Dynamic Simulation and Analysis of the impact of a planned Windfarm on an Isolated Grid

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***Abstract*—A core task for all hybrid power system development projects is to reduce the consumption of fossil energy resources. To achieve this target a high renewable energy penetration is desirable. An analysis of the available renewable resources is usually the first step in a planning process for such systems. Initial feasibility studies and cost analysis show the profitability of the planned system from a cost and energy perspective. After these initial steps, an analysis of the impact of the renewable devices on the grid is necessary. Due to the highly nonlinear nature of such systems it is not possible to make system independent assumptions about the expected system behavior. Therefore each system behaves different and has to be analyzed for its stability individually.**

This paper shows such a study. A dynamic model of an isolated grid is set up using PowerFactory to investigate the impact of a windfarm extension to the generation. The characteristics and topology of the isolated power system will be used for the analysis of the grid impact. Step load testing on the generators was done prior to the simulation to verify the generator models. Long term wind mast measurements were the base for the simulated wind profile. The model results are compared to measurements from site after commissioning the wind turbines.

The purpose of this paper is to show approaches for modeling an isolated power system with the integration of renewable devices. It shows the importance of model verification and the consequences of making wrong assumptions during the simulation process.

***Index Terms*—Windfarm, Power System Modeling, Verification, Generator Testing**

I. INTRODUCTION

A grid connection study for an isolated power system was undertaken prior to the installation of wind turbines on an island. The electrical grid of the island consists of a diesel power station, the windfarm and the connection to the domestic loads via overhead lines. Figure 1 gives an overview of the island system. The purpose of the grid connection study was to analyze the frequency variation and system stability with the inclusion of the wind turbines to the existing power system. The simulation tool for this study was the PowerFactory stability package.

The wind speed was measured on a wind tower at the planned windfarm location for one year. With this data the mean wind speed was calculated, while the turbulence was determined by a meteorological service provider. The wind profile was modelled with a stochastic approach according to mean wind speed and turbulence. To simulate the worst case scenario no wind park spatial dispersion factor was used.

The generator controller models were tuned according to step load tests conducted on site prior to the study. The tuned and verified models were then embedded into the grid model. A verified model of the wind turbine was used. The grid connection study showed the variation of the system frequency due to the impact of the windfarm.

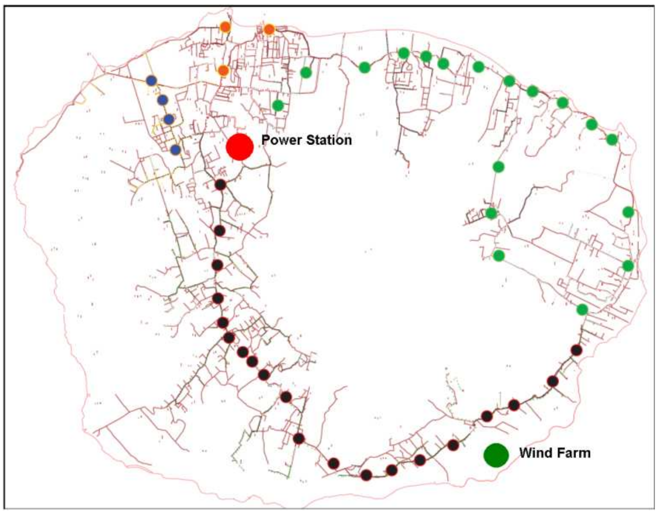

Figure 1: Power system overview

After commissioning all wind turbines, measurements of the real system were recorded. Two high resolution data recorders were connected to the generator terminals and a power quality meter was connected to the windfarm substation.

In this document the simulation model in PowerFactory will be described and methodologies of model verification will be introduced. Measurements of the real system will be compared to the simulated results of the study. To highlight some of the problems inherent in the modelling process the simulation model in different development stages will be compared to the real data.

