 Fault clearance [12]

Fig. 14 shows a disturbance in Germany's 380 kV grid (fault L1-L2 without earth connection, January 2012). The fault was clarified within 70 ms what means compliance to transmission codes. Shunt conductors have been in operation because of huge amount of wind power and low voltage. Even during the short loss of voltage several distributed energy resources have been disconnected. The loss of wind energy released the northern grid. The voltage in the connected 380-, 220- and 110-kV grid increased by 8% -this caused further shutting downs of wind miles.
Switching on of shunt conductors could move the voltage back to band (Fig. 15).
Lessons learned:

- Need to verify why wind farms do disconnect
- Investigate if this happened because of voltage drop or overvoltage.
- Refurbish existing wind farms with equipment according to new rules ("SDLWindV")
- Checking protection setting
- Installation of PQ-devices and fault recorders at important points of common coupling

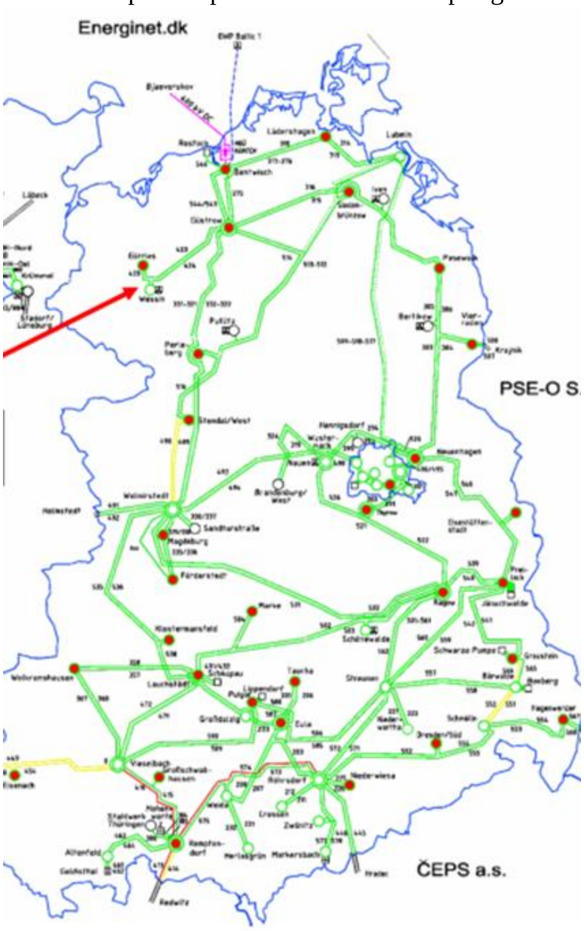

Fig. 14 Disturbance

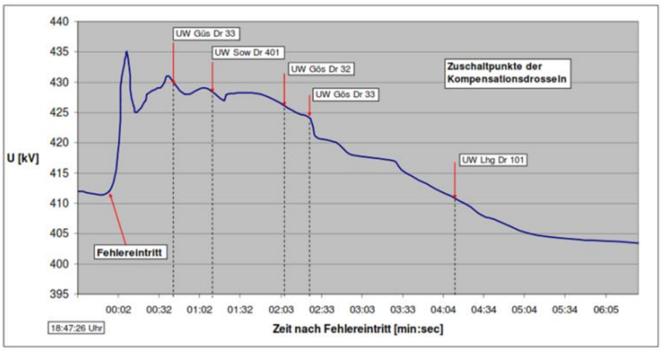

Fig. 15 Voltage increase

3.10 Re-dispatch

In general we observe much more re-dispatches in the grids. What was an exception in the past (2 per year in 2003) became normality (1024 events per year demanding further actions in 2011) [13]

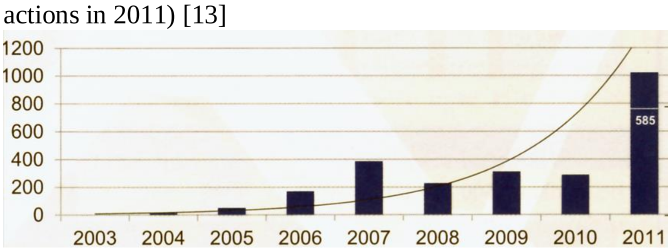

Fig. 16 Number of re-dispatches [13]

This has an impact on n-1 safety.

3.11 Examples for planning errors

In general we observe a decreasing quality of planning work done. The interest for technical background is sometimes missing For instance there was a protection device, just connected to 230-VAC-power. Asking why this was done-because it is written in protection device's datasheet that this is possible.

3.12 Problems in UCTE grid

The huge amount of renewables in some countries changes the European load flow [14].

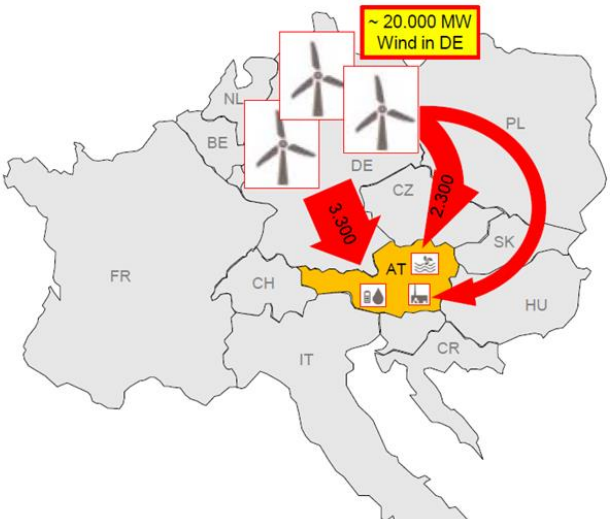

Fig. 17 Load flow [14]

This has an impact on stability in other grids- so for instance the Czech TSO claimed huge problems with this huge amount of power [15].

3.13 Blackout because of huge amount of data?

Even "just data" can be a risk for grid's stability. In Austria a huge amount of broadcasts between controllers have been sent out again as broadcasts and blocked the communication infrastructure on 2013-05-13. Several power plants and substations had to be manned to observe and control them [16].

4 Précis and Outlook

This paper showed disturbances in several countries and risks observed. The European grid is extremely stable but the risks and dangers peril this level. It is challenging task but worth to take care about it.

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