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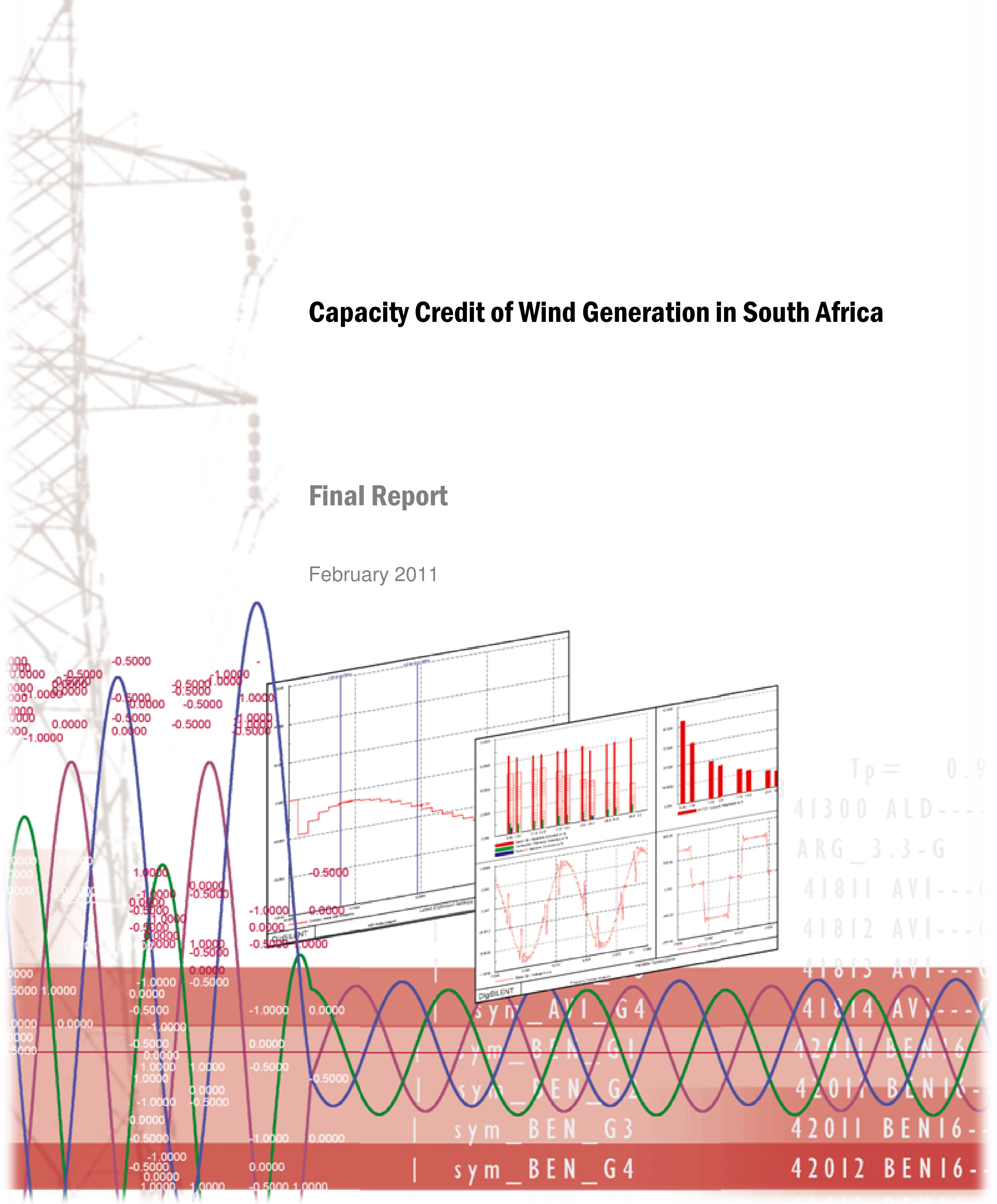

Capacity Credit of Wind Generation in South Africa

Final Report

February 2011

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1 Introduction

Renewable energies, such as wind energy, allow electricity production without consuming fossil resources and without any direct carbon dioxide emissions. Just by producing electrical energy, the use of these sources is justifiable and represents in many locations an economical alternative to the use of fossil resources such as coal or oil. Particularly the cost of wind generation has considerably decreased over the last decade and while fossil fuel prices are increasing it is anticipated that wind generation at high wind sites will represent the most economical method for generating electrical energy in the near future.

However, in contrast to more conventional power plants based on fossil resources, electricity production from wind farms cannot be planned because of the variable nature of wind speeds. Therefore, and because there aren't any suitable electricity storage technologies available (yet), conventional, dispatchable power plants using fossil fuels are always required for times during which electricity demand is high and wind generation is low.

This leads to the question about how much conventional generation capacity is still required in a system with high amount of wind generation. Is it the same amount as without wind generation or is it less? If it was the same amount, there would still be the benefit of consuming less fossil resources and reducing carbon dioxide emissions compared to a scenario without wind energy use, but there wouldn't be any positive influence on the installed conventional generation capacity. However, in the case that less conventional generation capacity would have to be installed, this capacity effect could be seen as an additional benefit from wind generation and would make this technology even more economical. In this case, a "Capacity Credit" could be assigned to wind generation meaning that a certain percentage of the installed wind generation capacity could be considered as a contribution to the firm capacity of a system that is required for ensuring a safe and reliable electricity supply.

Even in systems not using renewable energy generation, it is necessary that the installed generation capacity exceeds the peak demand because also conventional power plants are not permanently available because of planned outages (for maintenance) and unplanned outages (faults). The excess of installed capacity over the peak demand is the Reserve Margin and represents an important constraint in the capacity planning process. According to [6], a reserve margin of 15% has been considered to be appropriate for ensuring a sufficiently reliable electricity supply of South Africa.

With the addition of wind generation, the classical, empirical approach based on the consideration of a reserve margin on the basis of typical availability indices of conventional power plants does not work anymore for assessing the required installed capacity:

- When applying the same reserve margin to the total generation capacity, including wind generation, the required installed capacity will be highly underestimated because the availability of wind generation is much below conventional generation based on fossil fuels.
- When applying the same reserve margin to conventional generation capacity only, hence considering that wind generation has a capacity credit of zero, the required installed capacity will be overestimated because the installed wind generation will tend to improve the reliability of supply, an effect which would be ignored by such a simplified approach.

Hence, the question arises how the capacity credit of wind generation can actually be quantified and used in the capacity planning process for determining the required electricity generation capacity.

This report presents the results of simulation studies for assessing the capacity credit of planned wind farms in South Africa. Therefore, three scenarios have been defined and agreed between ESKOM, GTZ and DIgSILENT [1]:

- Scenario 1: Year 2015: 2 000 MW of installed wind generation capacity
- Scenario 2: Year 2020 – low wind generation scenario: 4 000 MW of installed wind generation capacity
- Scenario 3: Year 2020 – high wind generation scenario: 10 000 MW of installed wind generation capacity

Based on Scenario 3, additional simulations have been carried out looking at up to 25 000 MW of installed wind generation capacity while keeping the specific distribution of wind generation constant.

The three scenarios are based on realistic assumptions with regard to wind farm sites, the potential installed wind generation capacity at these sites and the relevant characteristics of the South African power system, such as load and generation characteristics and planned expansions of thermal and hydro power plants, which have been provided by ESKOM [3].

A second part of the presented studies is analyzing simulated time series of load and wind generation for the three above defined scenarios.

This part of the studies is mainly looking at the following aspects:

- Worst case situations with regard to wind generation, load.
- Worst case situations with regard to wind and load variations (ramp-up/ramp-down speeds).
- Impact of wind generation on the cumulative probability curve of the residual load, which has to be covered by thermal and hydro power plants.
- Impact on residual load variations.
- Energy production and avoided carbon dioxide emissions.

The results of these studies will help determining the impact of wind generation on the required dynamic performance of thermal and hydro power plants.

2 Part 1 – Capacity Credit Studies

2.1 Approach and Methodology

2.1.1 Generation Adequacy

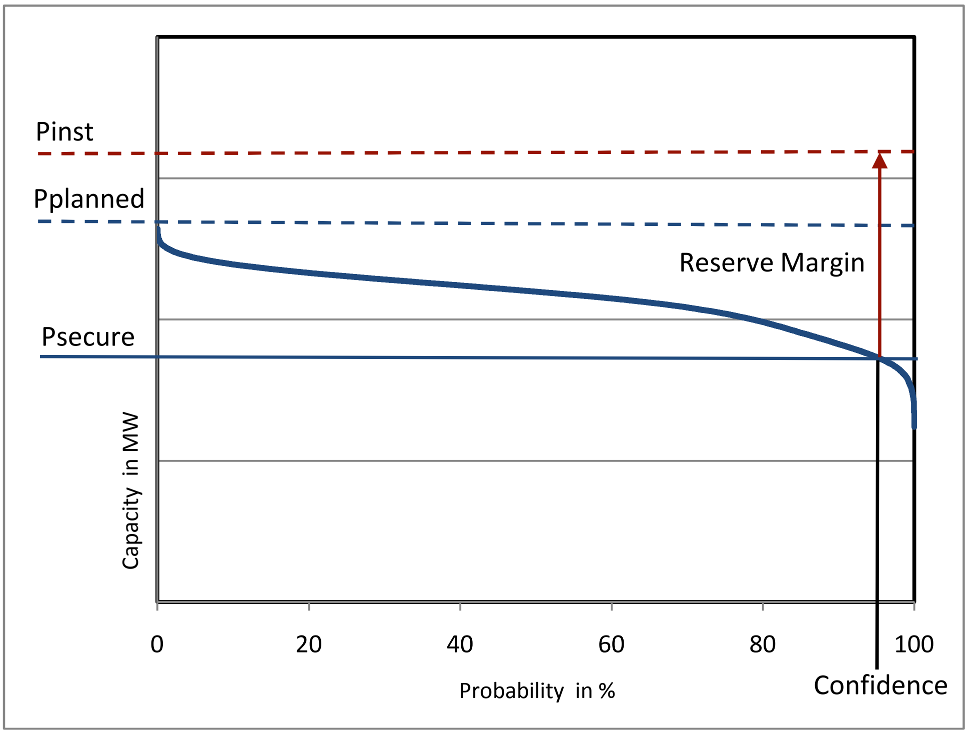


Figure 1: Generation Availability Curve

For assessing the capacity credit of wind generation, probabilistic methods for analyzing generation adequacy have to be applied. The basic concepts can best be explained using the generic example according to Figure 1. The blue curve in Figure 1 represents the cumulative probability curve for the available generation in a power system. The x-axis depicts probabilities in %, the y-axis shows the available capacity in MW. The blue curve shows the minimum available capacity at a specified probability level.

The available generation depends on the following parameters:

- Pinst: The installed capacity of the system
- Pplanned: Planned capacity during the observation period. The planned capacity is equal to the installed capacity minus planned outages (maintenance).
- Finally, the cumulative probability of the available capacity can be calculated on basis of the unplanned outages of all power plants in the system.

Using this approach, the demand that can be supplied with sufficient reliability (Psecure) is defined by the capacity that is at least available at a given confidence level (e.g. 99%).

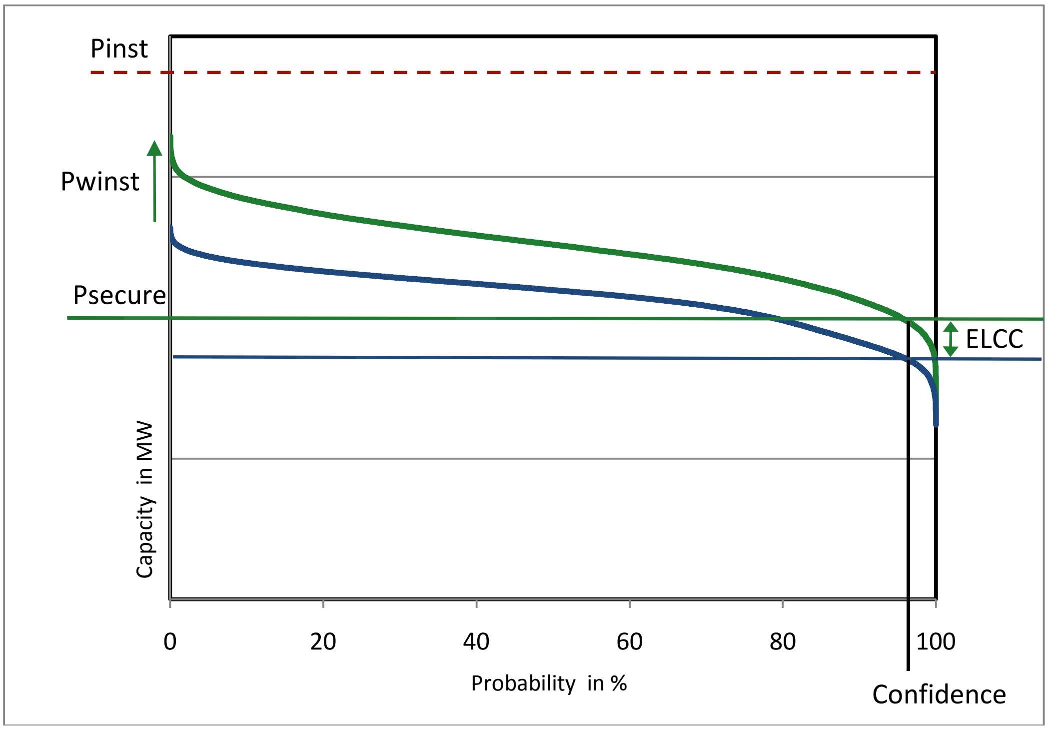


Figure 2: Generator Availability Curve - With Wind

For analyzing the influence of wind generation on the firm capacity the cumulative probability curve of the total available capacity, including conventional power plants and wind power plants, as depicted in Figure 2 needs to be calculated. The two curves have the following meaning:

- Blue curve: Cumulative probability curve of conventional generation.
- Green curve: Cumulative probability curve of conventional and wind generation together.

When comparing the green curve and the blue curve, it can be observed that the load level that can be supplied at the given confidence level has increased. This increase of securely supplied load is also named "Equivalent Load Carrying Capability" (ELCC) of the system and is a useful index for defining the capacity credit of wind generation.

2.1.2 Consideration of Correlation Effects - Methodology of the Presented Studies

In countries, in which a very distinct peak load situation can be identified, an approach purely based on the peak load situation might be sufficiently accurate because it can be assumed that only the peak load level contributes considerably to the average Loss of Load Probability (LOLP). In this case, it is sufficient to calculate the generation availability during the peak load time (season and hour of day) and to work out the capacity credit of wind generation purely on the basis of this simplified analysis.

However, in systems, in which the yearly load profile is relatively flat, not only the peak load situation might lead to loss of load situations but also other load situation may considerably contribute to the average LOLP. A simple analysis of generation availability at peak load is then inappropriate.

For this reason, the approach on which these studies are based on considers generation availability and the seasonal variation of daily peak loads together and calculates a cumulative probability curve of the available Reserve, whereas Reserve is defined by the excess of generation capacity over the daily peak load.

The relevant reliability index, on which the capacity credit definition of the presented studies is based on, is the average loss of load probability (LOLP) for daily peak loads. The average LOLP during peak load hours can be translated into a figure indicating the expected number of days per year during which the peak load cannot be covered by the available generation capacity.

The advantages of this approach are the following:

- It provides a realistic measure for system adequacy improvements due to wind generation.
- Considers correlation between load and planned outages.
- Considers correlation between wind speeds and seasonal load variations.
- Considers correlation between wind speeds and daily load variations.

The LOLP at daily peak loads is expressed in % but can also be expressed in terms of an average number of days per year during which a loss of load situation has to be expected. For example:

- An average LOLP at daily peak load of 1% would be equivalent to an average of 0,01x365=3,65 days per year during which the peak load cannot be covered by the available generation.
- An average LOLP at daily peak load of 0,1% is equivalent to an average of 0,365 days per year, hence around 1 day in 2,7 years at which the daily peak load cannot be covered.

The use of the average LOLP at daily peak load requires an assessment that considers the yearly load variation and the available capacity simultaneously. Instead of a cumulative probability curve of the available generation capacity, as presented in the previous section, the cumulative probability of the Reserve is calculated. A negative Reserve indicates a loss of load situation. Consequently, the probability with which the Reserve is lower than zero represents the average probability with which the daily peak load cannot be covered by the available generation capacity.

In this study, Capacity Credit is defined in terms of Equivalent Firm Capacity, which represents a firm capacity (capacity with 100% availability) that has the same influence on the reliability of supply of the system as the actually installed wind generation. Because the addition of a perfectly firm capacity would increase the Reserve by exactly the amount of the added firm capacity, the increase of Reserve at a given confidence level is a suitable measure for assigning an Equivalent Firm Capacity (EFC) to wind generation.

