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Report

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Analysis of the Impact of the integration of 100MW of Non-Conventional Renewable Energy (PV/Wind) on the Spinning Reserve of the Electrical System of El Salvador

prepared for

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

cooperación alemana
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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M.P.E.
MOELLER & POELLER ENGINEERING

Moeller & Poeller Engineering
(M.P.E.) GmbH
Europaplatz 5
72072 Tübingen

Germany

Tel.: +49 7071 13879-0
Fax.: +49 7071 13879-99
Email.: info@moellerpoeller.de

Released by:

Dr.-Ing. Markus Pöller

Tel.: +49 7071 13879-10
Email.: markus.poeller@moellerpoeller.de

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1 Introduction

1.1 Background

The current plans of the electrical sector of El Salvador aim at reducing the dependence on fossil fuels. Until 2016, it is planned to install 195MW of additional renewable generation, amongst which 100MW are planned to be so-called *Non-Conventional Renewable Energies* (NCRE, wind and PV-farms).

The impact of up to 195MW of NCRE on the electricity grid of El Salvador, mainly the 115kV grid, has already been studied [1] with the result that the integration of up to 195MW of NCRE into the power system of El Salvador would be possible without any major grid reinforcements, under the conditions that wind and PV farms will comply with the technical requirements listed in [1] (e.g. LVRT capability, reactive power capability, etc.).

This report presents the results of studies analysing the impact of up to 100MW of NCRE on frequency control and spinning reserve requirements of the power system of El Salvador.

There are the following characteristics of NCRE, which can have a considerable impact on system flexibility aspects and spinning reserve requirements:

- Variability of the primary energy resources (wind, solar radiation)
- Inaccurate generation forecast, especially for time horizons of more than 24 hours

Besides this, for economic reasons, there is usually no spinning reserve allocated on NCRE as long as the remaining Conventional Generation is able to provide the required amount of spinning reserve. Consequently, even without the two above listed aspects (variability and forecast error) conventional generators have to allocate more spinning reserve during times of high wind and PV generation compared to situations with the same load but no NCRE generation, and dynamic performance requirements of these conventional power plants will potentially increase.

Another aspect, which is sometimes mentioned in this context, is the sudden disconnection of NCRE plants in the case of voltage dips: Until the beginning of the last decade, system operators usually required wind and PV generators to disconnect in the case of grid disturbances because they were afraid of NCRE harming the system in case of severe voltage dips. However, with increasing penetration levels of NCRE in many countries it became evident that this strategy would not be sustainable and would require to limit NCRE penetration levels quite considerably for avoiding large unplanned generation outages caused by grid faults. For this reason it is nowadays a widely accepted fact that NCRE must remain connected during grid faults (Low Voltage Ride Trough/LVRT or Fault Ride Through/FRT Capability), which is possible with modern power electronics technologies and properly defied connection conditions for NCRE, in which a response of NCRE to voltage dips must be specified that supports the grid actively (see also [1]).

Assuming that up-to-date NCRE technologies will be installed in El Salvador, which will comply with the technical specifications defined in [1], it can be excluded that the installation of NCRE will have an impact on frequency control and spinning reserve requirements.

Therefore, this report is focusing on variability and predictability aspects.

Of course, the actual impact of all these aspects on the system's performance highly depends on many other aspects, such as:

- Penetration level of NCRE (installed NCRE capacity compared to peak load)
- Diversity of wind and PV generation
- Local wind conditions
- Load characteristics

The main objective of the studies presented in this report is to assess whether it is possible to continue with existing strategies for spinning reserve allocation and whether dynamic performance characteristics of existing conventional power plants are sufficient for balancing up to 100MW of NCRE. In more detail, the studies will answer the following questions:

- What is the impact of 100MW of wind and PV generation on the Residual Load of the system of El Salvador (Residual Load=Net Load=load minus wind and PV generation), especially with regard to ramp rates (load following) and predictability (secondary reserve)?
- Are the existing conventional generators sufficiently flexible for controlling frequency (and area exchange flows) in the presence of 100MW of wind and PV generation?
- Are existing strategies for frequency control and spinning reserve allocation still appropriate when adding 100MW of wind and PV generation?
- Is it required to limit the individual size of wind and PV farms in El Salvador?

1.2 Spinning Reserve Allocation and Frequency Control in the System of El Salvador

According to the regulations (ROBCP [2] and its annex [3]) spinning reserve comprises primary reserve and secondary reserve. There is no tertiary control in the system of El Salvador.

The main objective and characteristics of primary control is the following:

- Initial frequency control in the case of generation-load deviations (e.g. resulting from inaccurate load forecast or generator outages).
- Acts through automatic speed governors that provide additional power in function of the deviation of frequency from nominal frequency.
- Acts across national boundaries. In other words: in primary frequency control time scales, a generation-load mismatch is compensated by all generators in the same synchronous area (e.g. entire SIEPAC system).
- Primary frequency control is a pure proportional control, which means that there is a remaining deviation from nominal frequency after primary control has settled.

The main objective and characteristics of secondary control is the following:

- Frequency control in the case of generation-load deviations (e.g. resulting from inaccurate load forecast or generator outages) in the longer time frame (e.g. 5 minutes).
- Brings frequency back into a narrow band around nominal frequency.
- Re-establishes scheduled inter-area flows.
- Acts across a selected set of generators, which are controlled by AGC (Automatic Generation Control).

- Secondary control is a P-I-type of control, which means that there is no steady state deviation from the frequency set-point.

Both primary reserve and secondary reserve in El Salvador are allocated by a day-ahead hourly dispatch process.

Primary frequency control reserve is allocated in function of the actual system load. The allocation mechanism ensures that the amount of available primary frequency control reserve is always greater or equal to 3% of the actual system load at any moment in time.

Secondary frequency control reserve is allocated on AGC enabled power plants only. The allocation mechanism ensures that the available secondary reserve (or AGC reserve) is always greater or equal to 4% of the actual system load at any moment in time.

In the case that secondary reserve is insufficient for compensating generation-load mismatch in the system of El Salvador, additional reserve power can be allocated manually on primary controlled power plants. In this case, the effective primary reserve is reduced.

Hence, the overall amount of spinning reserve in the system of El Salvador is always greater or equal to 7% of the actual system load at any moment in time.

In the case that the mismatch between predicted and actual load is getting close to 7% of the hourly load, which means that the activated spinning reserve gets close to the allocated reserve, additional thermal units (predominantly diesel or gas fired plants) will be started (stand-by reserve).

At the same time, a new load forecast and a new pre-dispatch will be calculated.

1.3 System balancing with and without NCRE

As described in the previous section, in systems without large amounts of NCRE, spinning reserve is required in order to:

- compensate the error between scheduled and actual load (load following reserve);
- compensate the unexpected loss of a generator;
- compensate sudden load disconnection;

Insufficient spinning reserve would lead to frequency stability problems (frequency rise or frequency drop) and consequently to load disconnection.

In systems with large share of NCRE, spinning reserve has to compensate the error between predicted and actual NCRE generation additionally.

In the short term (time frame <5 minutes), the total amount of wind and PV generation is relatively constant. Therefore the amount of required reserve mainly depends on worst case assumptions with regard to large, unplanned power plant outages, and not on variability of wind speed and solar irradiation.

However, in the longer time frame (>5 minutes), wind and PV generation have considerable impact on the amount of spinning reserve requirements because of their variability and limited predictability.

In systems without considerable share of wind and PV generation, spinning reserve has to balance the mismatch between predicted and Actual Load. However, in a system with considerable share of

NCRE (wind and PV), it is the variation of the Residual Load that has to be balanced by spinning reserve.