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II. Theoretical Description

A. *Load Flow Grid Model*

The actual grid model in PowerFactory was constructed according to Figure 1; there are no other renewable energy sources or storage devices. The power station consists of 6 diesel generators with a rated power range from 0.9MW to 2.7MW. Parameters of the generator models were extracted from data sheets. Typical parameters of devices with the same size were used for unavailable parameters on the data sheets. The power station connects to five feeders where one feeder connects the windfarm.

For the transient grid connection study only one generator was equipped with dynamic controllers as it is online most of the time and operates in droop. The other generators were not equipped with dynamic controllers because they operate in power set point mode.

The windfarm model is shown in Figure 2. The 415V induction generators connect to the main grid via step-up transformers. Reactive power is compensated by static capacitors. A dynamic wind turbine model determines the torque of the generator and therefore the output power. The windfarm is connected to the main overhead line and hence to the power station.

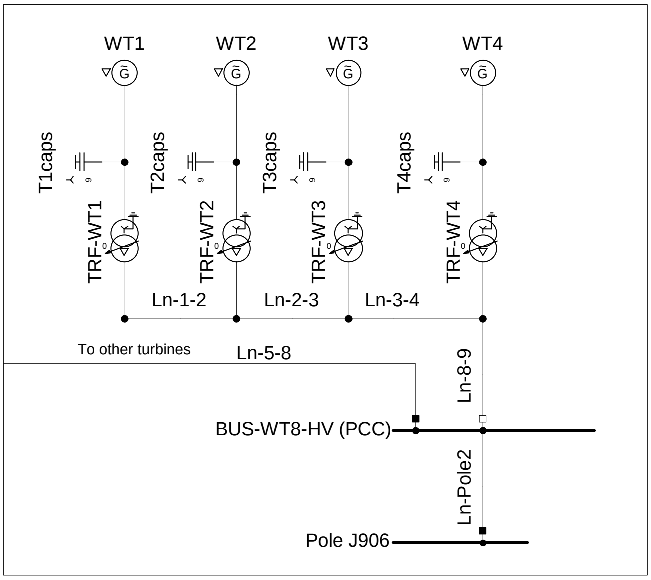

Figure 2: Windfarm model in PowerFactory

To verify the functionality of the grid model and the correct sizing of devices a load flow study was conducted. This showed voltage levels at various points in the grid and at the point of common coupling (PCC) of the windfarm. A flicker and protection study gained more information about the system and system security.

B. *Transient Dynamic Models*

In transient simulations the generation devices need to be controlled to maintain system operation and stability. In isolated systems the variables of interest are the system voltage as well as the frequency. The considered wind turbines do not have sophisticated voltage and frequency controllers and therefore can be treated as a disturbance to the system. The diesel generators have to compensate for the unavoidable fluctuations of the load as well as the fluctuations in the wind power.

For the generator controllers a generic model approach was considered; see Figure 3. This approach seems to be adequate as the generators of the system are fairly old, and thus basic.

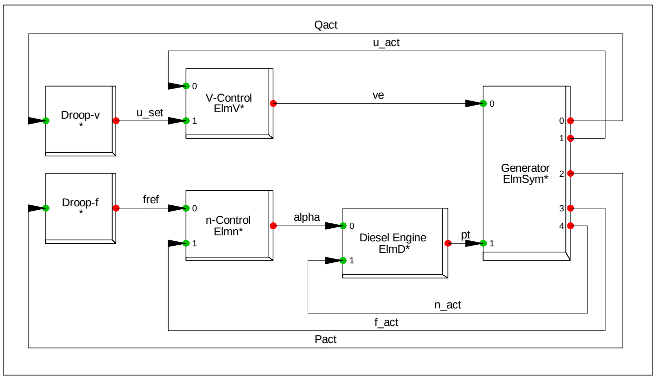

Figure 3: Generic generator controller model

Their performance is slow due to the mechanical control. Inner voltage and speed control loops maintain voltage and frequency at their set points. Load sharing between the generators is achieved by using frequency and voltage droop. So whenever the system load changes, the system voltage/frequency will change. A diesel engine model enhances the performance of the model and gets it closer to the real system behavior. Phenomena like turbo-lag are included within this model.