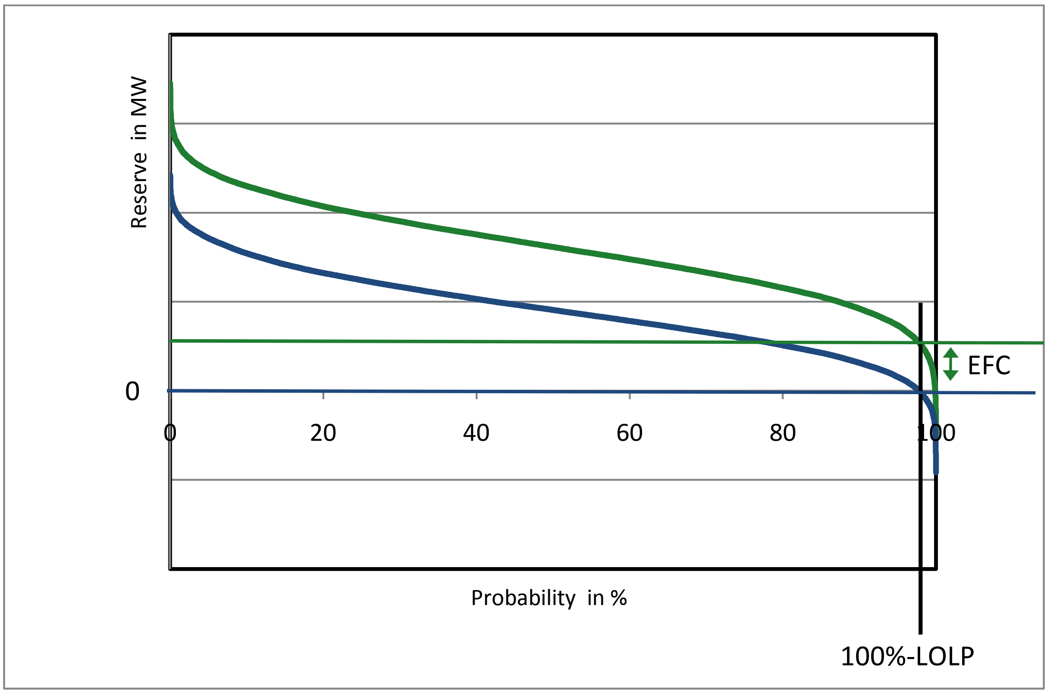


Figure 3: Cumulative Probability of the Available Reserve

Figure 3 shows the cumulative probability of the "Reserve" for a generic system.

According to Figure 3, the average LOLP without wind generation (blue curve) is equal to around 2%, which is equivalent to around 7,3 loss of load events per year. The LOLP of the system with wind generation (green curve) is equal to 99,9%, which corresponds to 0,365 loss of load events per year or 1 loss of load event within 2,7 years on average.

In a real system, there is always some operational reserve required for being able to compensate frequency deviations etc. Therefore, the equivalent firm capacity has not been defined at the zero crossing of the probability curve of the Reserve in the presented studies, but instead, the increase of available Reserve at a given confidence level of 99,9% has been taken.

Besides this, only the winter season has been considered, which represents the South African peak load season. Because the observed time frame corresponds only to half a year, a confidence level of 99,9%, as used in these studies, corresponds to less than 1 loss of load event within 5 years.

2.1.3 Assignment of Capacity Credit to Individual Regions or Wind Farms

The capacity credit of wind generation is a non-linear function that depends on

- Average generation of wind farms or capacity factor.
- Wind penetration level (ration between installed wind capacity and installed conventional generation capacity).
- Planned and unplanned outage rates of conventional power plants.
- Load variations.

Because of the nonlinear relationship, it is not possible to calculate the capacity credit of individual wind farms or wind farms in different regions directly. Capacity credit calculations must always consider the whole system.

However, with the following assumptions it is possible to assign portions of the total equivalent firm capacity to individual wind farms or regions:

It can be shown that the Equivalent Firm Capacity (EFC) of wind generation can very well be approximated by a formula that decomposes nonlinear and linear parts:

$$EFC = CR(cp) \cdot Pav_{fl}$$

$$CC = {}^{EFC}\!/_{P_r} \times 100$$

with:

- EFC: Equivalent Firm Capacity (in MW)
- CR: Capacity Reduction factor
- cp: Wind penetration level (ratio of installed wind capacity and installed conventional generation capacity)
- Pav_{fl}: Average production during full load period (season and hour per day)
- CC: Capacity Credit (in %)
- P_r: Rated power of totally installed wind generation (in MW)

In this approximate formula, all non-linear parts are lumped into the "Capacity Reduction Factor" CR, which is a system-wide parameter that mainly depends on the wind penetration level and which is highly independent from the wind conditions at individual sites or regions.

The dependence of EFC on site-specific parameters, such as the average production during full load hours, is a linear relationship in this formula and therefore superposition can be applied:

$$EFC = CR(cp) \cdot \sum_i Pav_{fl_i} = \sum_i EFC_i$$

The index i represents the individual wind farms or regions of a system. The equivalent firm capacity of each wind farm or region i can be calculated using:

$$EFC_i = CR(cp) \cdot Pav_{fl_i}$$

A verification of this approach is depicted in Figure 15 on page 27 showing the factor CR in function of the wind penetration level for the two different study years 2015 and 2020. Based the calculated EFC for each study year and the average production during full load hours (Pav_{fl}), which can directly be obtained by analyzing the available wind speed time series data, CR can be calculated using CR(cp)=EFC/ Pav_{fl}.

As it can be seen in Figure 15, the two curves representing the two study years are lying almost on top of each other even if wind conditions, number and size of the modelled wind farms are highly different. This confirms the assumption that CR is mainly independent from site specific data and only depends on system characteristics.

Besides regional allocation of capacity credit of wind generation, the simplified formula allows an easy prediction of capacity credit and equivalent firm capacities for variations with regard to the wind scenarios (see section 2.2).

In the case that the actual wind farm development will considerably deviate from the assumptions on which the scenarios of the presented studies were based, it will still be possible to calculate equivalent firm capacity and capacity credit of wind generation by using the approximate formula and the capacity credit reduction factor CR in function of the wind penetration level according to Figure 15 and to multiply the CR with the average production of the considered wind farms.

2.1.4 Modelling

2.1.4.1 Load Model

The load data used for the presented studies correspond to the "Moderate Load Growth Scenario" of the IRP2010 [6]. Further, the load model considers the Net Demand forecast that has been made for 2015 and 2020 considering the regular load forecast and the effect of Demand Side Management measures that will be implemented until 2015 and 2020.

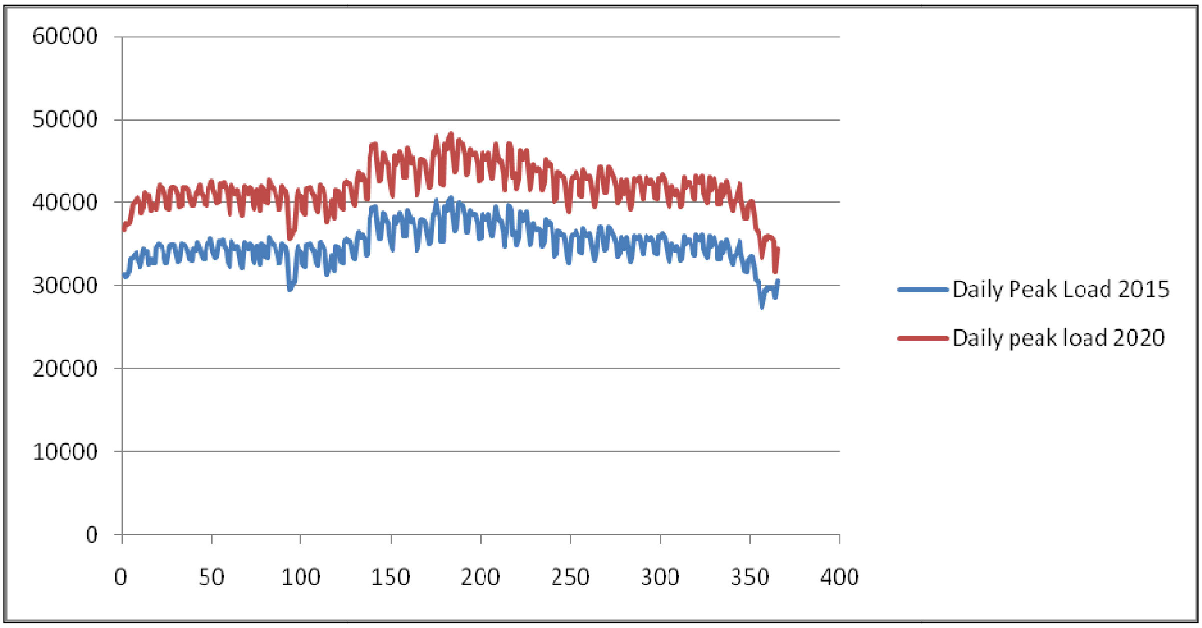


Figure 4: Forecast of Daily Peak Load (Net Demand) for 2015 and 2020

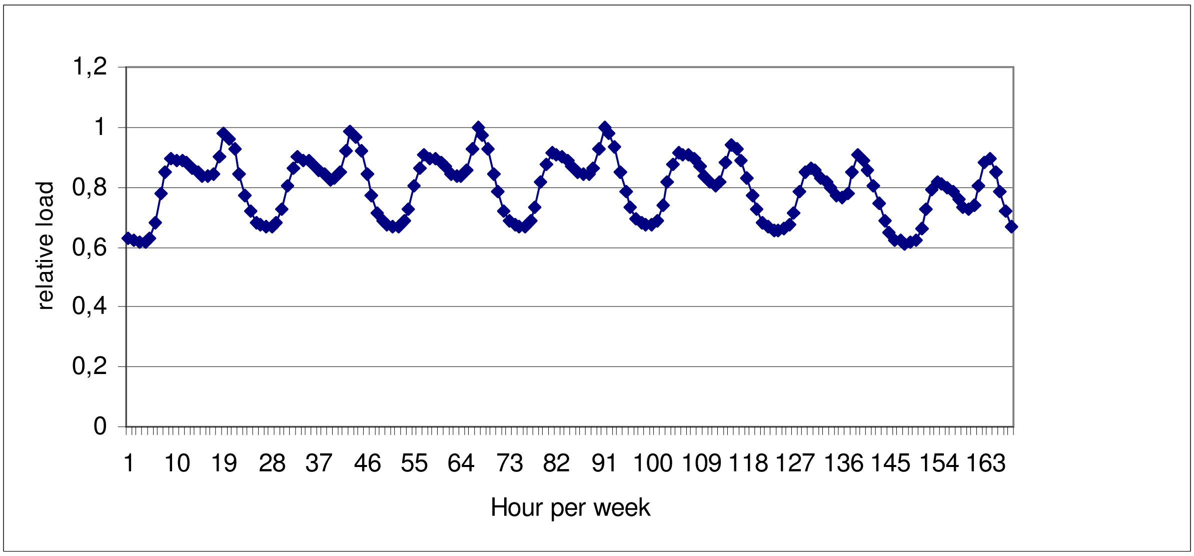


Figure 5: Typical hourly load variations in winter

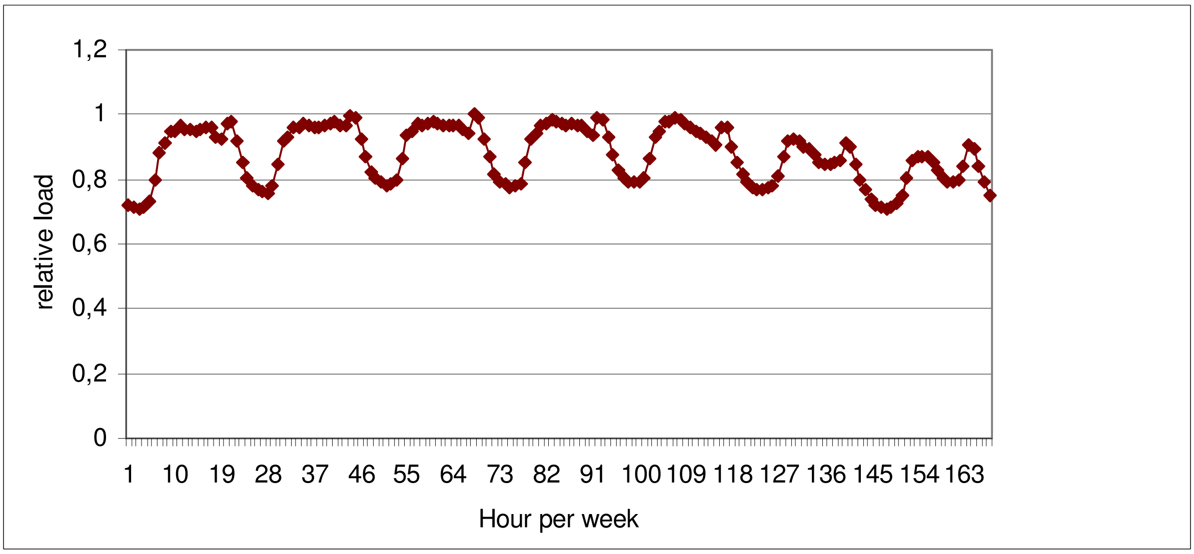


Figure 6: Typical hourly load variations in summer

More precisely, the load model is based on the following load data according to [3]:

- Forecast of daily peak load for 2015 and 2020 (see Figure 4)
- Typical relative hourly load variations for a typical week in winter (see Figure 5) and a typical week in summer (see Figure 6).

Based on the typical hourly load variations (see Figure 5 and Figure 6), the following information has been extracted and used by the studies:

- In winter, full load hours are between 18:00h and 21:00h.
- In summer, the daily load is relatively flat and full load hours can occur between 08:00h and 21:00h.

2.1.4.2 Modelling of Dispatchable Generation

For modelling the availability of dispatchable power plants, ESKOM provided planned and unplanned outage rates of all South African power stations [3]:

Unplanned outages are modelled by two-state Markov-models considering their unplanned outage rates as provided by ESKOM.

For considering planned outages (maintenance) the monthly system-wide planned outage rate has been provided by ESKOM [3]. Based on this information, a number of generators have been "put on maintenance" in each month. The total number of generators on outage in each month considers the maximum limits that were provided by ESKOM.

2.1.4.3 Modelling of Wind Generation

2.1.4.3.1 Wind Speed Data

Windlab Systems has carried out studies [4] for producing time series data of hourly average wind speeds at 80m height at all potential wind farm sites, which have been defined by ESKOM [2],

The Windlab methodology is based on an atmospheric modelling approach whose input are synoptic weather data gathered by the world meteorological organisation (WMO).

Based on these data a regional scale model is initially applied allowing modelling wind speeds with a 6 hours/1 degree resolution.

This regional model accounts for forces associated with stratification and inertial forces, friction with the earth's surface, accelerations and steering over and around large scale topographical features (such as mountains) and thermal circulations such as sea breezes.

The fine-scale model then uses the regional-scale model as a boundary condition to create a yet finer grid, typically of 100 meter resolution. This model takes into account friction from various types of land cover (forests, crops etc) and acceleration over and around smaller-scale topography.

The fine-scale model is then validated using Automatic Weather Stations (AWS) and Meteorological mast data, where available. This validation is applied to the model to reflect the long-term average.

Time-series of wind speed with a time resolution of 1 hour and direction at the points of interest are extracted from the model. These allow the generation of statistical tools such as wind roses, probability distributions and monthly averages. These time-series are point statistics and unless great attention has been paid to the selection of these locations they cannot be used to represent the absolute wind resource of a region such as a wind farm or collection of wind farms, for instance for assessment of individual project feasibility.

These time series data of wind speeds have been calculated for each potential wind farm site as defined by ESKOM for the different scenarios and were used as input into the capacity credit studies.

2.1.4.3.2 Transformation into Power Time Series Data

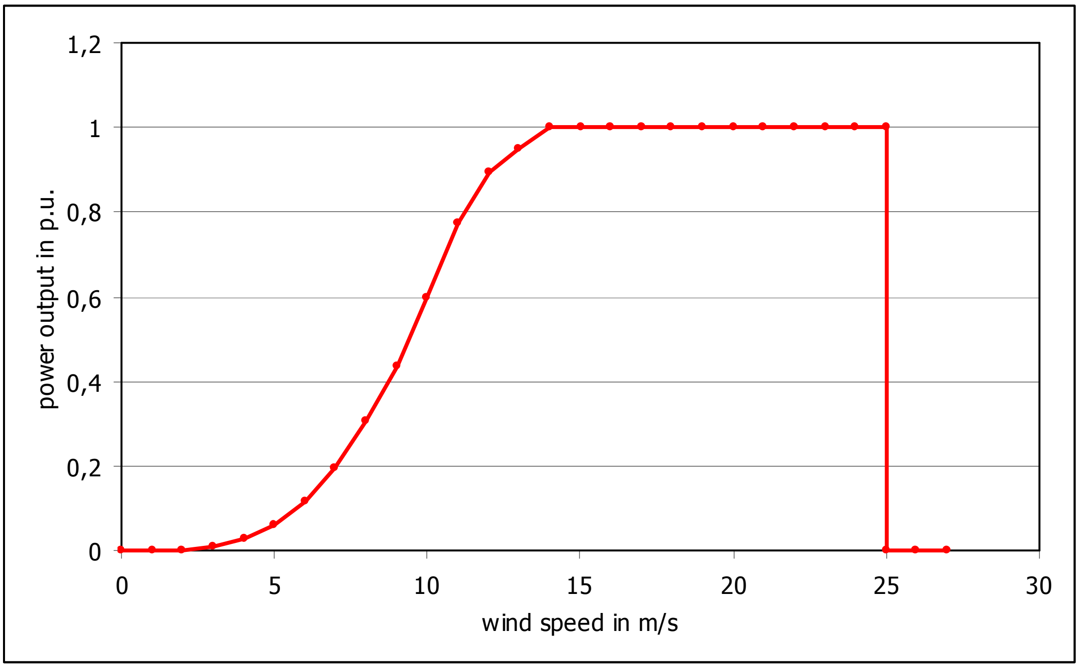


Figure 7: Generic power curve used for Capacity Credit Studies

For transforming wind speed data into power data, a generic power curve was considered (see Figure 7).