The Residual Load is defined by the Actual Load minus NCRE Generation. In a system with NCRE, conventional power plants have to supply the Residual Load.

Consequently, the impact of NCRE on spinning reserve and frequency control can be assessed by comparing the Residual Load with the Actual Load, especially with regard to predictability and variability.

In particular, the following characteristics of the Residual Load are of particular interest for assessing the impact of NCRE variability on spinning reserve requirements and frequency control:

- Residual Load Duration curve in comparison to Actual Load Duration Curve
- Ramp rates of Residual Load vs. ramp rates of Actual Load (for assessing the impact on ramp rate requirements)
- Day ahead prediction error of Residual Load vs. day ahead prediction error of Actual Load (for assessing impact on spinning reserve requirements).

Besides analysing Residual Load and comparing it against Actual Load, ramping capabilities of existing conventional power plants have to be analysed and compared with ramping requirements resulting from Residual Load variation. This is required in order to identify whether existing power plants will be able to balance the load in case of increased NCRE penetration levels and whether the existing frequency control and spinning reserve allocation mechanisms can remain unchanged or will have to be modified and adapted to the new situation.

2 Methodology

2.1 Data Preparation

2.1.1 Data Sources

For executing the studies presented in this report, the following data were provided by ETESAL, UT and CEL:

- Load time series (1 min time resolution, 1 year, national level) [4]
- Time series data of Load forecast and actual load (30 min resolution, 1 year, national level) [5]
- Time series data of global irradiation and temperature (1min resolution, several years and one single location) [6]
- Wind speed time series (10 min resolution, 1 year and 1 location) [7]

Raw input data could not be used directly, because some of the times series data had to be converted into a common resolution of 1 minute. Additionally, some input data weren't complete or unrealistic and therefore, bad data elimination had to be applied.

All data have been converted into an actual MW basis with a time resolution of one-minute.

Time series data were organized in CSV files, one file per month. Each column in each CSV file represents a complete data set for one day, 1440 values for each column. Incomplete days (columns) were excluded from the analysis.

The following data relating to conventional generation in El Salvador have been provided [8]:

- List of power plants including technology and capacity.
- Ramp rate capability of each power plant.
- Cost of production of each power plant.
- Dispatch order (Merit order table).

The results of the studies presented in this report apply to the year 2016.

2.1.2 PV input data conversion

2.1.2.1 Transformation of solar irradiation into power

For modelling PV generation, time series data of global solar irradiation [W/m²] and temperature [°C] with a resolution of 1 minute were provided [6].

For transforming solar irradiation into solar generation in MW, a "Solar Irradiation/Temperature to Power Curve" as shown in Figure 1 has been applied.

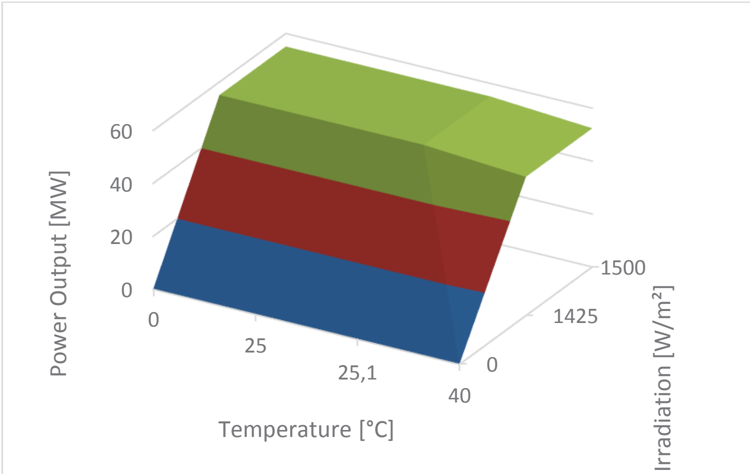

Figure 1: Solar Irradiation/Temperature to Power Curve

The relationship between solar irradiation and power generation was assumed to be linear. In order to scale the power output appropriately, a maximum solar irradiation of 1500 W/m² was identified using the provided time series data of solar irradiation.

Additionally, the impact of ambient temperature on PV generation has been considered. An efficiency reduction of around 0.31% per Kelvin was assumed for ambient temperatures exceeding 25°C resulting in the relationship between power and ambient temperature according to Figure 1.

2.1.2.2 Consideration of Diversity within a PV Farm

Time series data of solar irradiation, as provided for these studies, reflect variations of solar irradiation at a single location.

However, even when assuming that the entire PV generation is produced by one single PV farm, smoothing effects resulting from the diversity of solar irradiation across the area of a 58MWp PV farm has to be considered and will have a smoothening effect on PV variations.

Therefore, an estimated area of 58 hectares was split up into 227 strings of 6m each and the effect of clouds passing over the site has been considered by a moving average filter applied to the effects of clouds, which has been estimated by the deviation between actual solar irradiation and the mean sinusoidal fit, as described in section 2.3.3. The time constant of the moving average filter depends on the assumed speed, with which clouds are passing across the PV farm (wind speed).

Figure 2 shows the impact of diversity across a single PV farm on power generation assuming a wind speed (speed of clouds) of around 10m/s. As shown in this figure, the generation profile is generally smoothened and especially steep ramps are almost perfectly filtered.