The model of the wind turbine, shown in Figure 4, was developed together with the wind turbine manufacturer. Verification against measured data from a site with similar turbines improved the accuracy of the model.

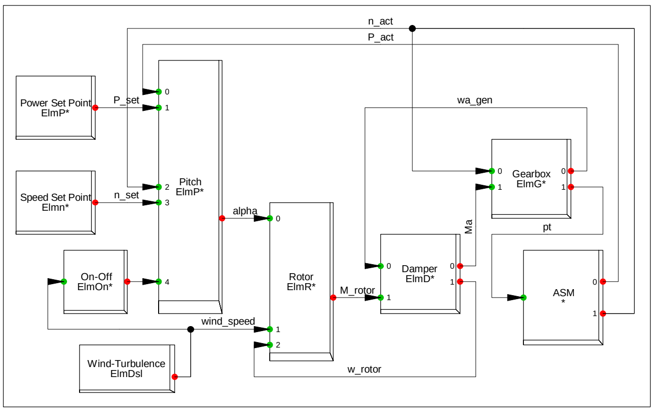

Figure 4: Wind turbine controller model

This model comprises a wind profile model and the dynamics of the wind turbine. A pitch controller limits the power output of the wind turbine. The wind speed is transformed into mechanical power via a rotor model which drives the shaft. The shaft is considered as a single mass shaft.

Finally a gear box couples the low speed rotor shaft to the high speed generator shaft. In summary it can be said that the power output of the turbine is mainly determined by the wind speed and the pitch angle of the rotor blades.

C. Wind Model

As there was no high resolution wind speed data available, a wind profile had to be modelled. The wind model can be described using the following equation:

$$v_w(t) = v_{w0} + v_t(t) \qquad (1)$$

Where:

- v_{w0} is the mean wind speed and
- $v_t(t)$ is the turbulent wind.

A stochastic Kaimal filter is used to simulate the dynamic wind turbulence implemented for this project. The filter can be described with the equation [1]

$$S_t(f) = \frac{\sigma^2 L}{2 v_{w0} \left(1 + \frac{3Lf}{2 v_{w0}}\right)^{\frac{5}{3}}} \qquad (2)$$

where L is the turbulence length scale.

III. Model Verification

A. Generator Dynamic Model

The step response of the real generator for different load steps was recorded on site. These measurements were then used to adjust the simulation model. Figure 5 shows an example graph of the generator model verification process.

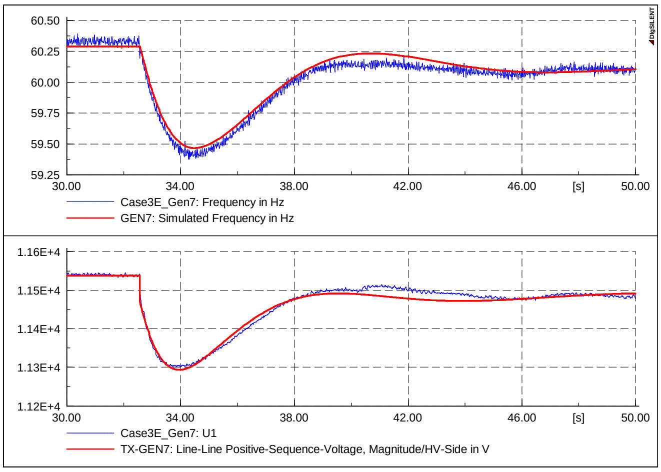

Figure 5: Generator step response (blue-real; red-simulation)

The curves of frequency and voltage show that the simulated system (red) and the real systems response (blue) are very close. However this process showed that the real generators behave different for load steps from a low load level than they do from a high load level. Therefore, to get an accurate model of the generator a series of step load tests needs to be undertaken.