Losses or technical unavailability have not been considered explicitly because these effects are covered by the general uncertainty margin that has to be expected by the study results.

For accurately considering correlation between wind generation and load, time series of wind speeds have been used and converted into a power time series (see e.g. Figure 8) at each site using the power curve according to Figure 7. The daily and seasonal correlation between wind speeds and load is therefore automatically considered by the corresponding time series data.

The diurnal correlation between wind speed and load is considered by only using wind speed data during full load hours (see also Figure 8). As described in section 2.1.3, these full load hours are different for summer and winter. For this reason, two capacity credit calculations have been carried out for each scenario, one for the summer season and one for the winter season.

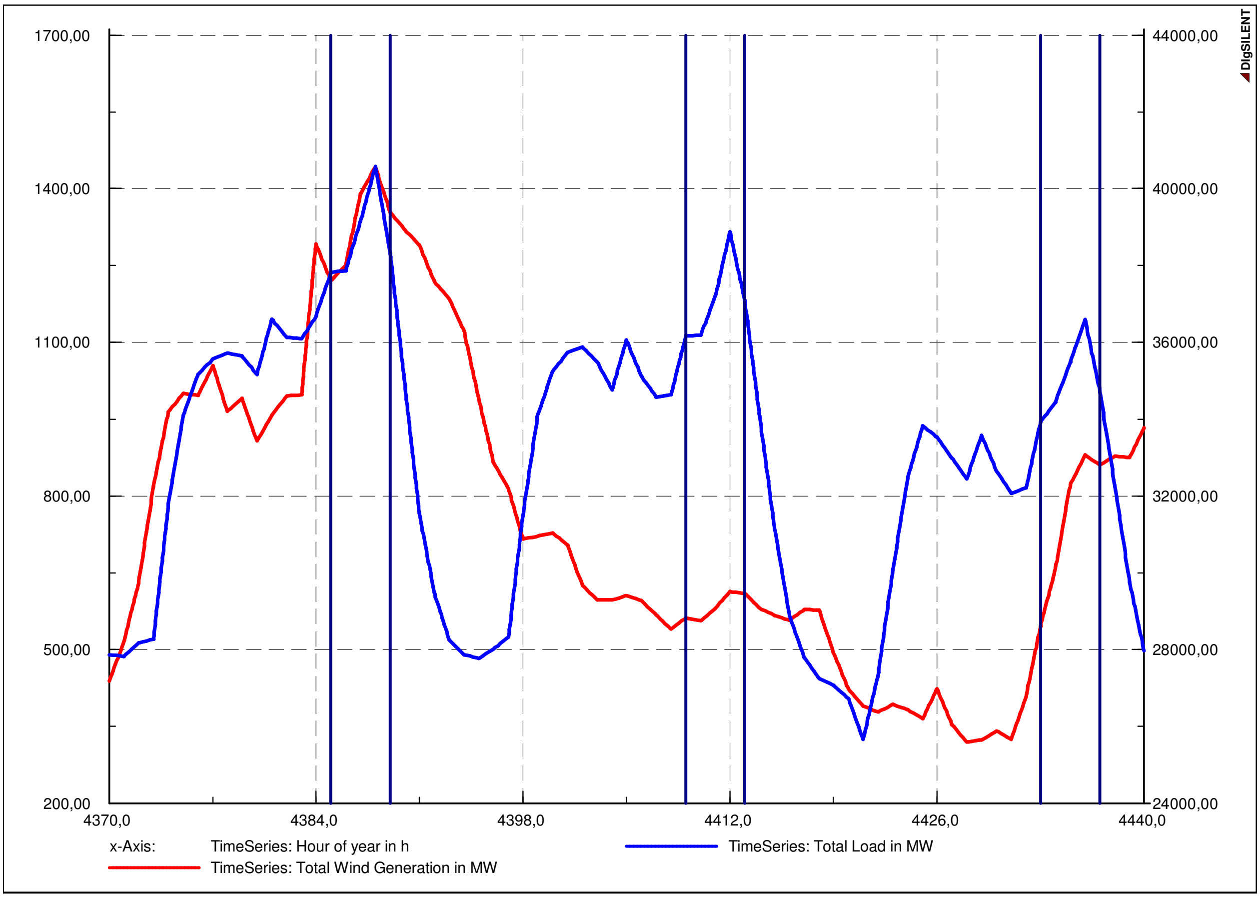


Figure 8: Example of Wind Generation Time Series as used for studies (red line)

The following wind speed data were considered for each season:

- Winter season: Wind speed time series of the months April to September considering only wind speeds during 18:00h and 21:00h every day.
- Summer season: Wind speed time series from October to March considering only wind speeds during 08:00h and 21:00h every day.

Because the winter load is considerably higher than the summer season it can be assumed that events in summer have only a very low contribution to the LOLP. Therefore, only the results obtained for the winter season have finally been used for assessing capacity credit of wind generation.

2.1.5 Simulation Model

Capacity credit studies for the South African case have been carried out by the use of 3 main scenarios, representing different study years and different assumptions with regard to the installed wind generation capacity.

The DIgSILENT PowerFactory model integrates all conventional generators, all wind farms as defined for each scenario and the system load represented by a daily peak load characteristic.

For calculating the capacity credit of wind generation, a Monte Carlo analysis approach has been used, considering:

- Daily peak load characteristic.
- Planned and unplanned outages of conventional generators.
- Correlation of wind speeds at different sites.
- Daily, weekly and monthly correlation between wind speeds and the daily peak load.
- Correlation between wind speeds and daily full load hours.

The Monte Carlo Simulation model calculates the following key quantities:

- Cumulative probability curve of the available conventional generation capacity
- Cumulative probability curve of daily peak-loads (peak-load duration curve)
- Cumulative probability curve of the residual load (load minus wind generation)
- Cumulative probability curve of the "Reserve" (generation – load)

The average loss of load probability at daily peak load can be obtained from the cumulative probability of the Reserve: Every case, in which the Reserve is less than zero indicates that the available generation capacity is not able to cover the load at this point. An evaluation of the cumulative probability curve of the Reserve allows quantifying the probability of such a loss of load situation.

2.2 Scenario Definition

For analyzing the contribution of wind generation in South Africa to the firm capacity of the system, three main scenarios for different study years and different assumptions with regard to the prospected installed wind generation capacity have been defined:

- Scenario 1: Year 2015 with 2000MW of wind generation
- Scenario 2: Year 2020 with 4800MW of wind generation (low wind scenario)
- Scenario 3: Year 2020 with 10000MW of wind generation (high wind scenario)

2.2.1 Scenario 1 – Year 2015 with 2000MW of Installed Wind Capacity

Scenario 1 applies to the year 2015. The assumed installed wind generation capacity is equal to 2000MW.

The main parameters of Scenario 1 are the following:

- Total installed conventional (thermal, hydro, pump storage and nuclear) capacity: 52 537MW
- Installed wind generation capacity – total: 2 000MW
- Installed wind generation capacity in Western Region: 1 550MW
- Installed wind generation capacity in Southern Region: 450MW
- Peak load (Peak Net Demand): 40 582MW
- Wind penetration level based on installed conventional capacity: 3,8%
- Wind penetration level based on peak load 4,9%

2.2.2 Scenario 2 – Year 2020-Low Wind Scenario with 4800MW of Installed Wind Capacity

Scenario 2 applies to the year 2020 and makes rather pessimistic assumptions for the amount of wind generation that will be installed in South Africa until then. The main parameters of Scenario 2 are:

- Total installed conventional (thermal, hydro, pump storage and nuclear) capacity: 59 753MW
- Installed wind generation capacity – total: 4 800MW
- Installed wind generation capacity in Western Region: 3 200MW
- Installed wind generation capacity in Southern Region: 1 600MW
- Peak load (Peak Net Demand): 48 316MW
- Wind penetration level based on installed conventional capacity: 8,0%
- Wind penetration level based on peak load 9,9%

2.2.3 Scenario 3– Year 2020-High Wind Scenario with 10 000MW of Installed Wind Capacity

Scenario 3 is identical to Scenario 2 with regard to the conventional generation and the load data but making more optimistic assumptions with regard to the wind generation capacity that will be installed until 2020. The key parameters of scenario 3 are:

- Total installed conventional (thermal, hydro, pump storage and nuclear) capacity: 59 753MW
- Installed wind generation capacity – total: 10 000MW
- Installed wind generation capacity in Western Region: 7 800MW
- Installed wind generation capacity in Southern Region: 2 200MW
- Peak load (Peak Net Demand): 48 316MW
- Wind penetration level based on installed conventional capacity: 16,7%
- Wind penetration level based on peak load 20,7%

The wind penetration level of the three scenarios varies between around 5% and 20% (based on peak load), which can be considered to be moderate, even in Scenario 3.

2.3 Results of Simulation Studies

For analyzing the capacity credit of planned wind farms in South Africa, Monte-Carlo simulations using the power system analysis software DIgSILENT *PowerFactory* have been carried out applying the methods described in section 2.1.

The increase of the available Reserve at a confidence level of 99,9% has been defined to be the Equivalent Firm Capacity of wind generation in South Africa (see section 2.1). The results of the capacity credit assessment for the three scenarios are presented in the following sections.

2.3.1 Scenario 1 – Year 2015 with 2000MW of Installed Wind Capacity

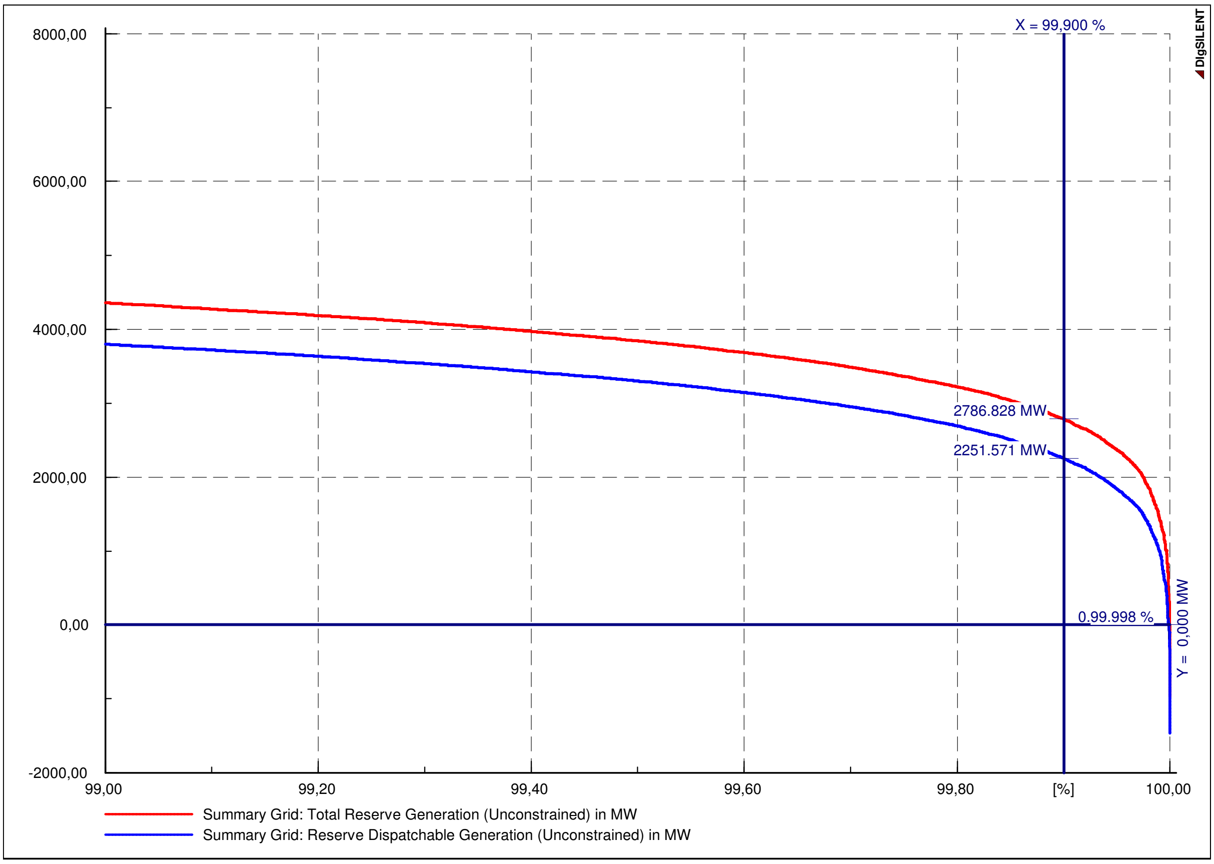


Figure 9: Available Reserve with and without wind generation for Scenario 1 (range > 99%)

Figure 9 shows the cumulative probability curve of the available Reserve in the South African System with wind generation (red) and without (blue) wind generation for the winter (high load) season.

At the given confidence level of 99,9%, the difference between the two curves is equal to 536MW, which corresponds to a capacity credit of 26,8%.

Additional results of capacity credit simulations for the winter 2015 case are depicted in Annex 1.1.

The key results for Scenario 1 (2015) are the following:

- Available Reserve at 99,9% confidence without wind: R=2 252 MW
- Available Reserve at 99,9% confidence with wind: R=2 787 MW
- Equivalent Firm Capacity: EFC= **535 MW**
- Capacity Credit: CC= **26,8%**
- Average Wind Generation (year): Pav= 543 MW
(Av. Capacity Factor: 27,17%)
- Average Wind Generation during full load hours: Pav_full= 605 MW (30,25% of Pwinst)

Because the wind penetration level is still relatively low in Scenario 1, the capacity credit of wind generation is very close to the average capacity factor of wind generation in Scenario 1.

Because of the low wind penetration level (around 5% based on peak load), the Capacity Reduction Factor CR is very close to 0,9 (see also Figure 15). On the other hand, the average wind generation during full load hours is considerably higher than the yearly average wind generation. These two aspects – Capacity Reduction Factor and positive correlation between wind generation and load – almost compensate each other leading to a capacity credit, which is almost equal to the capacity factor.

2.3.2 Scenario 2 – Year 2020-Low Wind Scenario with 4800MW of Installed Wind Capacity

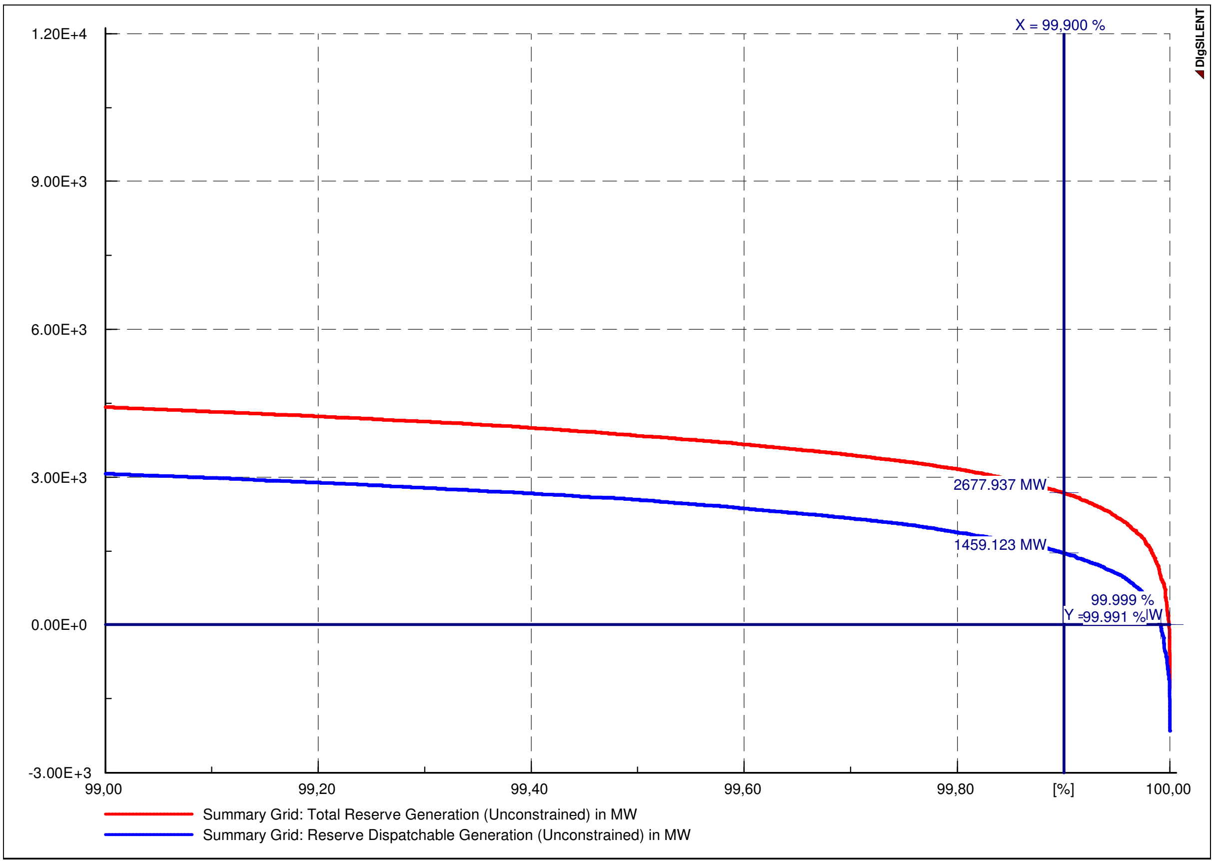


Figure 10: Available Reserve with and without wind generation for Scenario 2 (range > 99%)

The cumulative probability curve of the available Reserve with and without wind generation of Scenario 2 is depicted in Figure 10. At the given confidence level of 99,9% the difference between the Reserve with wind generation and without wind generation is here equal to 1218 MW, which is equal to 25,4% of the installed wind generation capacity of this scenario.