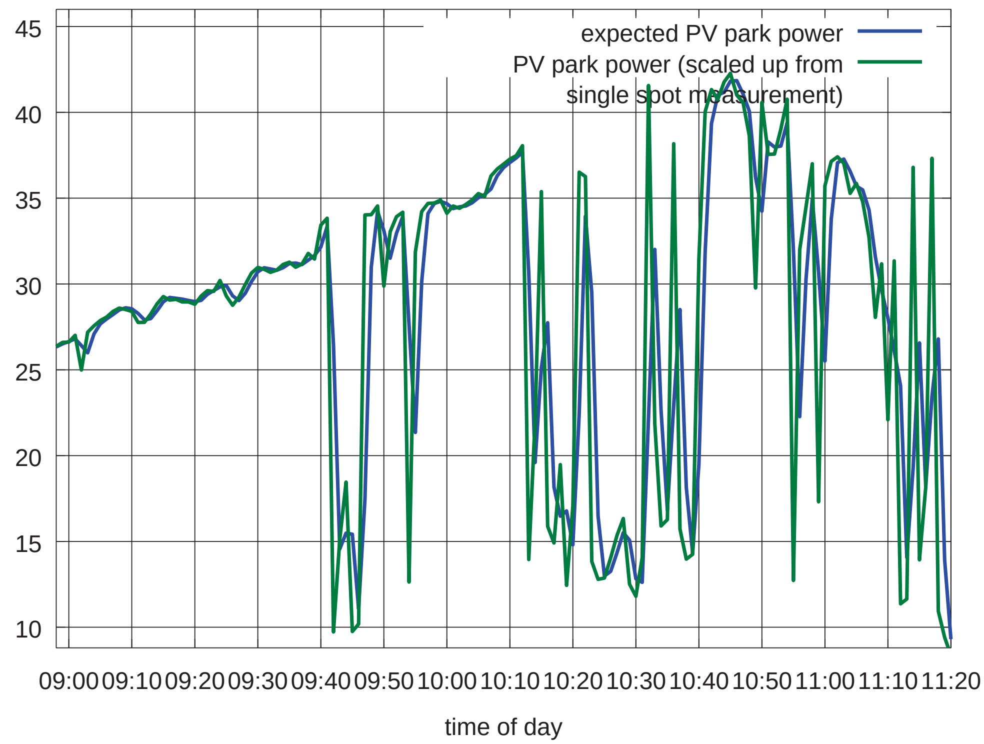

Figure 2 - PV time series with cloud simulation

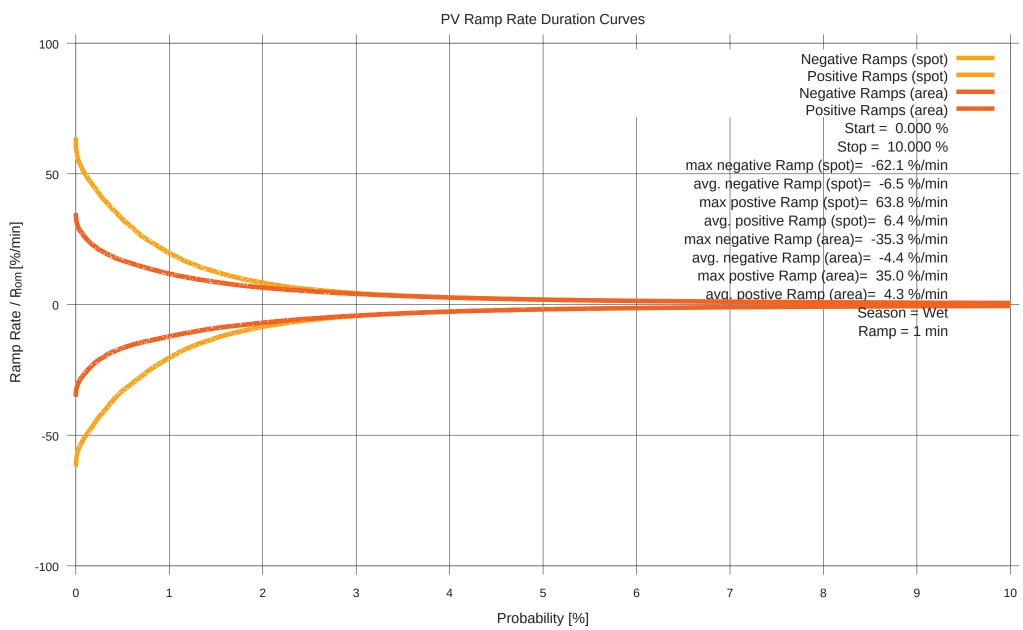

Figure 3 – Cumulative probability curve of ramp rates of PV generation with diversity (orange) and without diversity (red)

When the size of a PV farm increases, diversity increases and fast ramps will more and more be reduced in the PV generation profile.

This is confirmed by the cumulative probability curve of 1min ramp rates according to Figure 3. As this picture shows, the very fast ramps are highly reduced when considering diversity effects across the area of a single PV farm.

In the case that the total PV generation of El Salvador was not generated by one single PV farm but by several PV farms spread across the country, diversity effects would further increase. However, this effect cannot be quantified by simple modelling assumptions but would require evaluating measured time series data of solar irradiations at the different PV farm locations.

In order to carry out a worst-case assessment, the results described in chapter 3 and in Annex have been produced without considering diversity effects described in this section and therefore represent worst case assumptions with regard to ramp rates of residual load.

2.1.3 Wind input data conversion

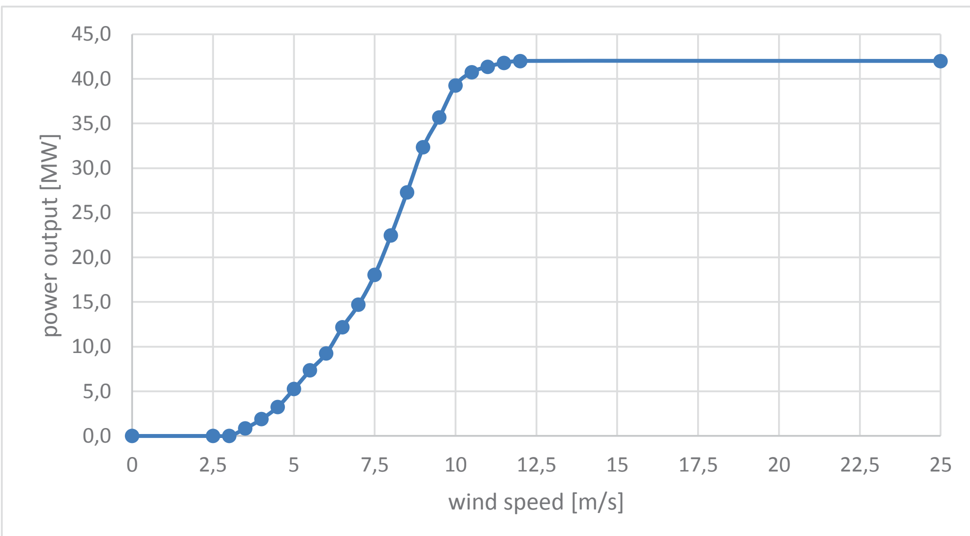

Figure 4: Power Curve of representative wind farm

Wind speed data in m/s from different measurement stations within a single wind farm location and different heights (50 and 60m) have been made available in the form of time series data with a resolution of ten-minutes [7].

Since wind speed measurements were taken at heights of only 50 or 60m, wind speeds were converted to a common hub-height of 80m using the following (simplified) formula:

$$\bar{\vartheta}_H = \bar{\vartheta}_{ref} \cdot \frac{\ln \frac{H}{z_0}}{\ln \frac{H_{ref}}{z_0}}$$

$\bar{\vartheta}_H$ = mean wind velocity at elevation H (m/s)
$\bar{\vartheta}_{ref}$ = mean wind speed at reference elevation H_{ref} (m/s)
H = height (m)

H_{ref} = reference elevation (measuring elevation) (m)
ln = natural logarithm (base e = 2.7183)
z_0 = roughness length (m)[1]

In a next step, the average of the wind speed values at the different measurement stations (at an equivalent hub-height of 80m) has been converted into power in MW using a power curve as depicted in Figure 4.

Finally wind generation data have been interpolated from 10min intervals to 1min intervals in order to be compatible with PV generation and load data.

Because wind speed data were only available at a resolution of 10min, the impact of wind speed variations faster than 10min could not be assessed by the studies presented in this report.

2.1.4 Bad data elimination

Especially for ramp rate calculations, it is important to exclude bad or incoherent data from the analysis.

In order to ensure that only coherent data is used, timestamps of each measurement (load, PV and wind) were reviewed according to the following criteria: if on minute (t) follows the expected next minute (t+1), information is considered as coherent. Whenever this criteria was not fulfilled, the whole daily data set has been excluded from the analysis.

2.1.5 Elimination of load shedding events

In order to avoid that load shedding events would be interpreted as regular load variability, these events have been eliminated systematically from the load data sets.

2.2 Residual Load Calculation

As explained in section 1.3 Residual Load is defined by the Actual Load minus NCER generation. It represents the load that has to be supplied by conventional generation at any moment in time.

The analysis of this report is based on only one year of load, solar irradiation and wind speed data. Because one year is too short for being stochastically representative, and in order to consider the probabilistic nature of wind and PV generation, load, wind speed and solar irradiation data have been recombined using a special type of convolution.

This special type of convolution considers stochastic variations across several days but preserves diurnal and seasonal correlation effects.