B. Wind Turbine Dynamic Model

Figure 6 shows the behavior of the wind turbine model against measured data from a real system. The upper graph shows the wind profile from site which was fed into the model. The green line in the lower graph shows the power set point for the pitch controller. The comparison of the real system power (blue) and the simulation model power (red) shows that both power outputs are similar. Due to quantization the curve of the real system is squarer shaped than from the simulated dynamic system.

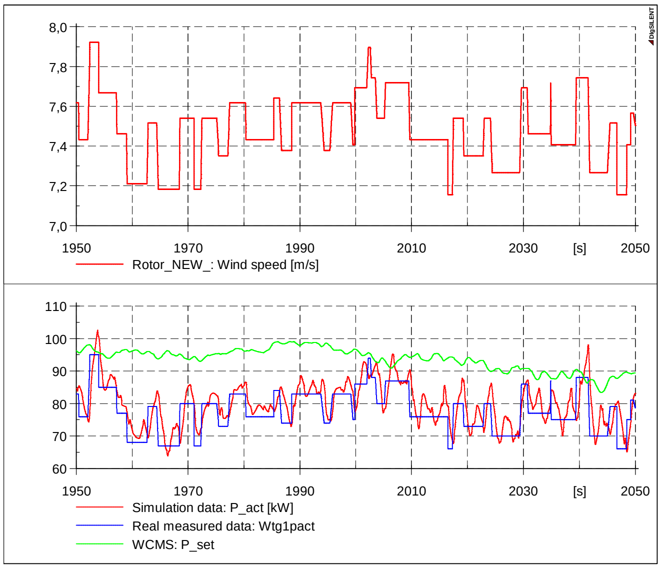

Figure 6: Wind turbine response (blue-real, red-simulation, green-set point)

IV. Transient Stability Study

A. Initial Simulation Scenario

After all single devices were verified against the available data the whole system was constructed and models implemented. The simulation scenarios were separated into a night simulation with low load and a day simulation with the highest load. Only the load consumption changed for these scenarios, everything else stayed the same. The following allocations were applied:

1. No wind park model with spatial dispersion
2. Duration of the simulation 1000 seconds
3. Mean wind 8m/s with 12% turbulence

Figure 7 shows the outcome of the simulation model for a day time scenario over 360 seconds. The upper graph shows a frequency variation of +/- 2Hz. The system is operating stable and does not show stability problems. These were the first results of the simulation model verified according to initial step load tests on site.

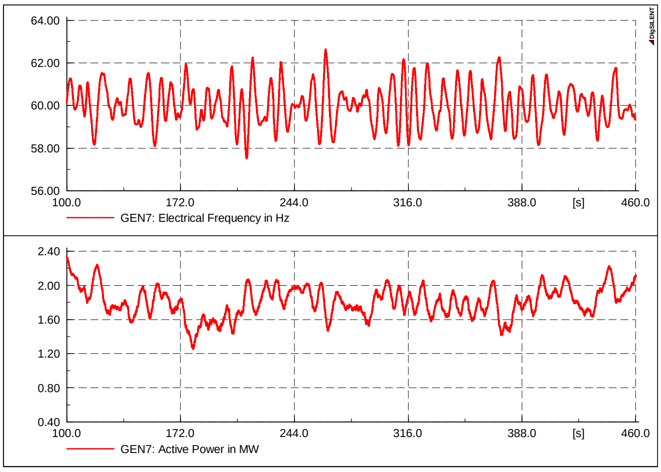

Figure 7: Base case simulation – Frequency and generator power

The next sections shows measurements from site recorded after the windfarm commissioning.

B. Comparison against measurements from site

After the grid connection study was completed, the whole system on site was commissioned. Frequency, voltage and power of the real system were recorded. These measurements were then analyzed and used to do post-commissioning model verification. The real data showed that the highest frequency variation, measured over 15 days, was +/- 0.5Hz, see Figure 8.