Additional results of capacity credit simulations for the winter 2020/low wind generation case are depicted in Annex 1.2.

The key results for Scenario 2 (2020-low wind generation) are the following:

Available Reserve at 99,9% confidence without wind:	R=1 459 MW
Available Reserve at 99,9% confidence with wind:	R=2 678 MW
Equivalent Firm Capacity:	EFC=**1 218 MW**
Capacity Credit:	CC= **25,4%**

- Average Wind Generation (year): Pav=1 468 MW (Av. Capacity Factor: 30,6%)
- Average Wind Generation during full load hours: Pav_full=1 652 MW (34,4% of Pwinst)

Comparing the capacity credit figures of Scenario 2 with Scenario 1 it can be observed that capacity credit for Scenario 2 is only slightly below the Scenario 1 capacity credit, even if the wind penetration level increases considerably (CP around 10% based on peak load), which would normally lead to a reduction of the capacity credit (see Figure 15).

The reason for this effect is that the average wind speeds of the wind farm sites considered for Scenario 2 are higher than in Scenario 1 (Av. Capacity Factor of 30,6% compared to 27,2%/Scenario 1). This means that the sites with the best wind conditions will not necessarily be developed first, but other aspects, such as the surrounding infrastructure (e.g. the next grid access point) might play an important role in the wind farm development process too. Additionally, wind farm developers will first develop smaller projects requiring lower investments and less grid expansion so that some of the very large wind farm projects proposed in high wind areas in South Africa will be expected to be developed at later stages.

2.3.3 Scenario 3– Year 2020-High Wind Scenario with 10 000MW of Installed Wind Capacity

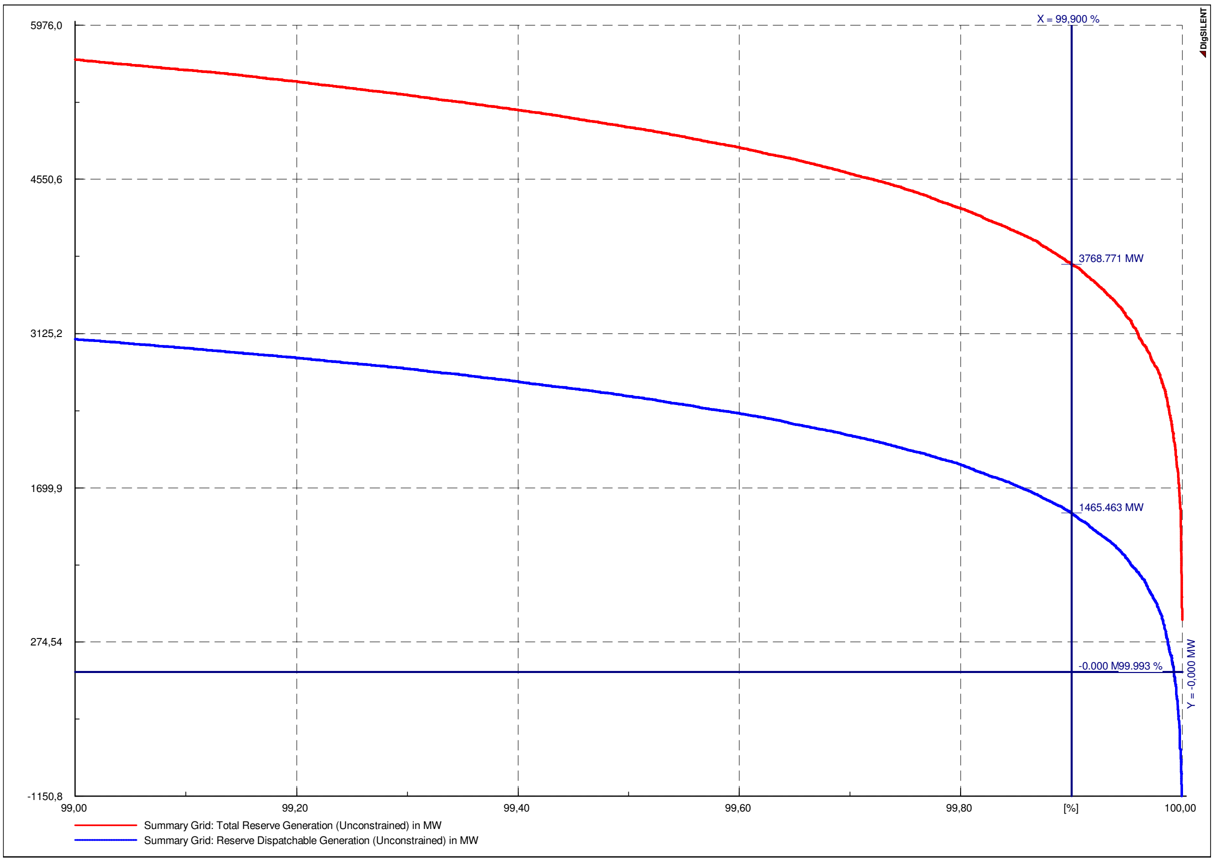


Figure 11: Available Reserve with and without wind generation for Scenario 3 (range > 99%)

Figure 11 shows the cumulative probability curve of the Available Reserve with and without wind generation for Scenario 3. The Equivalent Firm Capacity of this scenario is equal to 2 256MW, which is equal to 22,6% of the installed wind generation capacity.

Additional results of capacity credit simulations for the winter 2020/high wind generation case are depicted in Annex 1.3.

The key results for Scenario 3 (2020-high wind generation) can be summarized as follows:

Available Reserve at 99,9% confidence without wind:	R=1 456 MW
Available Reserve at 99,9% confidence with wind:	R=3 716 MW
Equivalent Firm Capacity:	EFC=**2 256 MW**
Capacity Credit:	CC= **22,6%**
Average Wind Generation (year):	Pav=3 200 MW (Av. Capacity Factor: 32%)
Average Wind Generation during full load hours:	Pav_full=3 577 MW (35,8% of Pwinst)

The average capacity factor of wind farms in this scenario further increase compared to Scenario 2, while the capacity credit decreases considerably. This is because of the considerably increased wind penetration level (CP=20,7% based on peak load), which leads to a degradation of capacity credit of wind generation. The Capacity Reduction Factor CR is down to 0,63 in this scenario, which explains the degradation of Capacity Credit compared to Scenario 1 and Scenario 2 (see also Figure 15).

2.3.4 Outlook for up to 25 000MW of Installed Wind Capacity

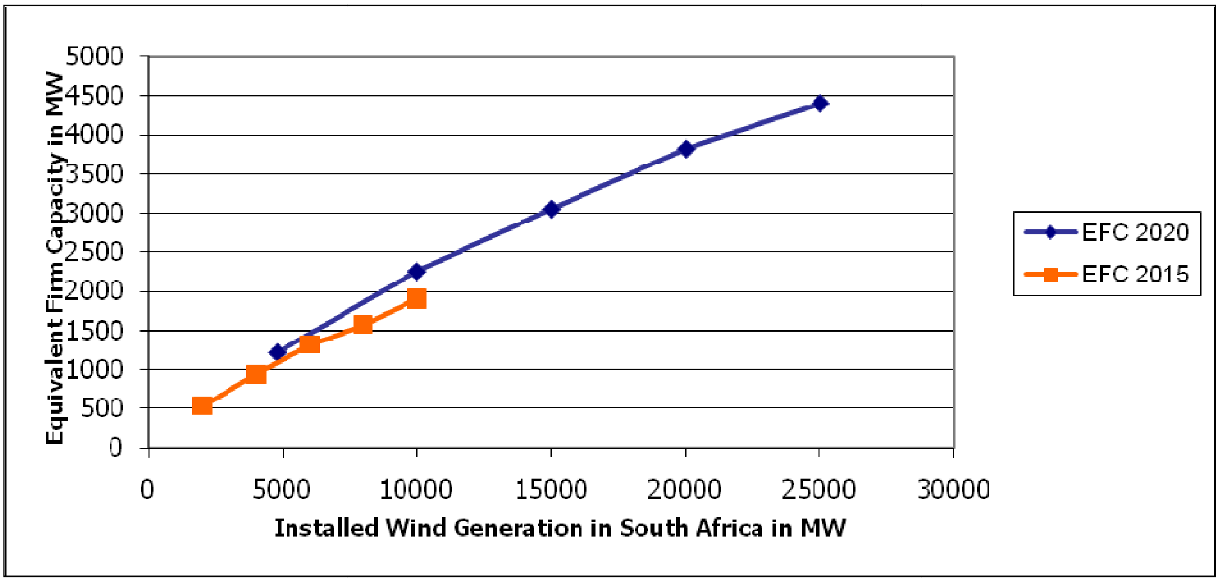


Figure 12: EFC in function of the installed wind capacity

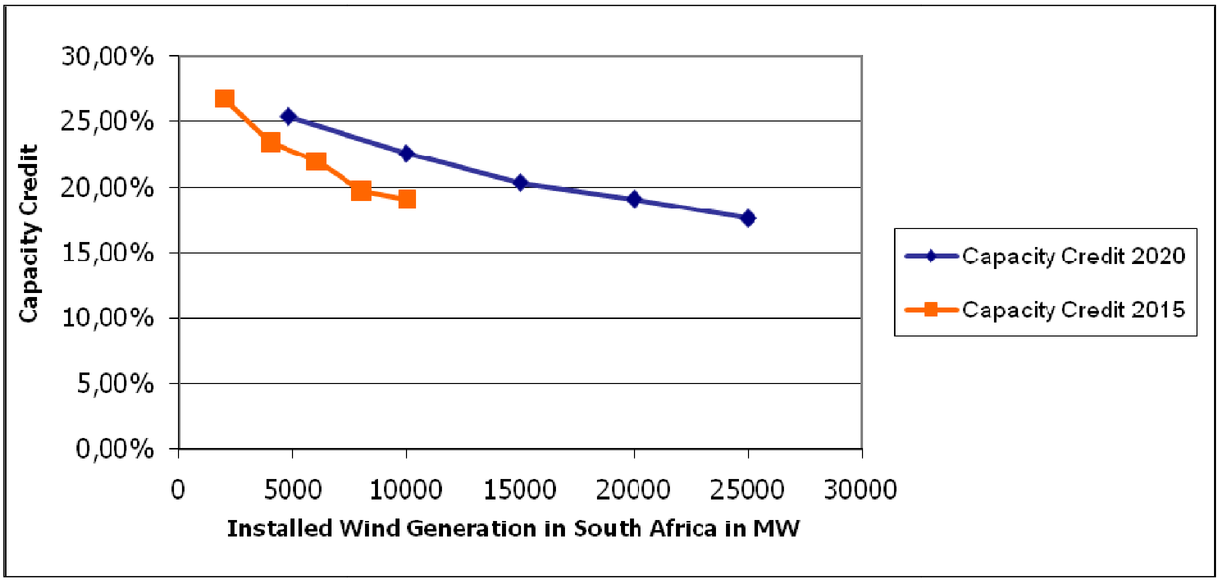


Figure 13: Capacity Credit in function of the installed wind capacity

For estimating the dependence of capacity credit on further increasing wind penetration levels, additional studies have been carried out looking at increased wind generation capacities while keeping the specific distribution of wind generation constant.

In practical terms this means that for the purpose of these sensitivity studies the rating of each individual wind farm is scaled up while keeping all other parameters unchanged.

The results of the sensitivity studies are depicted in Figure 12 and Figure 13. The results show that with increasing wind penetration levels, the capacity credit of wind generation is reducing.

But even at a level of 25 000MW of installed wind generation capacity, which corresponds to a wind penetration level of around CP=50% (based on the 2020 peak load) , the contribution of additional wind generation to the equivalent firm capacity of the South African system is still considerable and amounts to around 17,6%.

Because the Capacity Reduction Factor CR mainly depends on the wind penetration level, it is possible that the actual Capacity Reduction Factor CR will actually be higher when the installed wind generation capacity will reach a level as high as 25 000MW because the load will grow beyond the 2020 level. Hence, the estimated capacity credit for a totally installed wind generation capacity of 25 000MW can be considered to be a conservative estimate.

2.3.5 Wind Farms in the Western and Southern Region

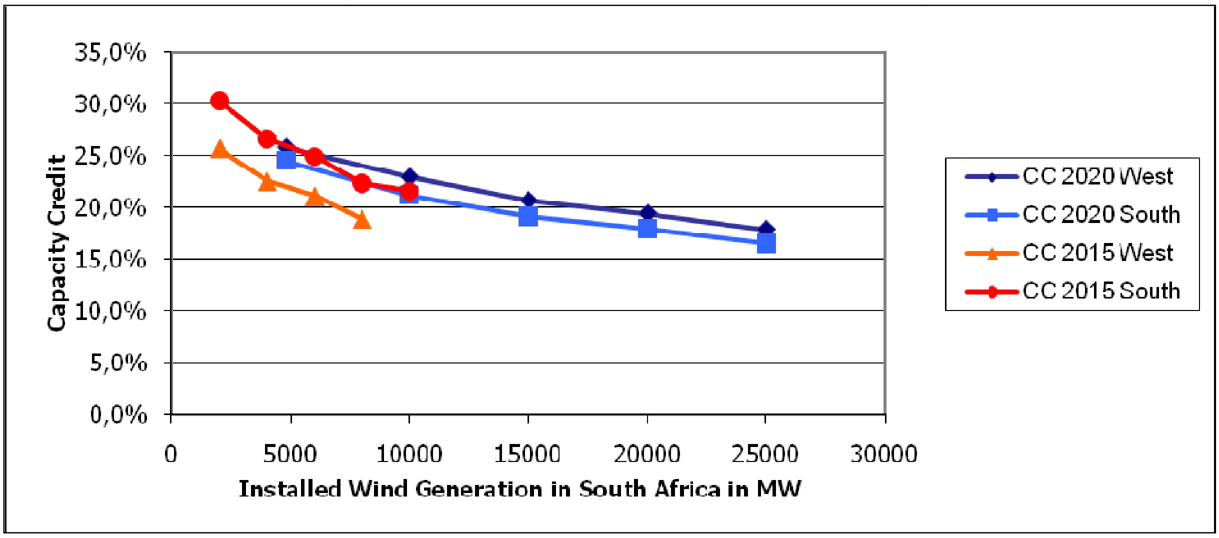


Figure 14: Capacity Credit of Wind Farms in South Africa (Western and Southern Region)

For assigning a capacity credit to the wind farms of the individual regions, it can be assumed that capacity credit is approximately proportional to the average wind generation during the peak load period (season and time of the day). The factor of proportionality is predominantly a system-wide parameter and depends mainly on the loss of load probability and the wind penetration level (see also section 2.1.3).

The results of capacity credit calculations for the different regions that have been calculated using the formulas described in section 2.1.3, are depicted in Figure 14. This figure shows that in Scenario 1/2015, the average capacity credit of wind farms in the Southern Region is considerably higher than the average capacity credit of wind farms in the Western Region, whereas in 2020 (Scenario 2 and 3), the average capacity credit of wind farms in both regions is almost equal.

This means that the wind farm sites in the Southern Region that have been selected for Scenario 1 have better wind conditions than the wind farm sites in the Western Region. In the longer term (Scenario 2020) the wind conditions of wind farms in both regions are very similar.