For Example:
In a month with 30 days (and 30 complete daily data sets of load, wind and PV generation), the convolution of the residual load calculation combines 30 daily load profiles with 30 daily PV-generation profiles with 30 daily wind-generation profiles, which produces a total of 27.000 combinations per month. In this process, complete daily time series data were combined, while maintaining the order of the intra-day values. An example of this convolution process, considering three days only, is visualized in Table 1.

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[1] *A roughness length of 0.2 m (Many trees and/or bushes) was chosen according to the actual position of the wind park.*

Table 1 – Example of a convolution of three day sets of load, PV and wind

Combination	Load [# day]	PV [# day]	Wind [# day]
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

2.3 Forecast Error Calculations

2.3.1 General

Day-ahead forecast errors of wind and PV generation will highly depend on the quality of forecast tools and measurement stations for wind speed and solar irradiation. In the absence of any prediction system for wind speed and solar irradiation in El Salvador, day-ahead prediction errors have been estimated using empirical approaches that reflect the most relevant influential factors of wind speed and solar irradiation prediction errors and the typical magnitude of those errors for large wind and PV farms.

2.3.2 Load Forecast Error Calculation

Day-ahead load forecast error has been provided directly in the form of historical time series data [5].

2.3.3 PV forecast error Calculation

The approximation of PV prediction errors is based on the assumption that the average cloud coverage during a day and hence the energy produced during a day can be estimated with reasonable accuracy but not its precise occurrence during a day. Therefore, the predicted day-ahead solar irradiation was approximated by a sinusoidal curve considering the time dependence of PV generation during a day (deterministic component). The parameters of this sinusoidal curve have been fitted to the actually measured solar production using a least square optimization algorithm, which minimizes the difference between the estimated PV prediction (sinusoidal shape) and actual PV generation for every hour per day (see Figure 5).

The actual PV prediction error has be assumed to be equal to the difference between actual PV generation and the sinusoidal fit representing day ahead PV prediction (see Figure 5).

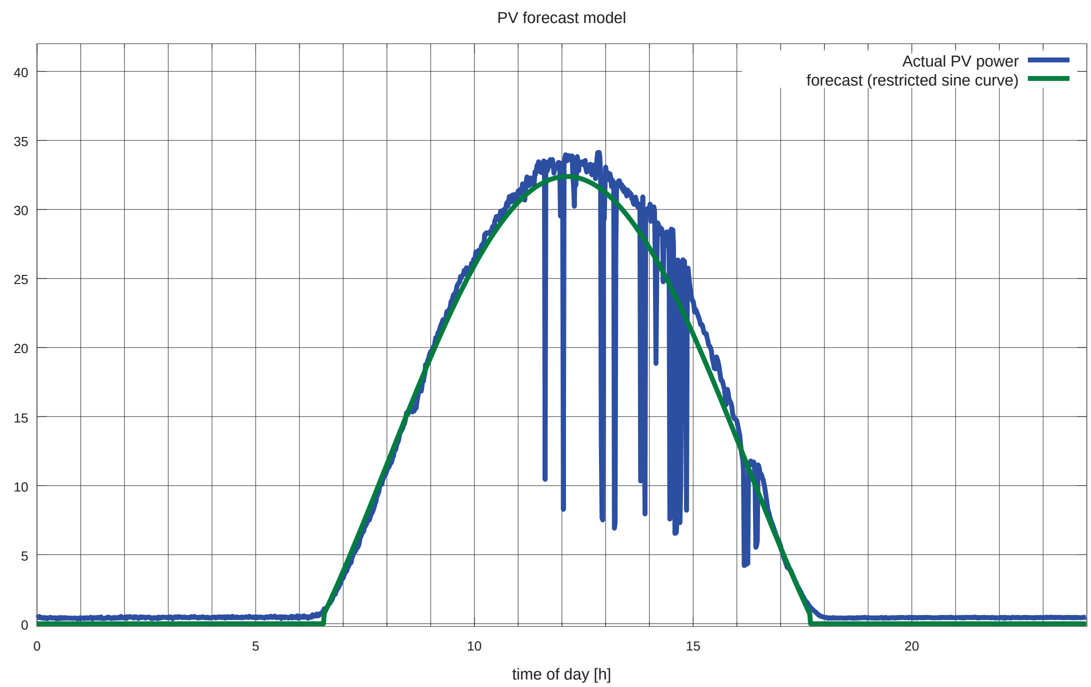

Figure 5: PV Prediction and actual PV generation of a representative day

2.3.4 Wind forecast Error Calculation

For modelling the impact of wind prediction errors on spinning reserve requirements, the following simplifying assumptions have been made:

- Wind prediction error is approximately proportional to the rate of change of wind generation.
- The total geometrical average day-ahead wind forecast error (nRMSE) of a single wind farm is typically around 15%.

This approximation, which represents a very rough simplification, considers the strong dependence of wind prediction errors on phase errors resulting from steep wind speed variations and ensures at the same time that the annual nRMSE is in a typical range.

2.3.5 Residual Load Forecast Error Calculation

In order to assess the impact of NCRE on spinning reserve requirements the day-ahead prediction error of the Residual Load has to be calculated.

This calculation can be carried out analogously to the Residual Load calculation (see section 2.2) by convoluting the prediction errors of load, PV generation and wind generation.

2.4 Conventional Generation

2.4.1 Generator Dispatch

In order to assess, whether there will be sufficient spinning reserve in the system of El Salvador and whether the existing algorithms for allocating spinning reserve is appropriate for balancing NCRE variations, an approximated generator dispatch for all relevant load levels has been calculated using the Merit-Order Table that has been provided for the purpose of these studies.

This algorithm applies a merit order dispatch considering the following constraints:

- Dispatched generation must be equal to load;
- Primary reserve is equal to 3% of the load;
- Secondary reserve is equal to 4% of the load;

This approach is illustrated by Figure 6.

The actual algorithm for dispatching generation while considering the required levels of primary and secondary frequency control reserve is depicted in Figure 7.

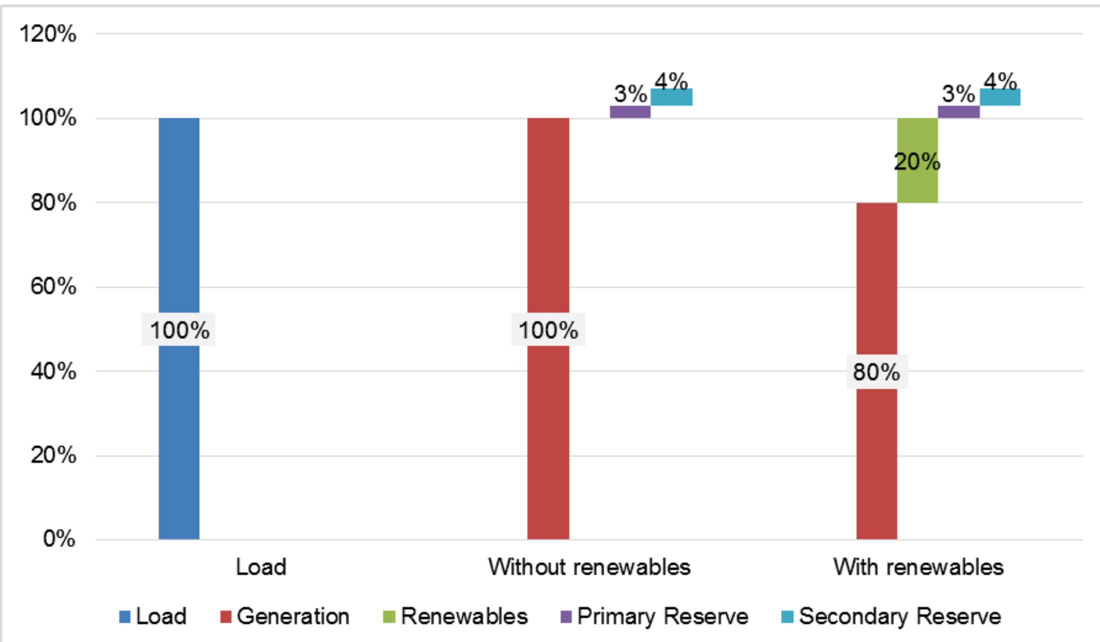

Figure 6: Allocation of primary reserve in the presence of NCRE.