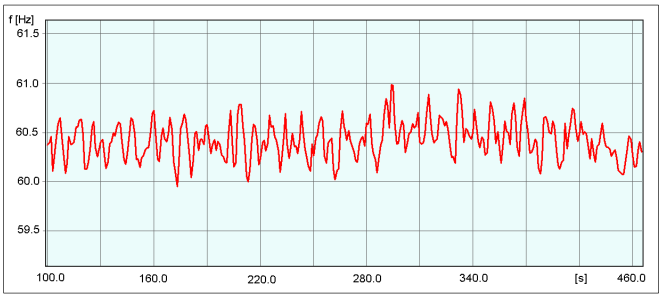

Figure 8: Frequency recorded in the real system

The fluctuation profile, over 360 seconds, in fact looks similar to the simulated system in Figure 7. With a frequency variation of +/- 2Hz in the simulated system, the variation is much higher than in the real system. The next section shows reasons for the higher deviation.

C. Analysis of the Model response

A further investigation in the deviation between the systems showed different reasons for the higher fluctuation.

a) Generator Step Response

The initial step load measurements, used for the generator model verification, were not accurate. This can be proved by observing the frequency variation in Figure 9 and Figure 10. These figures show the frequency response of the real system and of the model for a 2MW load step. It can be noticed that the model deviation is 1 Hz higher than the real generators response (Frequency in real system down from 61Hz to 59Hz; in simulated model frequency down from 61Hz to 58Hz). The time back to steady state is similar.

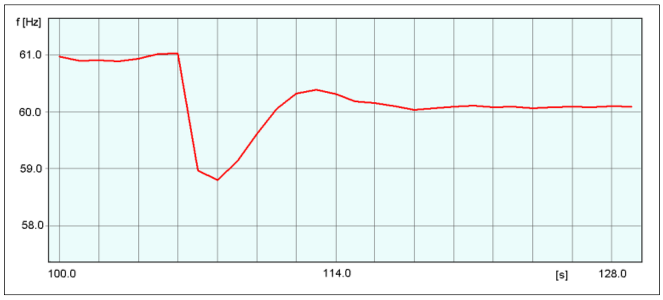

Figure 9: 2MW step response of the real system

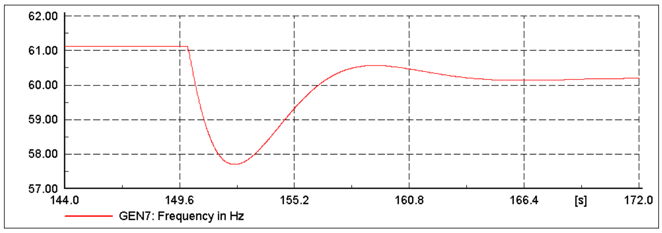

Figure 10: 2MW step response of simulation model

Another system simulation scenario with the modified generator controllers showed that the fluctuation of the model was still higher than in the real system. Deviations are 1.5 Hz in the model and 1 Hz in the real system.

b) Wind Turbulence Factor

The next approach to bring the model closer to the real system behavior was to analyze the simulated wind profile. It could be proved that the value of the turbulence factor has a significant effect on the frequency variation. After the commissioning of the windfarm no wind speed measurements were recorded. Therefore only assumptions about the turbulence factor could be made. It is noticeable that a turbulence factor of 6%, instead of 12%, brought the oscillation down to 1Hz. This is a reduction of 0.5Hz compared to the fluctuation with 12% turbulence.

c) Wind Park Spatial Dispersion

Another approach was to include a wind park model with spatial dispersion and turbulence remaining at 12%. Figure 11 shows the frequency and power of the simulated generator 7. The curve of the fluctuation still equals the real system oscillation in Figure 8. The time frame for both graphs is 360 seconds. The height of the fluctuation was reduced to 1Hz and equals the real system.