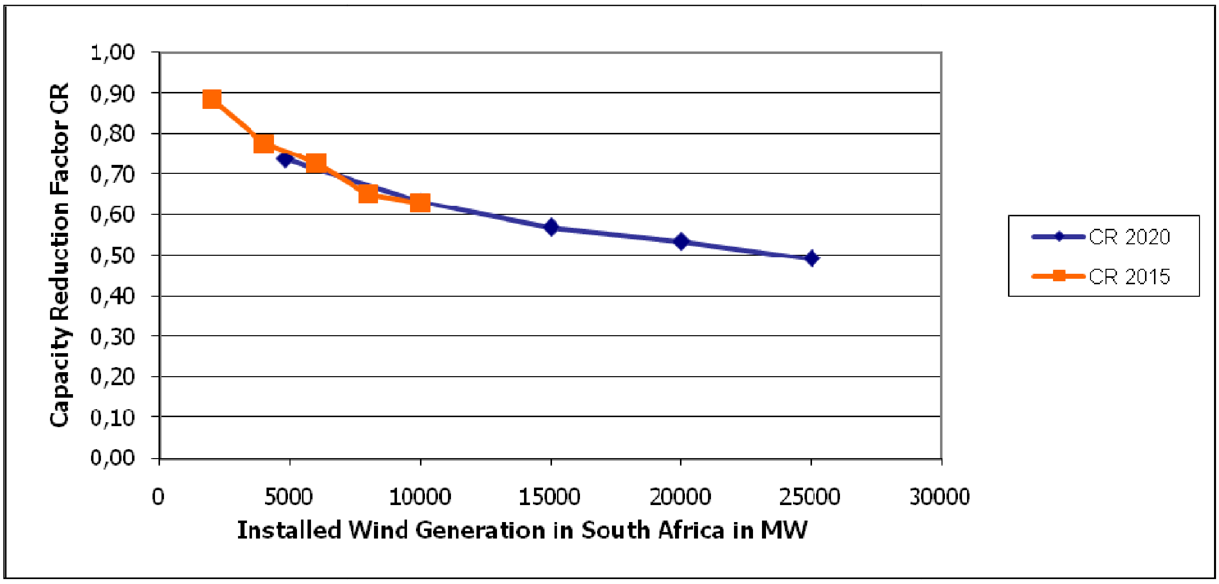


Figure 15: Capacity Reduction Factor in function of installed wind generation

The "Capacity Reduction Factor" CR, which is the ratio of capacity credit and average wind generation during full load hours is depicted in Figure 15 for the winter seasons 2015 and 2020. The "Capacity Reduction Factor" CR depends mainly on the following parameters:

- System characteristics (generation/load), especially the LOLP without wind generation.
- Wind penetration level.

and is (almost) independent from specific wind site characteristics. This is confirmed by Figure 15, in which the curves for 2015 and 2020 are lying almost on top of each other.

2.3.6 Comparison with Thermal or Hydro Power Plants

The results of the presented capacity credit studies are expressed in terms of "Equivalent Firm Capacity". This means that the contribution of wind generation to the reliability of the South African power system is compared with a perfect power plant with an availability of 100%.

However, actual coal fired power stations in South Africa have an availability between 80% and 90% (considering planned and unplanned outages). This means that when comparing wind generation in South Africa with actual coal fired power stations, the Equivalent Capacity (EC) is between 11% and 25% higher than the reported Equivalent Firm Capacity. Considering this aspect the following capacity credit figures can be assigned to wind generation in South Africa:

- Scenario 1: EFC= 536MW 596MW < EC < 670MW **29,8% < CC < 33,5%**
- Scenario 2: EFC=1218MW 1253MW< EC < 1523MW **26,1% < CC < 31,7%**
- Scenario 3: EFC=2256MW 2507MW < EC < 2820MW **25,1% < CC < 28,2%**

These figures mean that the installed capacity of a wind farm must be around 3 to 4 times higher than the installed capacity of a coal fired power plant in order to have the same effect on generation adequacy.

3 Part 2: Impact of Wind Generation in South Africa on System Operation

3.1 Approach and Methodology

This second part of the presented studies assesses the operational impact of wind generation in South Africa.

The approach of these studies is based on a time series analysis of load and wind generation for the three scenarios introduced in section 2.2, which are:

- Scenario 1: Year 2015, 2000MW of installed wind generation capacity
- Scenario 2: Year 2020, 4800MW of installed wind generation capacity
- Scenario 3: Year 2020, 10 000MW of installed wind generation capacity

Since the studies presented in this part 2 are only based on an analysis of the residual load, without looking in detail at dynamic performance characteristics of existing South African power plants, the results presented here can only give an indication about potential issues and cannot make any definite statement with regard to the impact of wind generation on operational reserve and dynamic performance requirements of thermal and hydro power plants in South Africa.

Further studies will be required for simulating the operation of the South African power system under the new conditions.

This report will present time series data of the following worst case situations:

- Worst-case Wind ramp-up and ramp-down conditions.
- Peak load situations.
- Minimum residual load situations.

These time series simulations are not based on actual measurements but on projected hourly load data for 2015 and 2020 (provided by ESKOM) and wind speed time series of all considered wind farm sites (provided by Windlab Systems, see section 2.1.4.3.1 and [4]).

Based on these time series data, duration curves (cumulative probability curves) are calculated for wind generation and load as well as for hourly variations of wind generation and load.

3.2 Results of Time Series Simulation Studies

Worst case situations for each of the three scenarios are depicted in Annex 3. The figures in Annex 3 show the following situations:

- Typical Winter Situation (long term)
- Typical Summer Situation (long term)
- Week with maximum observed wind generation
- Week with minimum observed wind generation
- Week with maximum observed ramp-up situation
- Week with maximum observed ramp-down situation
- Week during which peak load occurs
- Week during which minimum residual load occurs
- Load/residual load and wind generation duration curves
- Duration curves of hourly variations of load, residual load and wind generation

3.2.1 Impact on Main System Performance Characteristics

Table 1: Worst-case observations of time domain simulations

		Sc1	Sc2	Sc3
Peak Net Demand	[MW]	40582	48 316	48 316
Installed Wind Capacity	[MW]	2000	4800	10000
Max. Wind Generation	[MW]	1741	4227	8471
Max. hourly load variation (ramp-up)	[MW/h]	3897	4539	4539
Max. hourly load variation (ramp-down)	[MW/h]	-3845	-4536	-4536
Max. hourly variation of wind generation (ramp-up)	[MW/h]	502,4	1369	2547
Max. hourly variation of wind generation (ramp-down	[MW/h]	-356	-1102	-1670
Max. hourly variation of residual load (ramp-up)	[MW/h]	3862	4542	4788
Max. hourly variation of residual load (ramp-down)	[MW/h]	-3847	-4527	-4797

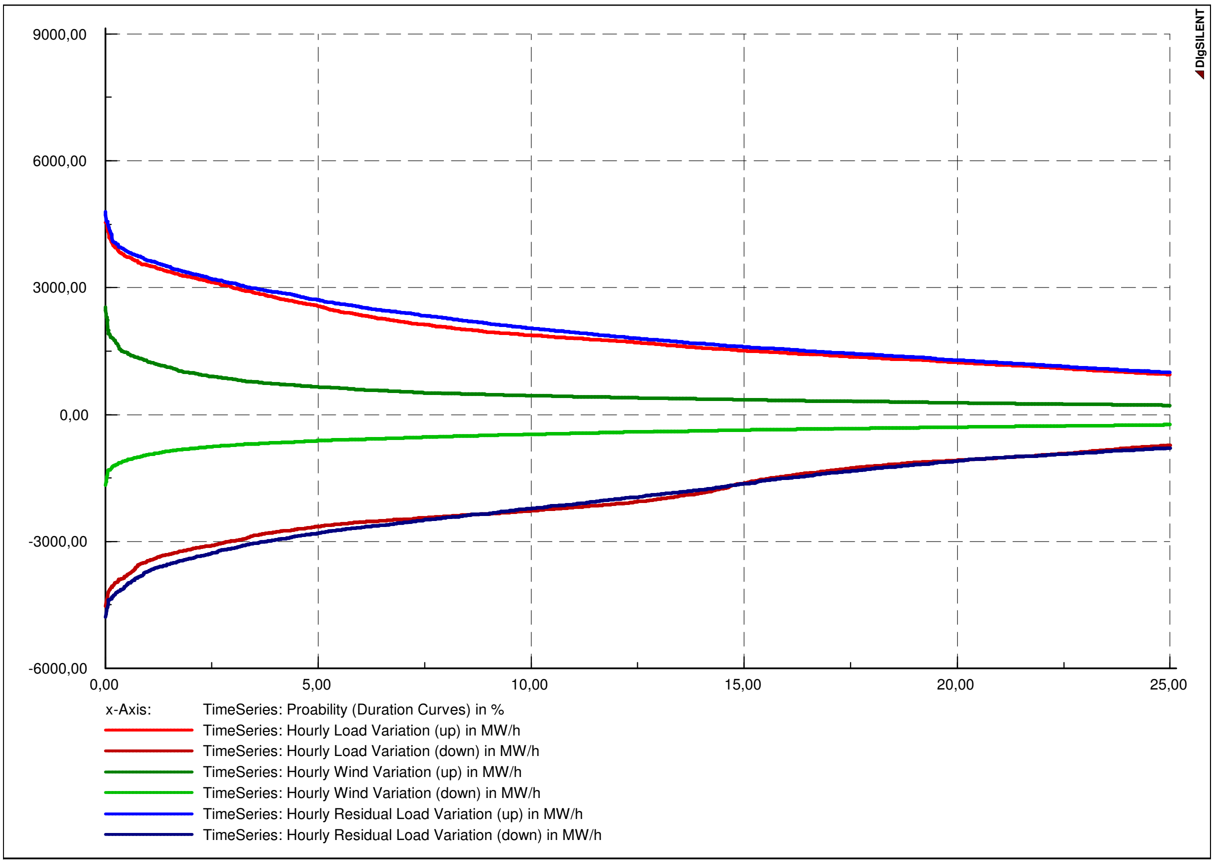


Figure 16: Cumulative probability of hourly variations of load, wind generation and residual load (Scenario 3)

Worst-case observations of time series studies carried out for the three scenarios are summarized in Table 1. The cumulative probability curves of hourly variations of load, wind generation and residual load of Scenario 3 are depicted in Figure 16.

Based on the cumulative probability curves, which are depicted in Figure 16, the following conclusions with regard to the impact of up to 10 000MW of installed wind capacity until 2020 can be taken:

- Hourly variations of wind generation (ramp-up and ramp-down) are substantially smaller than hourly load variations in all three investigated scenarios.
- Consequently, hourly variations of the residual load are almost not affected by wind generation considered for scenario 1, 2 and 3 (see also Figure 16).

Consequently, required ramp-up and ramp-down speeds of thermal and hydro power plants in South Africa don't have to be increased because of the added wind generation.

The main impact on the operation of the South African power system will result from the predictability of wind generation, which will depend on the quality of wind prediction tools that will be installed for supporting the operation of the system. Based on the studies presented in this report, it is not possible to assess the impact of wind generation in South Africa on regulation reserve. For this purpose, more detailed models considering the actual operation of the South African power system and simulated wind prediction will be required.

3.2.2 Local versus Global Wind Generation

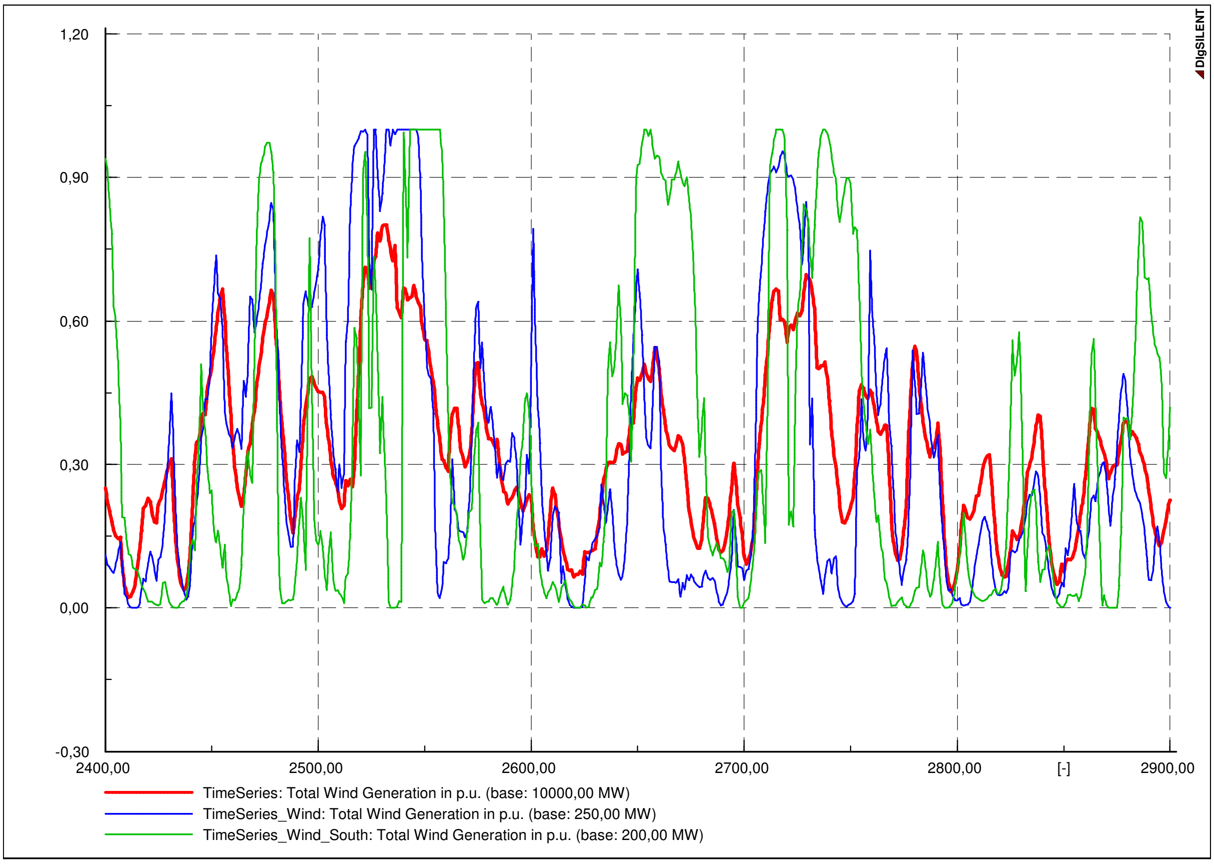


Figure 17: Total wind generation of Scenario 3 and wind generation of single wind farms in the Western Region (blue) and Southern Region (green).

Figure 17 shows the total wind generation for Scenario 3 (2020/high wind generation) in comparison to the generation of one arbitrary selected in farm in the Western Region (blue curve) and one arbitrary selected wind farm in the Southern Region (green curve).

The corresponding analysis leads to the following conclusions:

- It is unlikely that the total wind generation in South Africa exceeds a value of 90% of the installed capacity whereas the output of individual wind farms can reach 100% of their maximum possible output.
- Variations of the total wind generation are substantially smoother that variations of the output of individual wind farms.
- There is only a weak correlation between wind farms in the Western and the Southern Region.

The weak correlation between wind speeds in the Southern region and the Western region will lead to smoother overall wind variations and therefore to an improved overall predictability

3.2.3 Energy Production and CO2 Emissions

With regard to wind energy production, the following results for the average power (Pav), the capacity factor (CF) and the yearly energy yield (E) can be estimated:

- Scenario 1: Pav= 543MW CF = 27,2% E=4,76 TWh/year
- Scenario 2: Pav=1468MW CF = 30,6% E=12,86 TWh/year
- Scenario 3: Pav=3200MW CF = 32,0% E=28,03 TWh/year

Assuming that wind generation will mainly replace energy produced by coal fired power plants, the specific avoided CO2 emissions can be estimated to be in a range of around 1000 kg/MWh. For a more accurate assessment, one would have to look at the actual generator dispatch in South Africa in the presence of wind generation and take the reduced efficiency of coal fired power stations into account when letting them operate below rated output.

Based on 1000 kg/MWh CO2 and not considering any side effects on the efficiency of thermal power stations, the avoided CO2 emissions can be estimated as follows:

- Scenario 1: 4,76 Mio t CO2
- Scenario 2: 12,86 Mio t CO2
- Scenario 3: 28,03 Mio t CO2

Because of the large number of assumptions, which led to these results, their accuracy is very limited and the results should only be used for estimating possible order of magnitudes.

4 Conclusions and Recommendations

Renewable energies, such as wind energy can represent an economic and ecologic alternative for the generation of electrical energy. But besides contributing to the electrical energy supply, renewable energies such as wind energy can also have a valuable contribution to the equivalent firm capacity of a system. This means in other words, that with the addition of wind farms, the reliability of supply of a system is improved and that it is indeed possible to replace some conventional power plants by wind farms completely. The percentage of the installed wind capacity that can be considered to be "firm capacity" is named Capacity Credit and is subject to the analysis of the presented studies.

The studies presented in this report are based on three scenarios:

- Scenario 1: Year 2015, 2000MW installed wind generation capacity
- Scenario 2: Year 2020, 4800MW installed wind generation capacity
- Scenario 3: Year 2020, 10000MW installed wind generation capacity

For each of the three scenarios, the average loss of load probability (LOLP) at the daily peak load has been calculated and has been used as the relevant reliability index for assessing the capacity credit of wind generation in South Africa.

Capacity credit has been defined in terms of the Equivalent Firm Capacity (EFC), which is a generation capacity with 100% availability that one would have to add to the system in order to achieve the same improvement in terms of the available reserve at a given confidence level.

The resulting capacity credit figures for the different scenarios are the following:

- Scenario 1: CC=26,8%
- Scenario 2: CC=25,4%
- Scenario 3: CC=22,6%

With increasing wind penetration levels, the capacity credit of wind generation will drop. Based on Scenario 3 (year 2020, 10 000MW of installed wind capacity), an assessment has been carried out by scaling the 67 modelled wind farms up to a totally installed wind capacity of 25 000MW. The resulting capacity credit is equal to 17,6%.