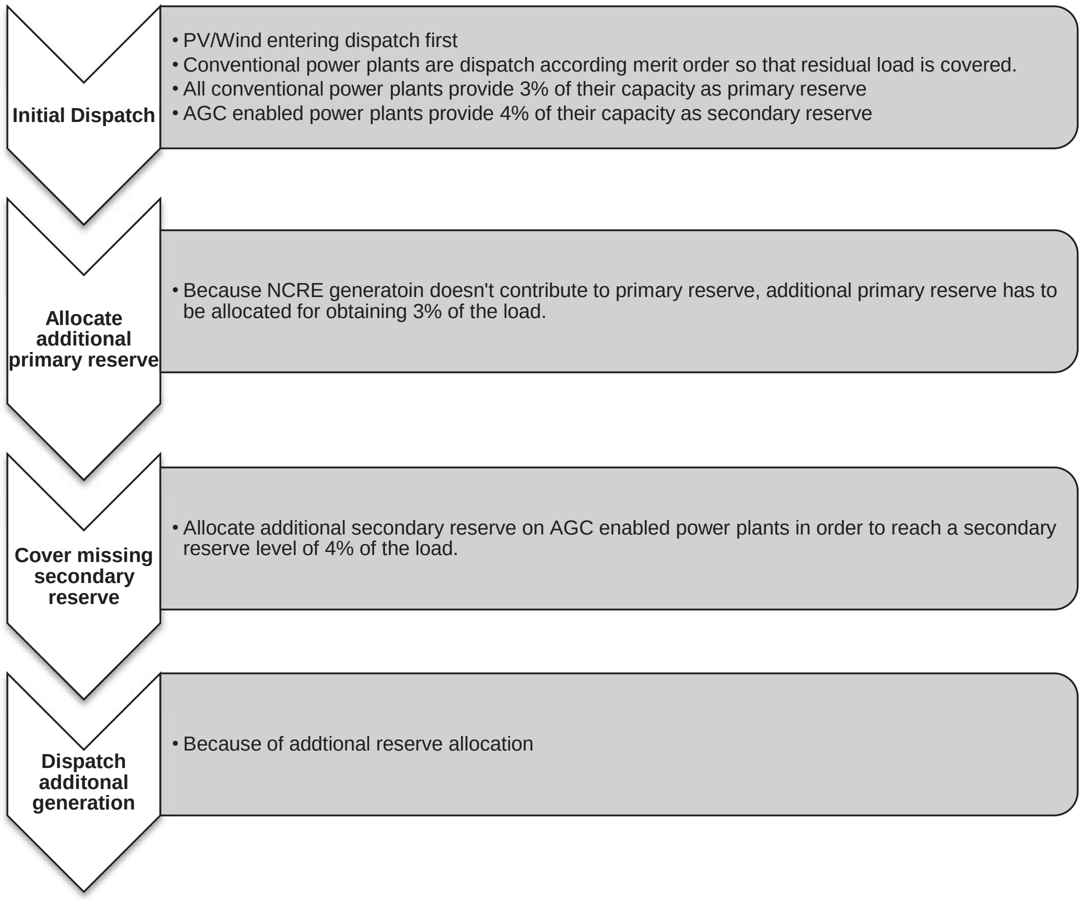

Figure 7: Algorithm for calculating the generator dispatch

2.4.2 Spinning Reserve Assessment

In order to be able to balance variations of generation and load, it is required that

- Generators provide sufficient spinning reserve for backing up deviations between predicted and actual values of residual load.
- Reserve power can be made available to the system sufficiently quickly (sufficient dynamic performance)

The first criterion can be assessed by analysing residual load prediction errors (see section 2.3) and comparing it to day-ahead prediction errors of the actual load.

The second criterion (dynamic performance) can be assessed by comparing the rate of change of residual load with the ramp rate capabilities of generators providing secondary and primary spinning reserve (see Figure 8 for secondary controlled power plants).

If it can be demonstrated that ramp rate capabilities of the generators providing spinning reserve is larger than actual ramping rates of residual load at any moment in time, it can be concluded that spinning reserve can be made available to the system sufficiently quickly.

In all situations, in which the spinning reserve of the system complies with both criteria, residual load variations resulting from load variations, wind speed variations and PV variations can be compensated by the allocated spinning reserve.

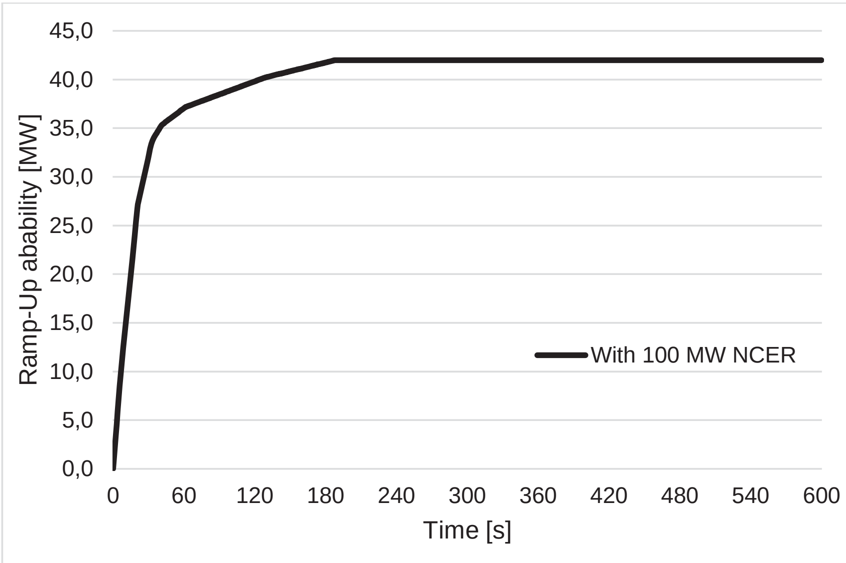

Figure 8 - Ramping Capability of AGC controlled power plants (Example: Wet Season, Load 1050 MW)

2.5 Methodology – Summary

For assessing whether the existing spinning reserve allocation method will still be appropriate when integrating up to 100MW of NCRE, the following analysis will be carried out:

- Calculate Residual Load based on historical time series data of actual load, wind speed and solar irradiation (see section 2.2).
- Calculate 1min, 10min and 60min ramp rates of actual load and residual load for assessing the impact of NCRE on the ramping requirements.
- Calculate of day-ahead prediction errors of the Residual Load based on historical time series data of day ahead load forecast errors and simplified estimates of day-ahead prediction errors of wind generation (see section 2.3.4) and PV generation (see section 2.3.3).

Based on this information, the following evaluation will be carried out:

- Analyse the probability that the actual load prediction error exceeds 4% of the load (secondary reserve) and 7% of the load (primary + secondary reserve) for assessing the impact of increased day-ahead prediction errors on spinning reserve requirements.
- Compare ramp rates of actual load and residual load with ramp rate capabilities of AGC enabled generators for evaluating whether the allocated secondary reserve can be made available sufficiently quickly.