Reviewing the simulation process with these approaches could demonstrate why the model did not accurately represent the real system. But phenomena like windfarm spatial dispersion need to be treated with care, as the model could underestimate the wind impact in worst case scenarios.

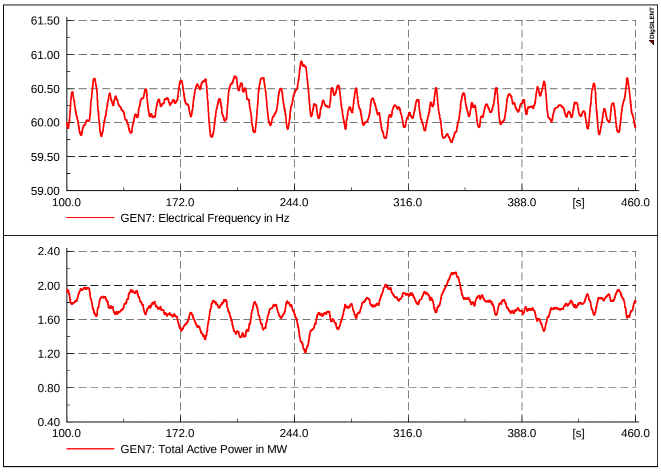

Figure 11: Frequency variation of the verified model with windfarm spatial dispersion

D. Simulation Conclusion

This section summarizes how the controller adjustment and different wind profiles changed the response of the model. Table 1 shows the frequency variation of the real system and the different models. The frequency variation in the real system is the highest found in the recorded data over 15 days.

Model	**Wind Turbulence**	**Frequency deviation**
Real System	Unknown	1.0 Hz(peak)
Model after first step load tests	12%	3.0 Hz
Model after commissioning	12%	1.5 Hz
Different Turbulence	6%	1.0 Hz
Wind park model with spatial dispersion	12%	1.0 Hz

Table 1: Frequency deviations at different model development stages

Correct generator step load testing had the highest impact on the accuracy of the model, and hence improved prediction in frequency variation. After reviewing the measurements from site and adjusting the generator models, the frequency variation was just half of that predicted initially. A different turbulence factor and a wind park spatial dispersion factor lowered the frequency variation further and aligned it closer to the real system response.

V. Conclusion

This paper investigates the accuracy of a simulation model. For this purpose a simulation model was compared to measured data from site. A grid connection study was conducted to show the impact of a wind turbine installation on an Island. The opportunity of capturing data after the commissioning of the system was used to validate the model accuracy and to find problems within the models and/or simulations. The comparison showed a higher frequency fluctuation in the simulation model.

Three main aspects which affect the accuracy of the model were in the centre of interest of this study. These aspects are:

1. Dynamic model design
2. Parameterization of models
3. Data input into the model

Different approaches have been analysed to increase the model accuracy and to find issues within the simulation model leading to the following conclusions:

The controller adjustment of the generator has a large impact on the frequency variation. The design of the generator controllers was correct but the parameters were adjusted to inaccurate step load measurements. This caused a weaker step response of the generator and therefore a higher frequency variation in the simulated system.

The wind turbulence factor has a considerable impact on the frequency variation. An analysis of the wind profile could confirm that that the wind turbulence is a critical factor for the frequency variation. A lower turbulence factor significantly reduces the frequency variation.

The inclusion of a wind park spatial dispersion impacts the frequency variation as it varies the power outputs between the wind turbines. This variation smoothes the power output of the windfarm and therefore lowers the frequency variation in the system.

Generally, it could be shown that the dynamic study based on PowerFactory was able to demonstrate the expected system behaviour. The importance of model verification against measured data could be proved and the effect of wrong assumptions could be shown. The key to an accurate simulation model is the parameterization of controllers as well as the use of correct input data, such as wind profiles.

References

[1] Markus Poller and Sebastian Achilles. Aggregated Wind Park Models for Analyzing Power System Dynamics. Technical report, DIgSILENT GmbH, 2004.