Comparing these figures with the availability indices of newly planned coal fired power stations in South Africa having a combined planned/unplanned outage rate of around 11%, the contribution of an average wind farm in South Africa to the equivalent firm capacity of the system will be in the following range:

- Scenario 1: CC=29,8%
- Scenario 2: CC=26,1%
- Scenario 3: CC=25,1%

When comparing the capacity credit of wind generation to older coal fired power stations with a combined planned/unplanned outage rate of around 20%, the capacity credit of wind generation will be around 33,5%/31,7%/28,2% (Sc1/Sc2/Sc3) of the capacity credit of such an older existing South African coal fired power station.

The second part of the presented studies analyses the impact of wind generation in South Africa on the residual load, which is the remaining load that must be supplied by thermal and hydro power plants.

The analysis was mainly looking at:

- Worst case situations with regard to wind and load variations.
- Impact of wind generation on dynamic performance requirements.

The results of the corresponding studies lead to the conclusion that:

- Hourly ramp-up and ramp-down rates of the residual load are comparable to the corresponding ramp-rates of the system load (without wind generation).
- There are no increased dynamic performance requirements for the existing thermal power plants in South Africa.

The main impact on system operation will result from the limited predictability of wind speeds and not from absolute wind speed variations. The limited predictability of wind generation will result in an increased forecast error of the residual load compared to the present load forecast error. Several factors will have an influence on the accuracy of wind prediction; some of them are related to the spatial distribution of wind generation, some of them to the actual wind prediction system that will be put in place for supporting the operation of the South African power system. Therefore, it is required to carry out additional studies that simulate the behaviour of a wind prediction system in order to obtain indicative values for the required increase of the load following reserve.

As overall conclusion, it can be stated that the capacity credit of wind generation in South Africa will be between 25% and 30% for installed wind generation of up to 10 000MW. In the case of higher wind penetration (25 000MW), capacity credit of wind generation in South Africa will drop below 20%.

Based on part 2 of the presented studies it can further be concluded that it is very likely that it will be possible to operate the system safely, without increased dynamic performance requirements for the conventional power plants of South Africa. However, the use of state of the art wind prediction tools for assessing the required load (and wind) following reserves will be important. This second aspects requires further, more detailed studies that model the dynamic performance characteristics of the South African power plants in more detail for ensuring a safe operation of the South African power system under all credible operating conditions.

5 References

[1] GTZ: Kleinteilige Energie- und/oder Klimarelevante Maßnahmen – Teilwerk: Capacity Credit Study – Pr.-Nr.: 95.3550.1-034.00 – Terms of Reference, 01.06.2010

[2] ESKOM: Wind Project Sites for Study (Wind Project Sites for Study - 2010 May - Locations - MTS Sub - MW sizes.xls), 2010

[3] ESKOM: File Wind_DigSilent_GxData_11062010.xlsx, 2010

[4] Windlab Systems: Capacity Credit Study in South Africa – Consulting Report, 14.07.2010

[5] Windlab Systems: Second version of wind speed data based on site adjustments, 15.11.2010

[6] ESKOM: Integrated Resource Plan for Electricity – Draft, Version 8, 08.10.2010 (IRP 2010)

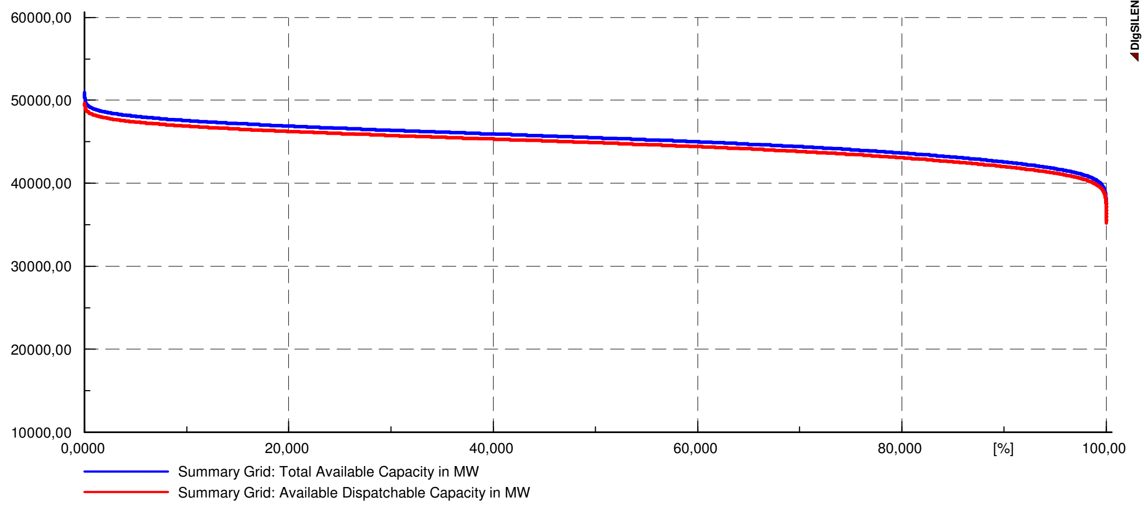
[7] Windlab Systems: WindScapeTM Methodology – Capacity Credit Study in South Africa, 03.11.2010

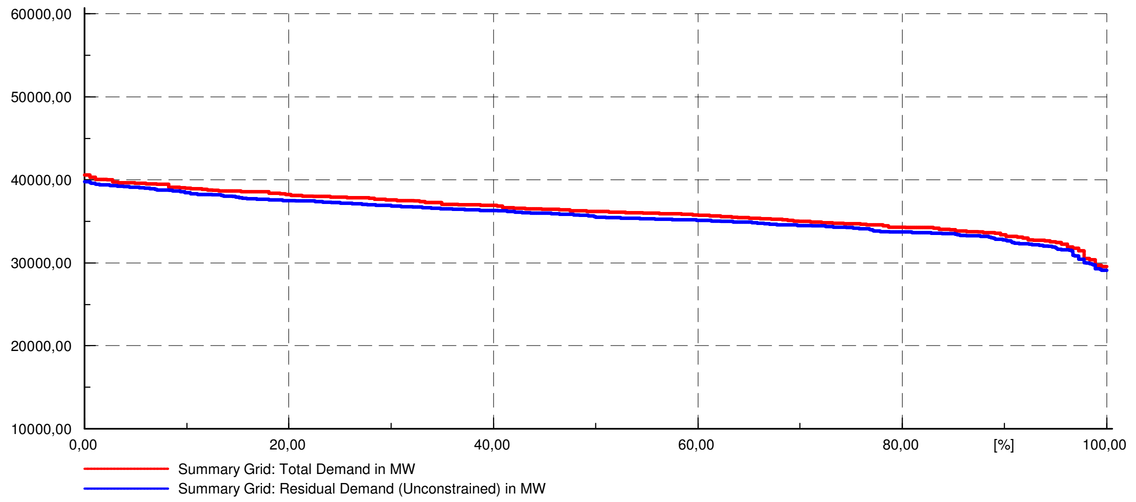
ANNEXES

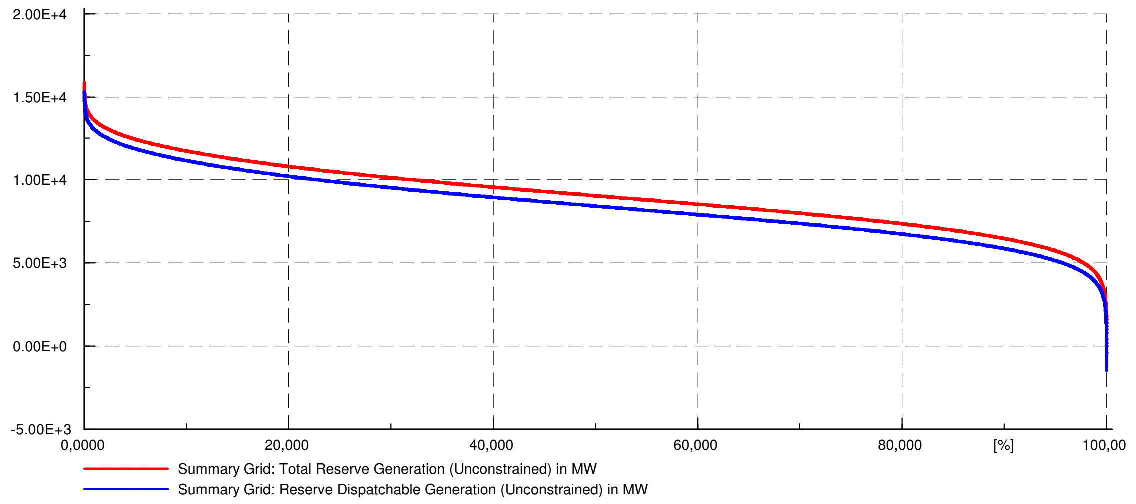
Annexes

Annex 1: Results of Simulation Studies

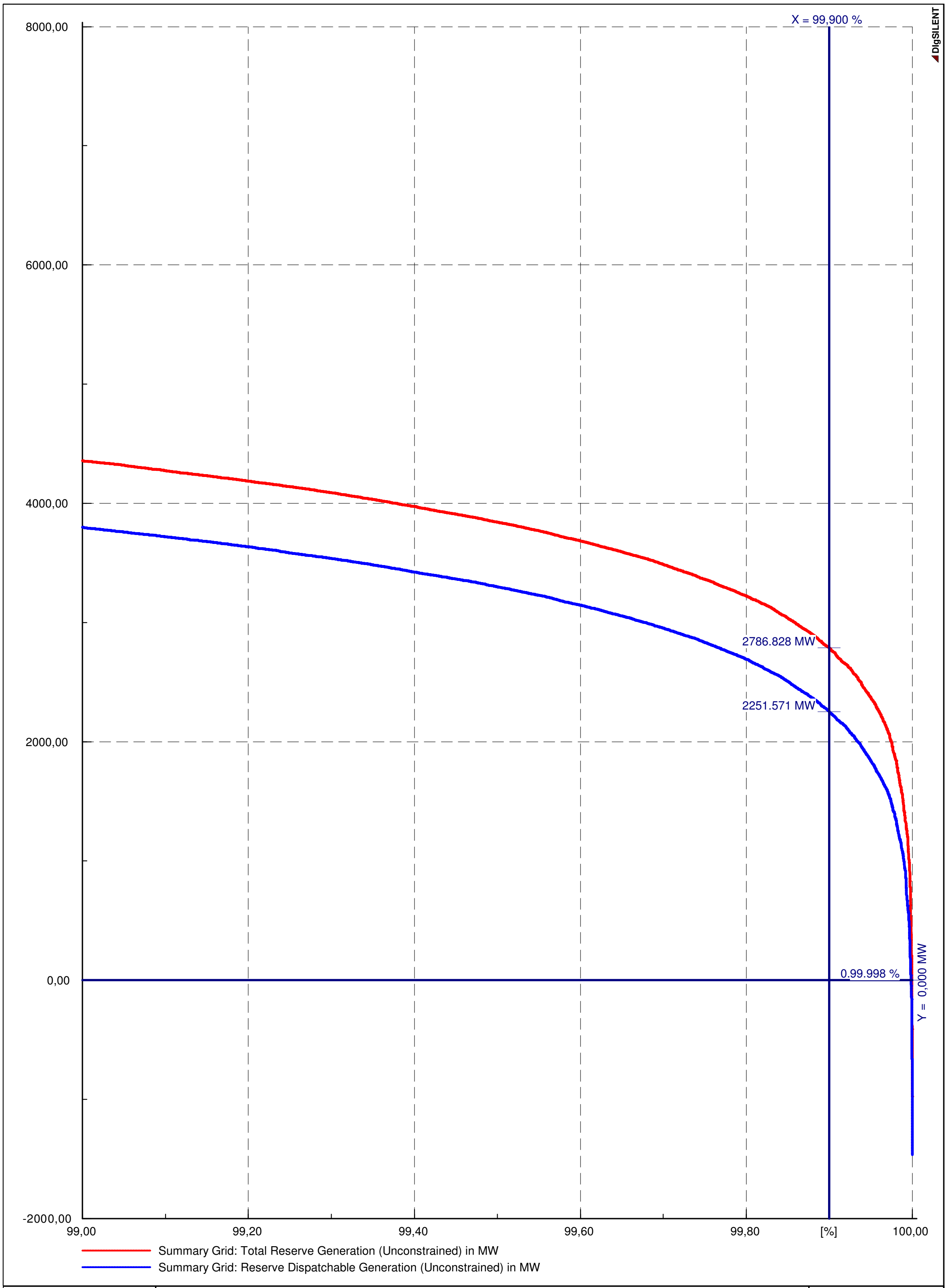
Annex 1.1: Scenario 1 – Year 2015 – 2000MW Installed Wind Generation





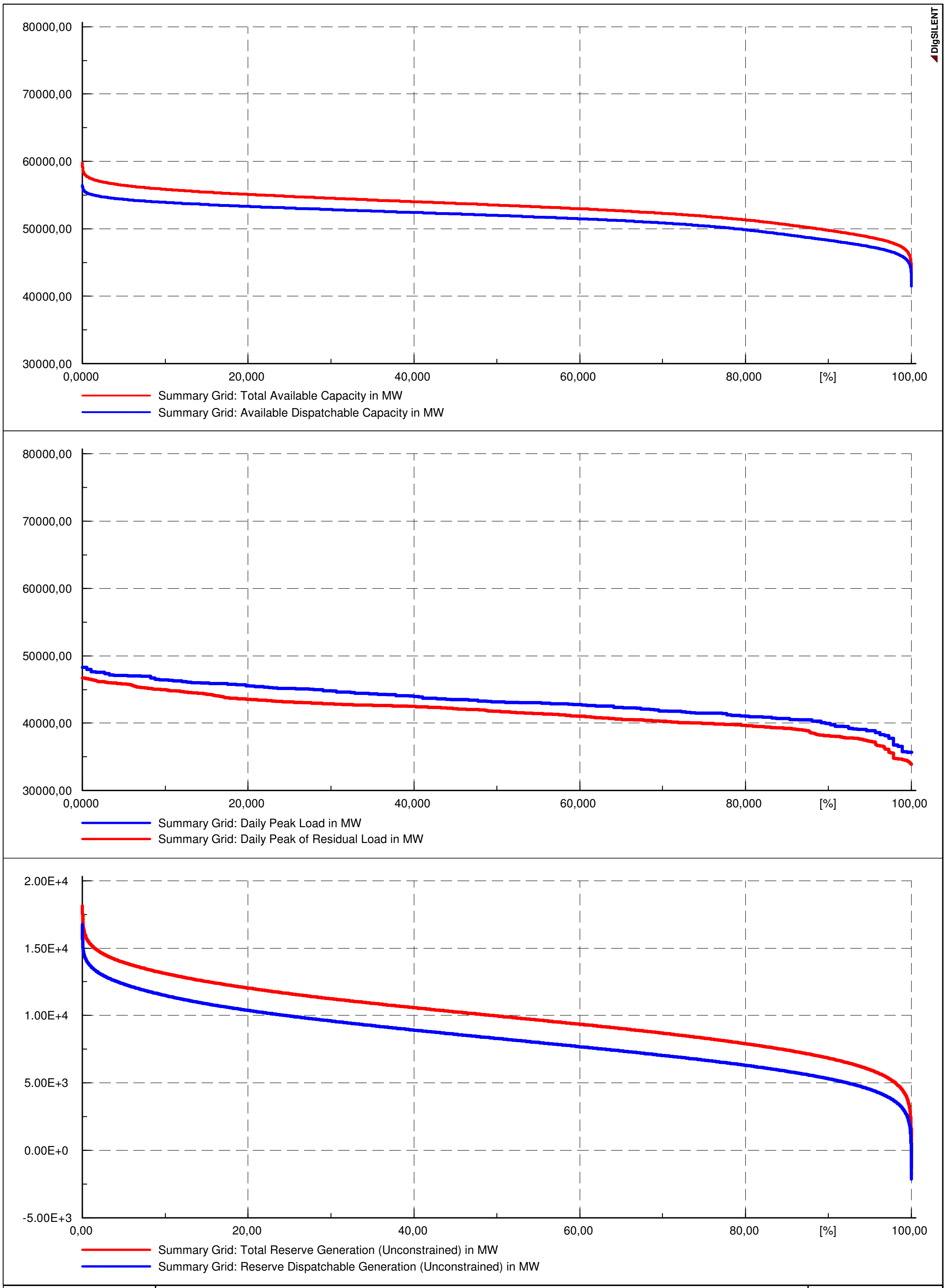


DIGSILENT	Capacity Credit Studies for South Africa	Distribution	Date: 12/25/2010
	Scenario 1 - 2015 - 2000MW installed Wind Capacity	Winter season	Annex: 1.1.1 /1



DIGSILENT	Capacity Credit Studies for South Africa Scenario 1 - 2015 - 2000MW installed Wind Capacity	Generation vs Demand Winter season	Date: 12/25/2010 Annex: 1.1.1 /2

Annex 1.2: Scenario 2 – Year 2020 – 4800MW Installed Wind Generation



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Capacity Credit Studies for South Africa