Based on this analysis it will be possible to evaluate whether NCRE will have a considerable impact on spinning reserve requirements or not.

Because a of the different system characteristics during dry and wet season, all types of analysis will be carried out for each season separately.

3 Main Results

3.1 Impact of NCRE on spinning reserve requirements

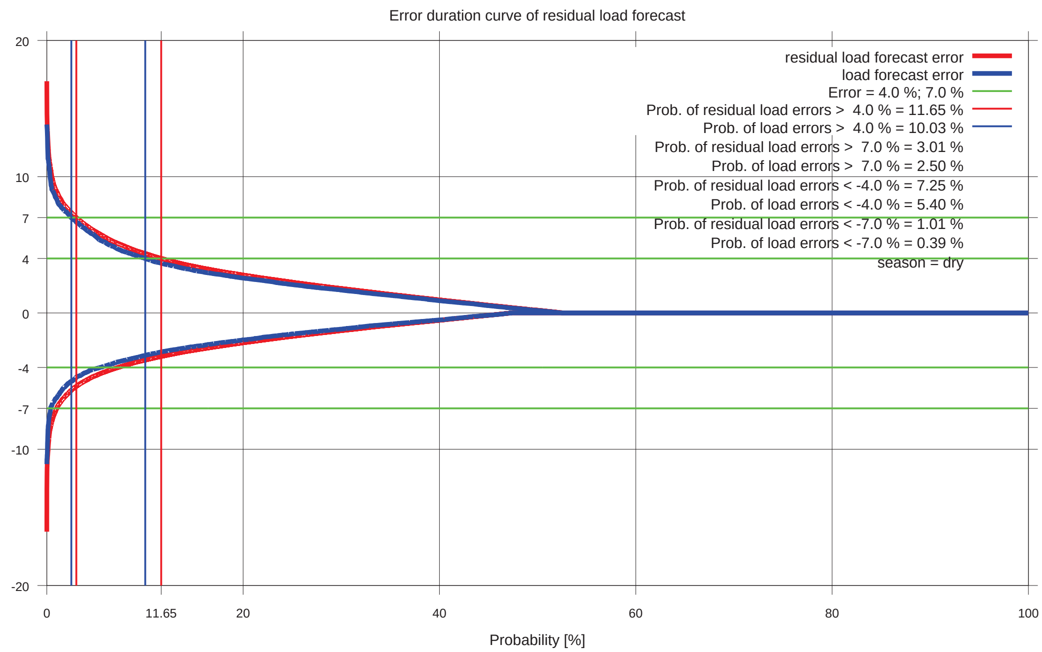

Figure 9 – Day-ahead prediction error of Residual Load and Actual Load during dry season

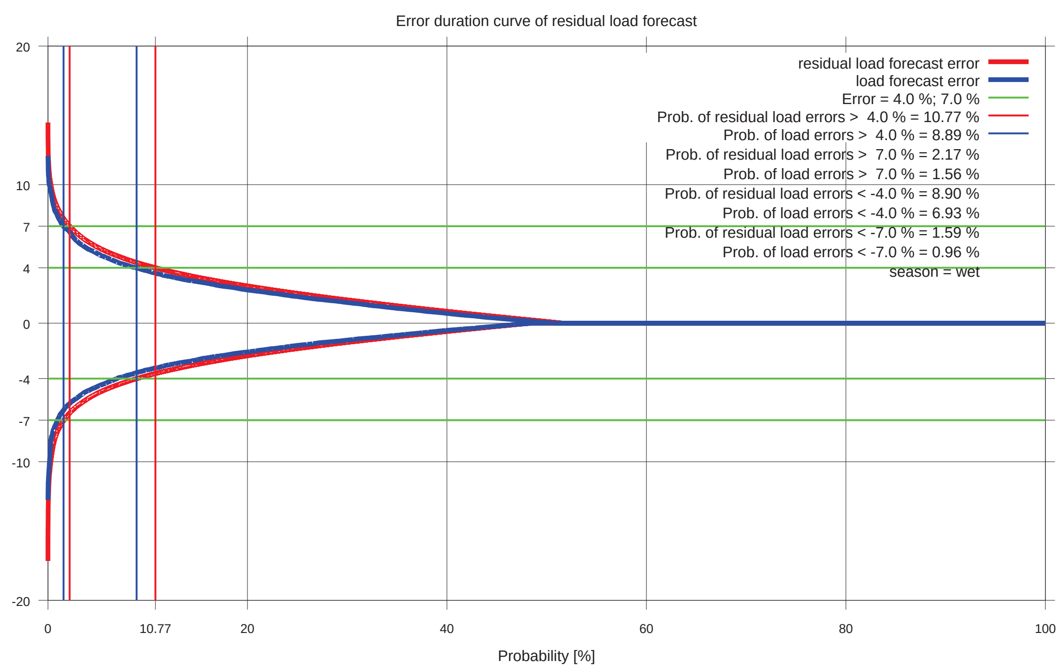

Figure 10 - Day-ahead prediction error of Residual Load and Actual Load during wet season

Figure 9 and Figure 10 show the cumulative probability distribution of prediction errors of actual load and residual load during dry and wet season in % of the predicted load.

In all cases, in which prediction errors exceed 4%, the scheduled secondary reserve is not able to cover deviations between actual and predicted load. In the case that prediction errors exceed 7% of the predicted load, the complete spinning reserve is not sufficient to cover the load mismatch and increased imports from neighbouring countries would be required together with a re-execution of load forecast and generator dispatch.

Generally, Figure 9 and Figure 10 show that the difference between day-ahead prediction errors of residual load and actual load is very small for most cases and that the integration of 100MW of NCRE only has a minor impact on overall day-ahead prediction errors.

Table 2: Probabilities and number of hours per year of prediction error >4%

	propability of error>4%		**no of hours per year error>4%**	
	Residual Load	*Actual Load*	*Residual Load*	*Actual Load*
dry season	11,65%	10,03%	510	439
wet season	10,77%	8,89%	472	389
Total	**11,21%**	**9,46%**	**982**	**829**

Table 3: Probabilities and number of hours per year of prediction error >7%

	propability of error>7%		**no of hours per year error>7%**	
	Residual Load	*Actual Load*	*Residual Load*	*Actual Load*
dry season	3,01%	2,50%	132	110
wet season	2,17%	1,56%	95	68
Total	**2,59%**	**2,03%**	**227**	**178**

The relevant results of this analysis are summarized in Table 2 and Table 3. As these tables show, the number of hours per year, during which secondary reserve is insufficient for covering the mismatch between predicted and actual load increases from 829h to 982h per year due to the integration of 100MW of NCRE.

The number of hours per year during which the complete spinning reserve (primary reserve + secondary reserve) is insufficient for covering the day-ahead prediction error, increases from 178h to 227h per year.

These differences are very low and certainly within the accuracy limits of this analysis. Consequently, it can be concluded that there is only a very small impact on day-ahead prediction errors when installing up to 100MW of NCRE when introducing wind and PV prediction systems for day-ahead prediction of wind and PV generation.

Another way of analysing the results according to analyse the results according to Figure 9 and Figure 10 is to fix the probability that AGC control reserve (4% of load) or spinning reserve (7% of load) is exceeded and to determine the amount of additional AGC-reserve and overall spinning reserve that would be required for maintaining the same probability that day-ahead prediction errors exceed the available AGC-reserve or total spinning reserve with and without the integration of 100MW of NCRE (see Table 4).