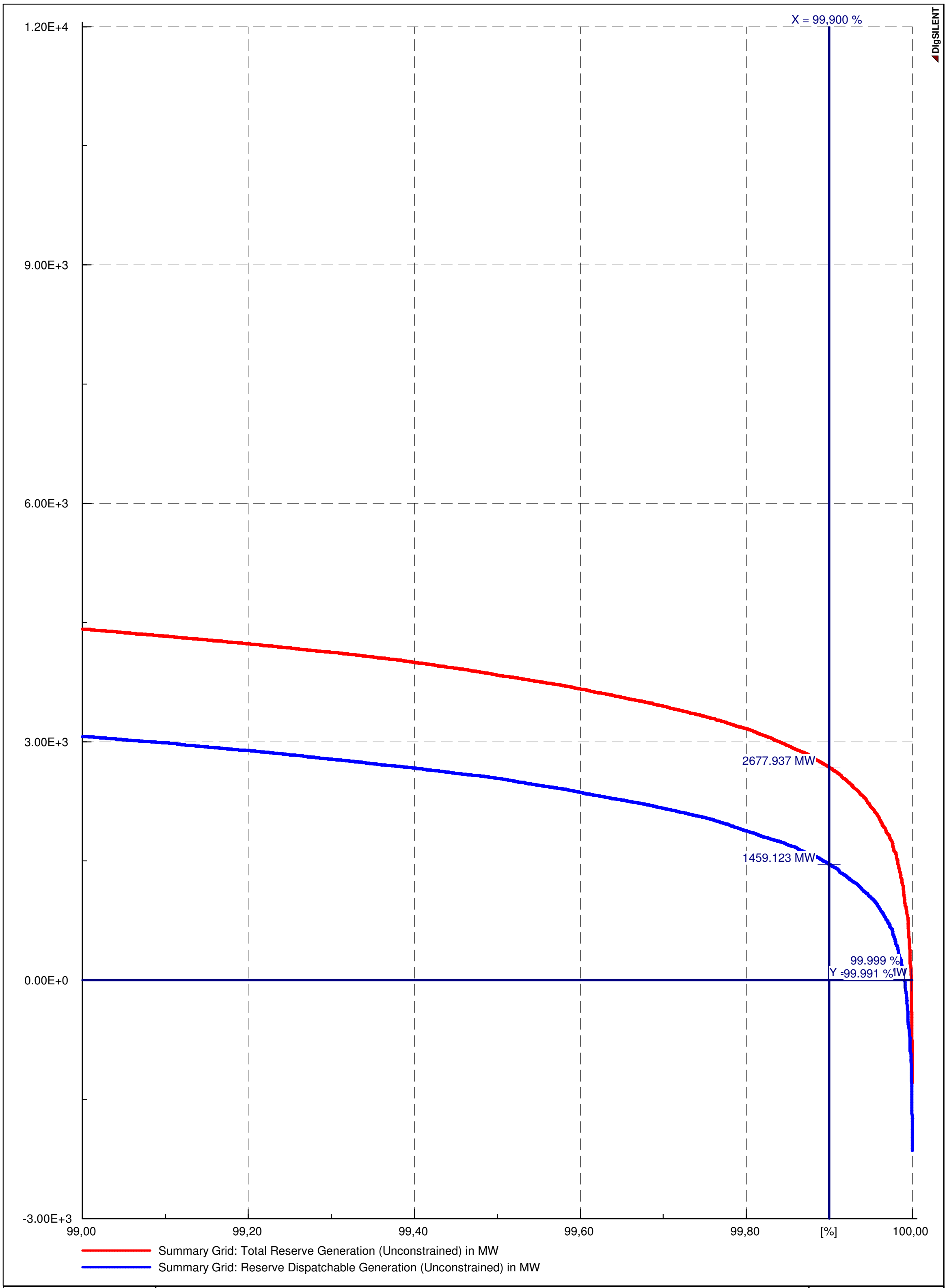
Distribution

Date: 12/25/2010

Scenario 2 - 2020/Low - 48000MW installed Wind Capacity

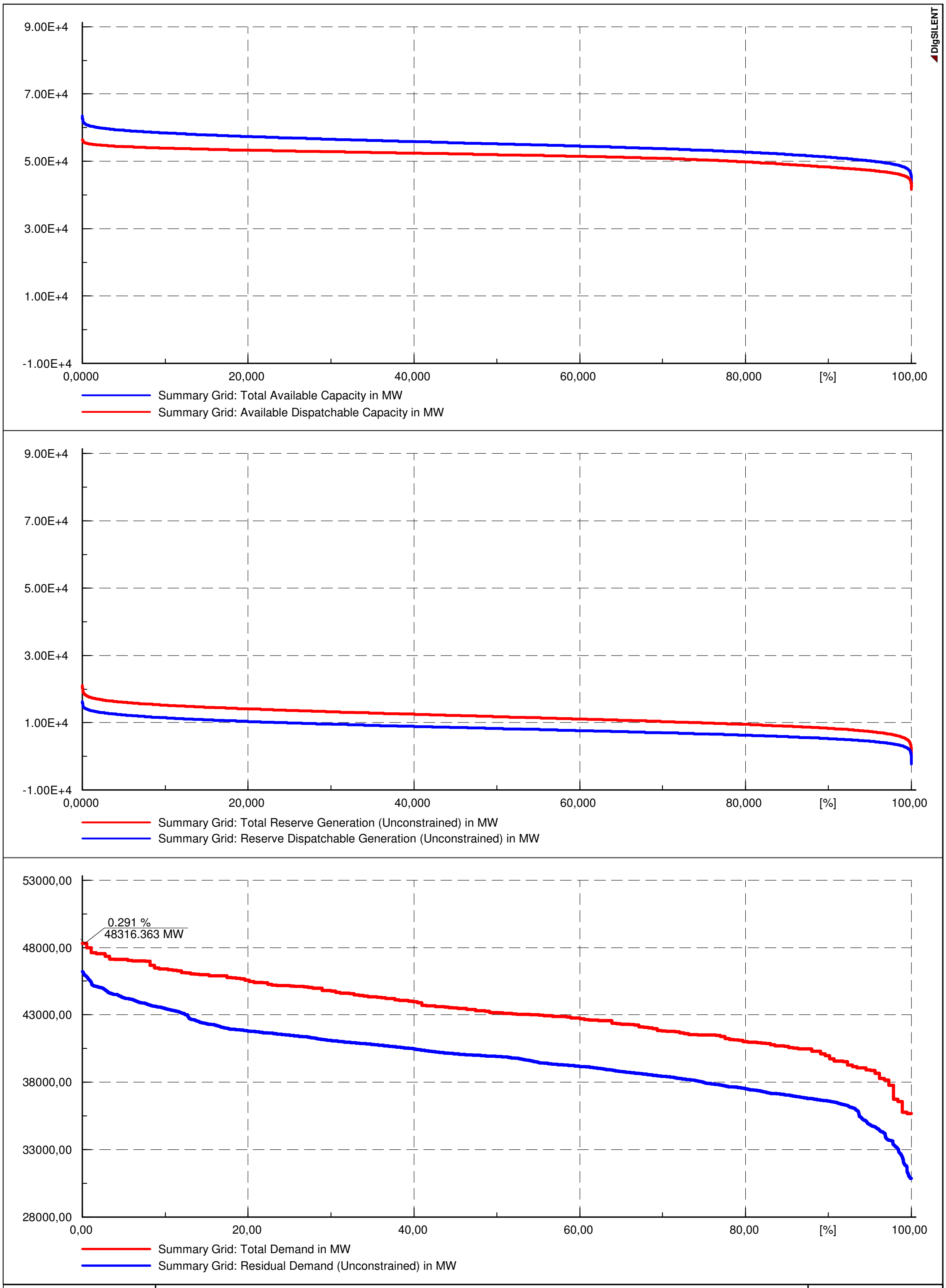
Winter season

Annex: 1.2.1 /1

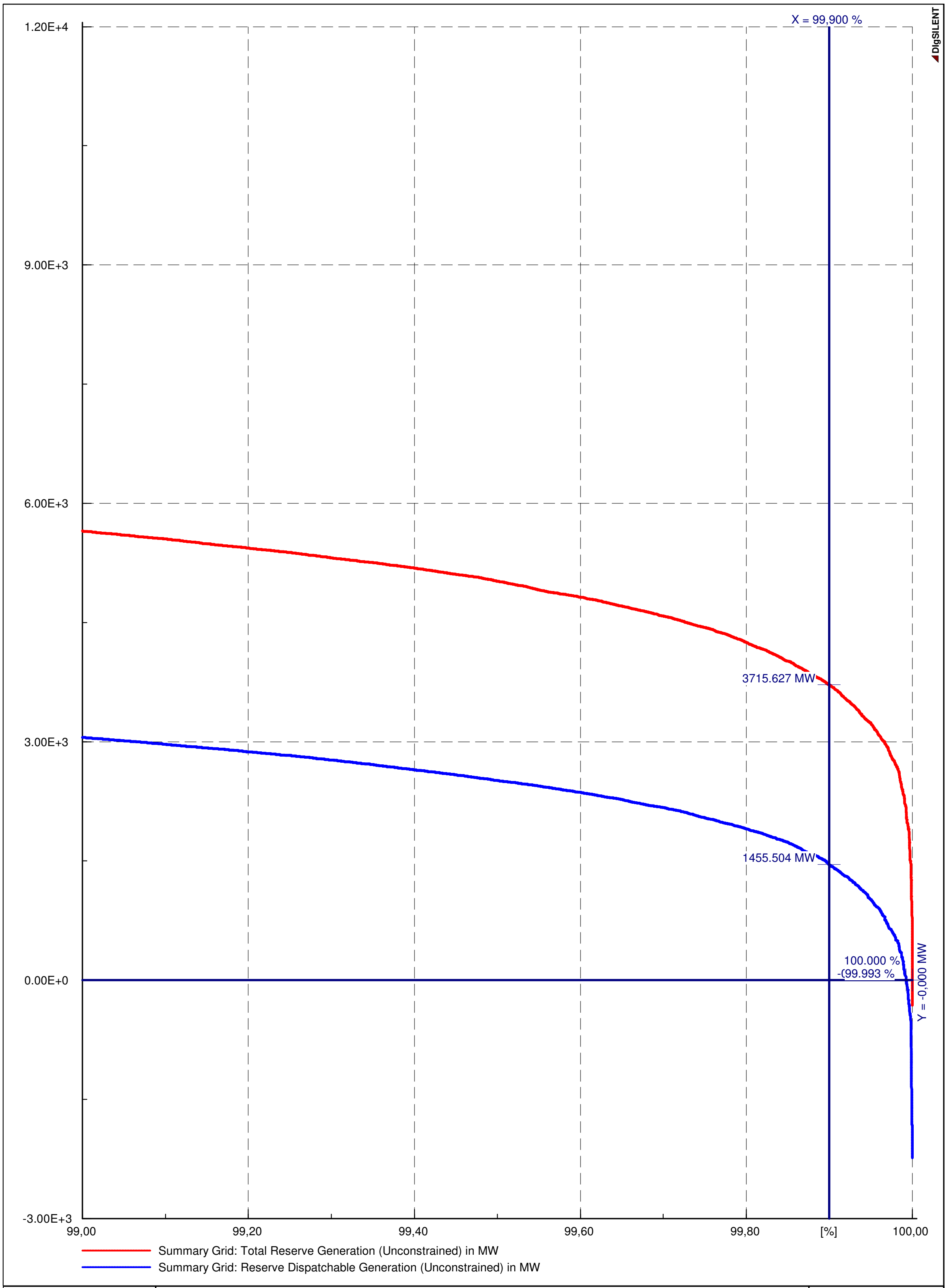


DIGSILENT	Capacity Credit Studies for South Africa	Generation vs. Demand	Date: 12/25/2010
	Scenario 2 - 2020/Low - 48000MW installed Wind Capacity	Winter season	Annex: 1.2.1 /2

Annex 1.3: Scenario 3 – Year 2020 – 10000MW Installed Wind Generation



DIGSILENT	Capacity Credit Studies for South Africa	Distribution	Date: 12/26/2010
	Scenario 3 - 2020/High - 10000MW installed Wind Capacity	Winter season	Annex: 1.3.1 /1



DIGSILENT	Capacity Credit Studies for South Africa	Generation vs Demand	Date: 12/26/2010
	Scenario 3 - 2020/High - 10000MW installed Wind Capacity	Winter season	Annex: 1.3.1 /2

Annex 2: Seasonal and Hourly Variations of the Wind Generation in South Africa

There are the following dependencies of capacity credit on wind characteristics:

- Capacity credit increases with increasing average wind speeds.
- A high correlation between wind generation and load increases capacity credits.

With regard to correlation between wind generation and load, the two following aspects are of major importance:

- Correlation between seasonal wind variations and seasonal load variations.
- Correlation between hourly wind variations and hourly load variations.

For better understanding the results of the previous sections, the above correlation aspects have been analyzed for the South African case.

Figure 18, Figure 21 and Figure 24 show the seasonal variations of wind generation in South Africa for the three analyzed scenarios. These figures highlight the positive seasonal correlation between wind speeds and load in South Africa.

Figure 19, Figure 22 and Figure 25 show the average wind generation per hour for the winter season and Figure 20, Figure 23 and Figure 26 for the summer season. Comparing these figures with the defined full load hours – between 18:00h and 21:00h in winter and 08:00h and 21:00h in summer- it can be concluded that the correlation between wind speeds and daily load variations is reasonably good:

- During winter, which is the most relevant case because this corresponds to the peak-load season, the average wind generation during full load hours is approximately equal to the seasonal average.
- During summer, there is a very good correlation between wind generation and the evening load peak. On the other hand, there is very low wind generation during morning hours, and hence only a low contribution of wind generation to the morning high load coverage.

Annex 2-1: Scenario 1 – Year 2015/2000MW of Installed Wind Capacity

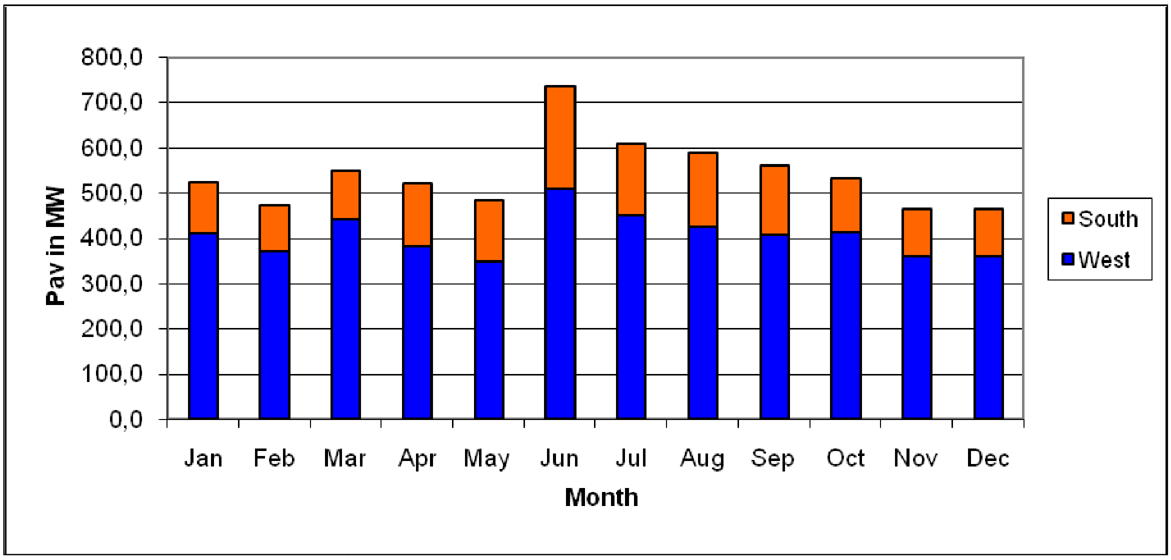


Figure 18: Monthly Average of Wind Generation in South Africa - Scenario 1

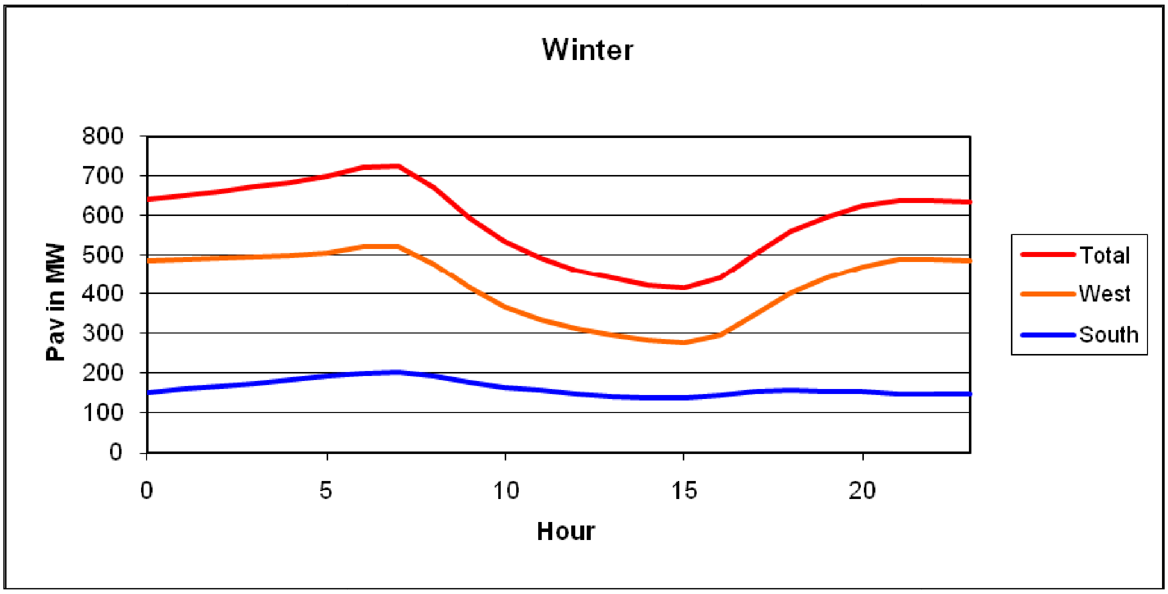


Figure 19: Hourly Average of Wind Generation in South Africa during winter - Scenario 1