Table 4 – Amount of AGC-reserve and spinning reserve required for maintaining the same probability that day-ahead prediction errors exceed the available AGC-reserve or total spinning reserve

	AGC-reserve (4% of load)		**Spinning reserve (7% of load)**	
	Probability level	*Required AGC-reserve*	*Probability level*	*Required spinning reserve*
dry season	10,03%	4,36%	2,50%	7,36%
wet season	8,89%	4,38%	1,56%	7,54%

As shown by the results of Table 4, the additional amount of spinning reserve required for compensating the effect of an increased day-ahead prediction error of load or residual load respectively when adding 100MW of NCRE to the system of El Salvador would be very low.

3.2 Impact of NCRE on dynamic performance requirements

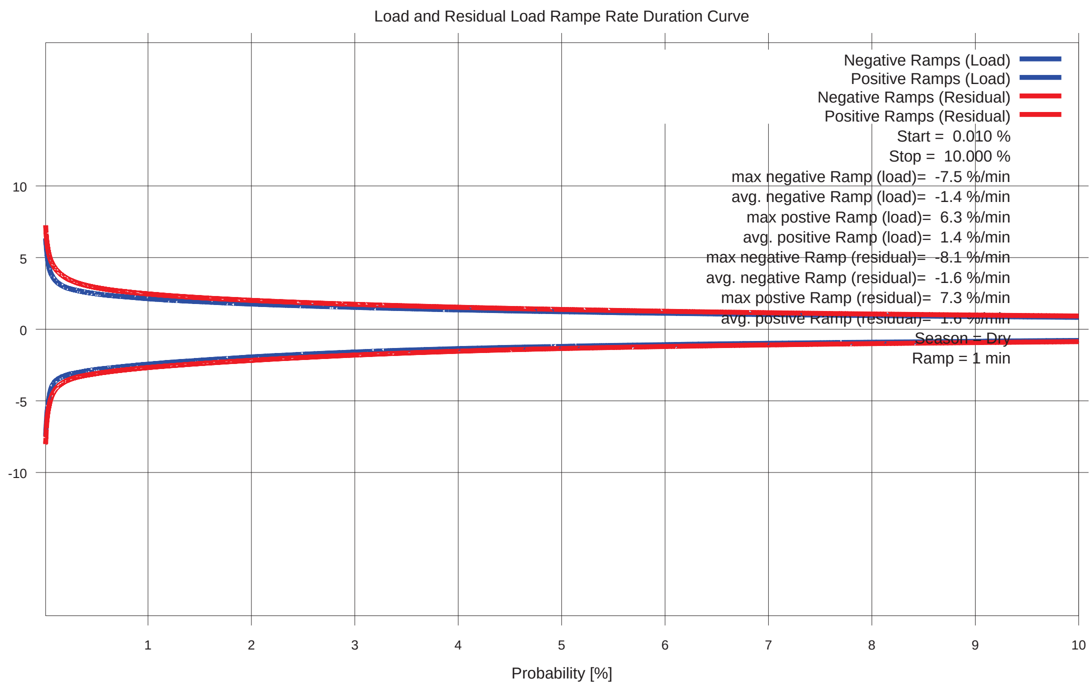

Figure 11- Ramp rates of Residual Load and Actual Load during dry season

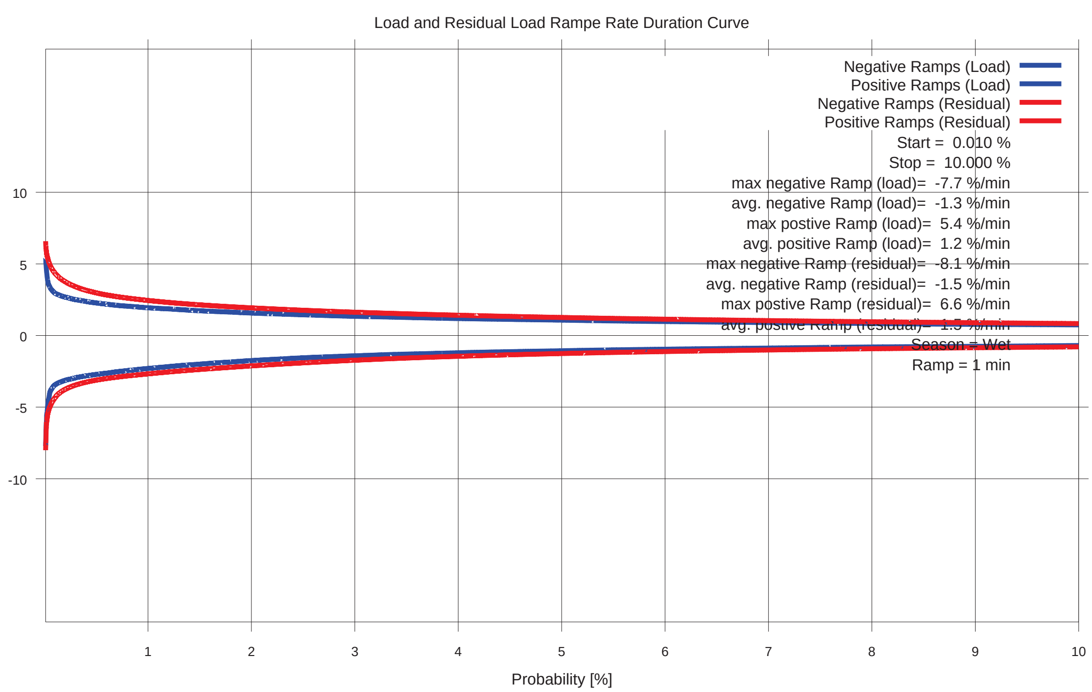

Figure 12- Ramp rates of Residual Load and Actual Load during wet season

The impact of 100MW of installed NCRE capacity in El Salvador on load ramp rates is depicted in Figure 11 (dry season) and Figure 12 (wet season). The ramp rates are expressed in %/min based on the predicted load level.

These figures clearly show that for the very large majority of all cases, the impact of 100MW of installed NCRE capacity in El Salvador on the speed of change (ramp rates) of the residual load is very minor.

Besides this, it should be kept in mind that diversity of solar irradiation has not been considered by the results of Figure 11 and Figure 12, which leads to an overestimate of fast ramp rates. On the other hand, there will be wind speed variations, which will be faster than 10min (turbulent effects), which haven't been considered by the results presented in this report. However, in larger wind farms, fast wind variations resulting from turbulent effects are smoothened because they are only weakly correlated between the individual wind turbine locations.

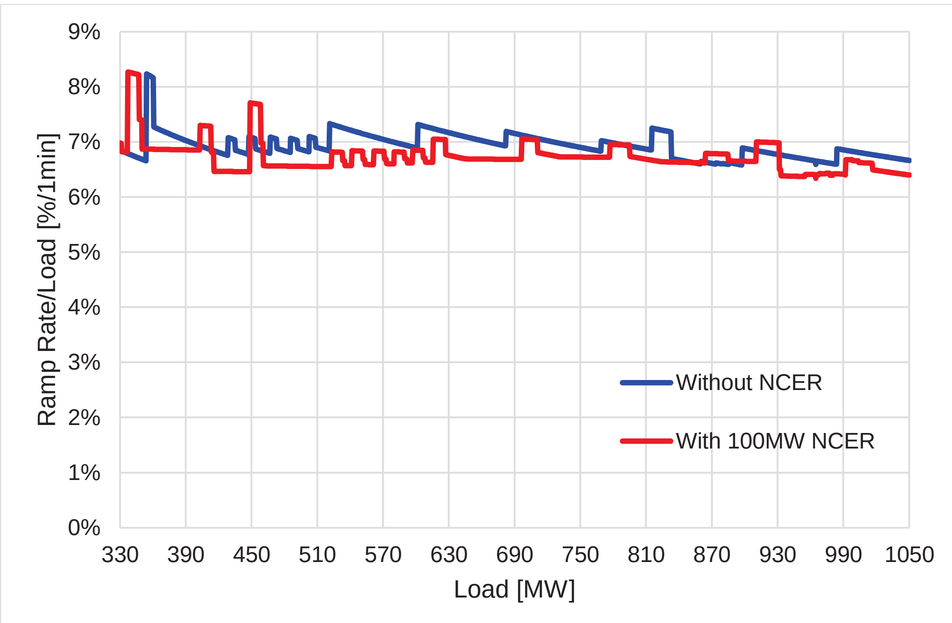

Figure 13- 1min Ramping capabilities of Spinning Reserve during dry season

However, besides the impact on load and residual load variations, the impact of NCER on ramping capabilities of conventional power plants must be analysed.

The impact of NCER on ramping capabilities of conventional power plants results from the fact that for each load state there are less power plants providing spinning reserve, when NCER are in operation, than in a comparable situation without NCER (because NCER don't contribute to spinning reserve). Therefore ramping capabilities of conventional power plants are potentially reduced.

The impact of NCER on one minute ramping capabilities of the spinning reserve for all relevant load states of the system of El Salvador is depicted in Figure 13 (dry season) and Figure 14 (wet season).

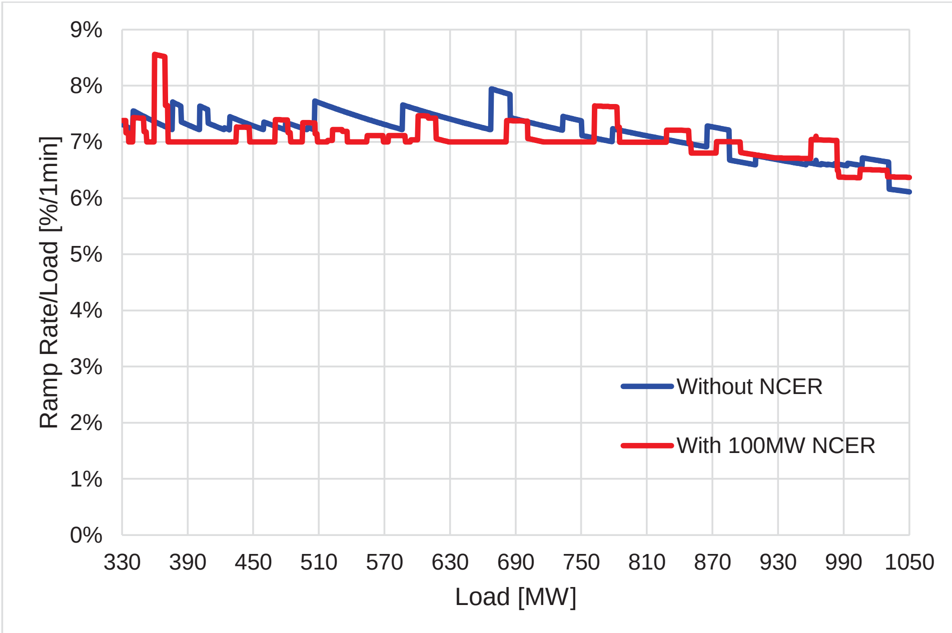

Figure 14 – 1min Ramping capabilities of Spinning Reserve during wet season

These figures allow the following conclusions:

- For almost all load states, the one minute ramping capability is equal to >=7% of the actual load, which is equal to the total amount of spinning reserve in the system. This means that the complete available spinning reserve can be made available to the system within less than one minute in most situations.
- During high load scenarios, when absolute spinning reserve (in MW) is at its highest value, the available spinning reserve requires more than one minute for being fully available (compare also example according to Figure 8)
- There is almost no impact of NCER on ramping capabilities of conventional power plants: The red line (with NCER) and the blue line (without NCER) of Figure 13 and Figure 14 are almost equal.

For this reason, issues relating to insufficient ramping capabilities of conventional power plants in El Salvador providing spinning reserve don’t have to be expected when integrating up to 100MW of NCER into the system of El Salvador.

3.3 Other Results

The results of all simulations that have been executed within these studies are depicted in the annex to this report. In particular, the annex contains:

- Duration curves of load, wind generation, PV generation and residual load
- Duration curves of ramp rates of load, wind generation, PV generation and residual load
- Duration curves of day-ahead prediction errors of load, wind generation, PV generation and residual load

Ramp rates and prediction errors are shown in actual units (MW) and in percent, normalized to the predicted load.

4 Conclusions and Recommendations

The results presented in this report lead to the following main conclusions:

- The impact of 100MW of installed NCRE capacity (wind and PV) will only have a minor impact on residual load variations and hence on spinning reserve requirements.
- Dynamic performance characteristics (ramping capabilities) of existing conventional power plants in El Salvador will be sufficient to follow wind and PV variations (residual load variations) and to balance the mismatch between predicted and actual residual load.
- The allocation mechanism for secondary reserve power (4% of the load) can remain unchanged without considerably increasing the need for manually allocating additional load following reserve using primary controlled power plants.

The impact of NCRE variability on actual area exchange control metrics, such as CPS1 or CPS2 could not be quantified within the scope of these studies because this would require more detailed data of wind speed and solar irradiation with very high time resolution, which were out of the scope of the presented studies. However, based on the results of the studies presented in this report, it should not be expected that there will be a considerable impact of 100MW of installed NCRE capacity on the quality of area exchange control between El Salvador and its neighbouring countries.

Besides this, it has to be highlighted that the results of the studies presented in this report were based on the assumption that wind prediction and PV prediction systems will be put in place in El Salvador and used for system balancing purposes. Without the introduction of an appropriate wind and PV prediction system, substantially higher mismatches between predicted and actual residual load would have to be expected and consequently, the impact of NCRE on spinning reserve requirements would be higher than shown in this report.

For supporting system balancing based on residual load, as suggested in this report, the following data would have to be transmitted from each wind or PV farm to the system operator:

- Real time data of actual generation in MW at the point of connection (POC) of each NCRE plant with sufficient time resolution (e.g. 5 min).
- Day-ahead prediction of the generated power of each wind and PV farm for every hour of the next day (analogously to day-ahead load forecast data).
- 4 hours-ahead prediction of the generated power of each wind and PV farm.
- 1 hour-ahead prediction of the generated power of each wind and PV farm.

The responsibility for wind and solar prediction can either be with each operators of NCRE plants or with the system operator. In the case that this responsibility is with the operators of NCRE plants, there must be some incentives for providing accurate wind and solar prediction values (e.g. penalties in the case of large deviations etc.) for ensuring that wind and solar prediction will be sufficiently accurate.

However, because of the importance of wind and solar prediction for system balancing, it is recommended that the system operator takes this responsibility or that both, operators of NCRE plants and the system operator carry out wind and solar prediction creating redundant forecast data allowing for even high accuracy.

In most countries with high share of NCRE it is nowadays common practice that more than one source of wind and solar prediction data (e.g. by contracting several service providers) is used for system operation. With the help of specialized software, the accuracy of the prediction can further be improved when using different sources.

5 References

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