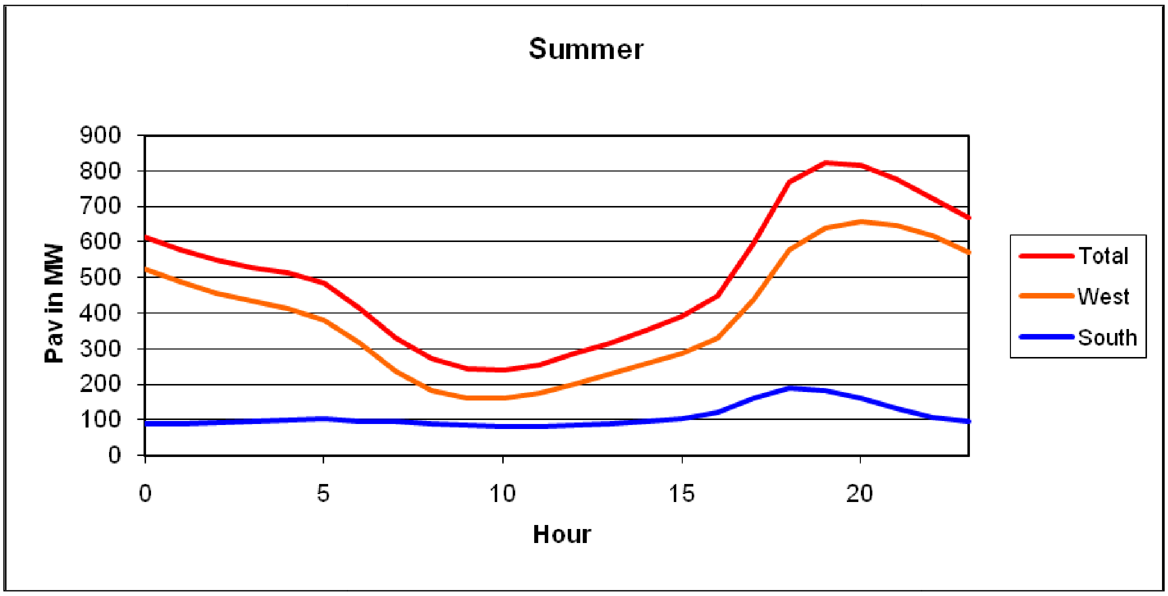


Figure 20: Hourly Average of Wind Generation in South Africa during summer - Scenario 1

Annex 2-2: Scenario 2 – Year 2020-Low/4800MW of Installed Wind Capacity

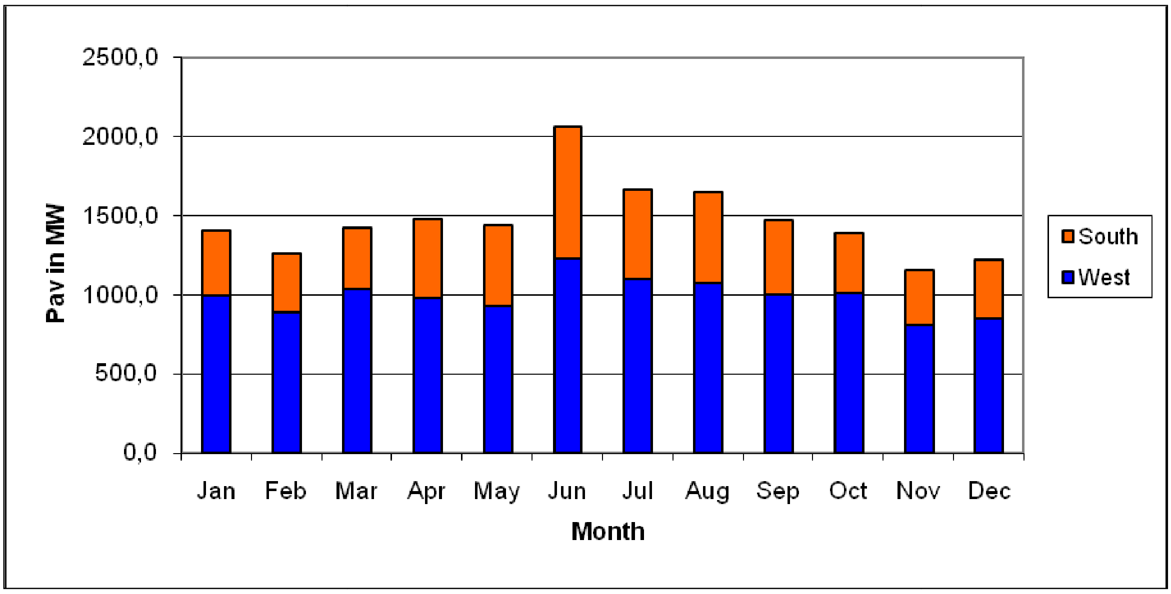


Figure 21: Monthly Average of Wind Generation in South Africa - Scenario 2

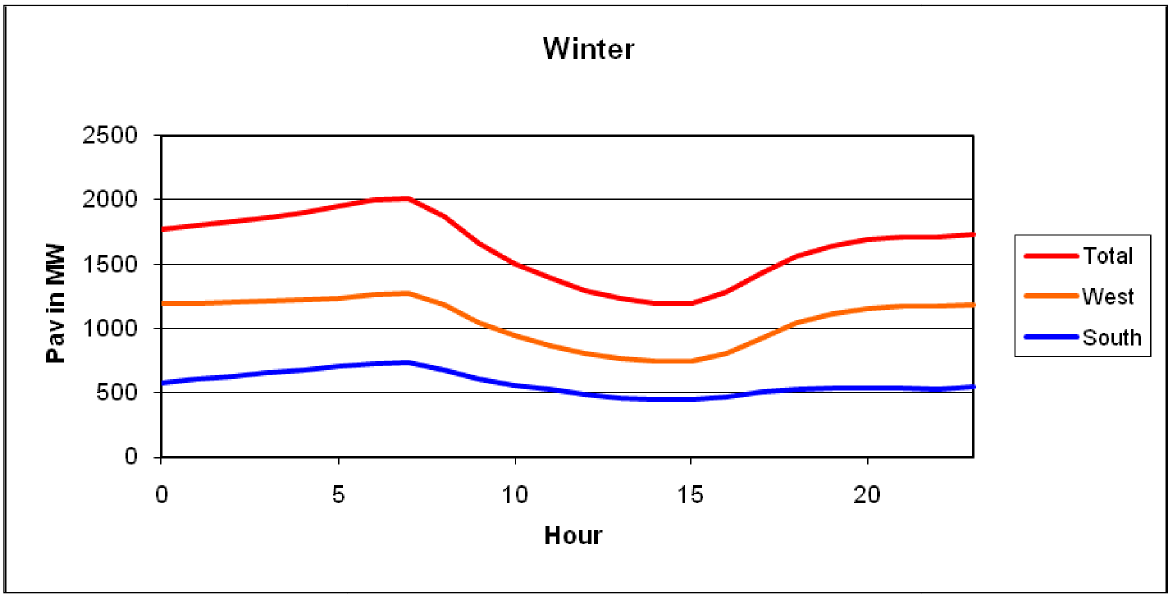


Figure 22: Hourly Average of Wind Generation in South Africa during winter - Scenario 2

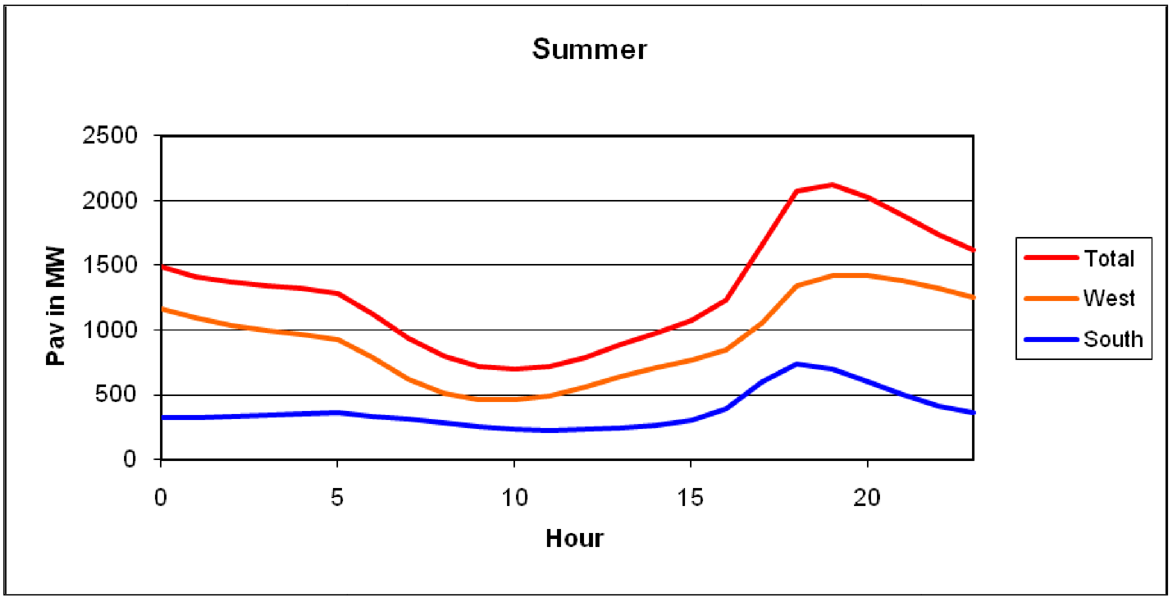


Figure 23: Hourly Average of Wind Generation in South Africa during summer - Scenario 2

Annex 2-3: Scenario 3 – Year 2020-High/10000MW of Installed Wind Capacity

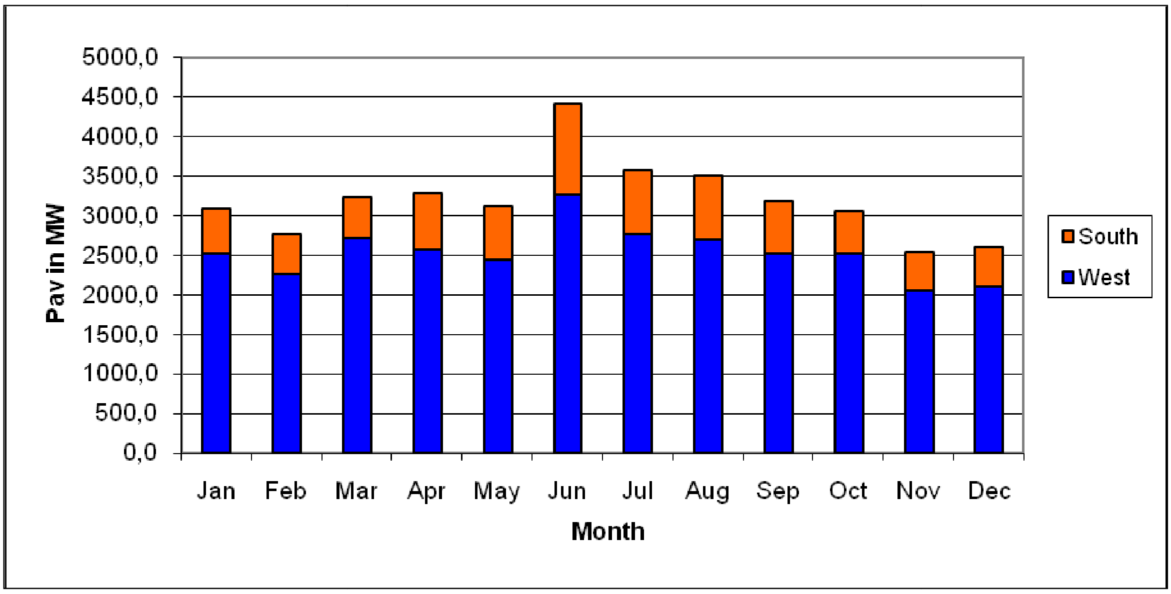


Figure 24: Monthly Average of Wind Generation in South Africa - Scenario 3

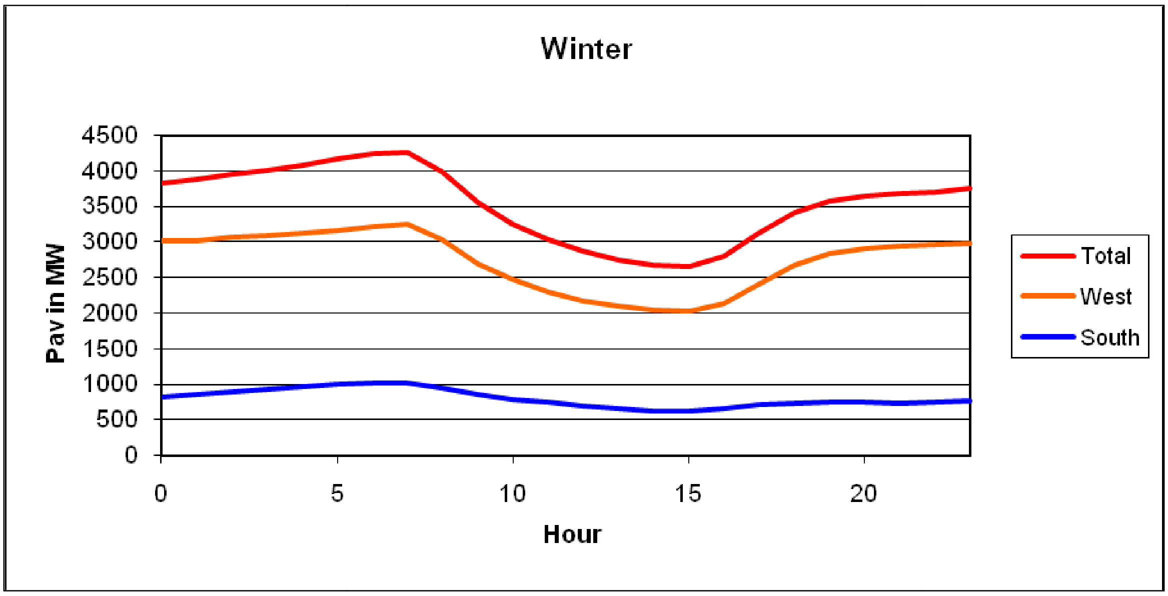


Figure 25: Hourly Average of Wind Generation in South Africa during winter - Scenario 3

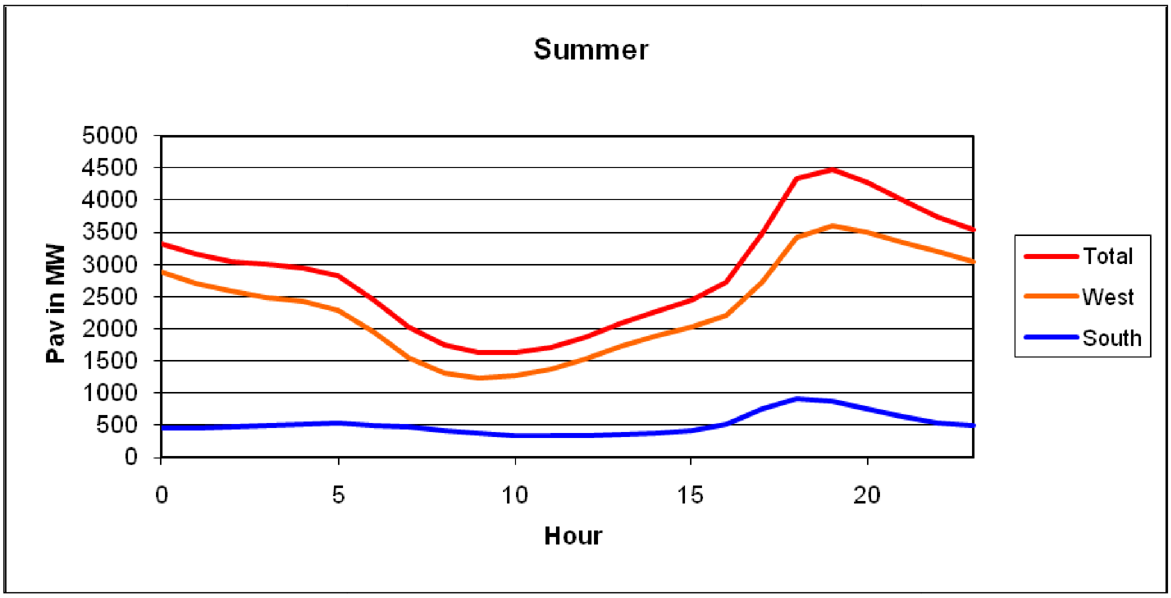
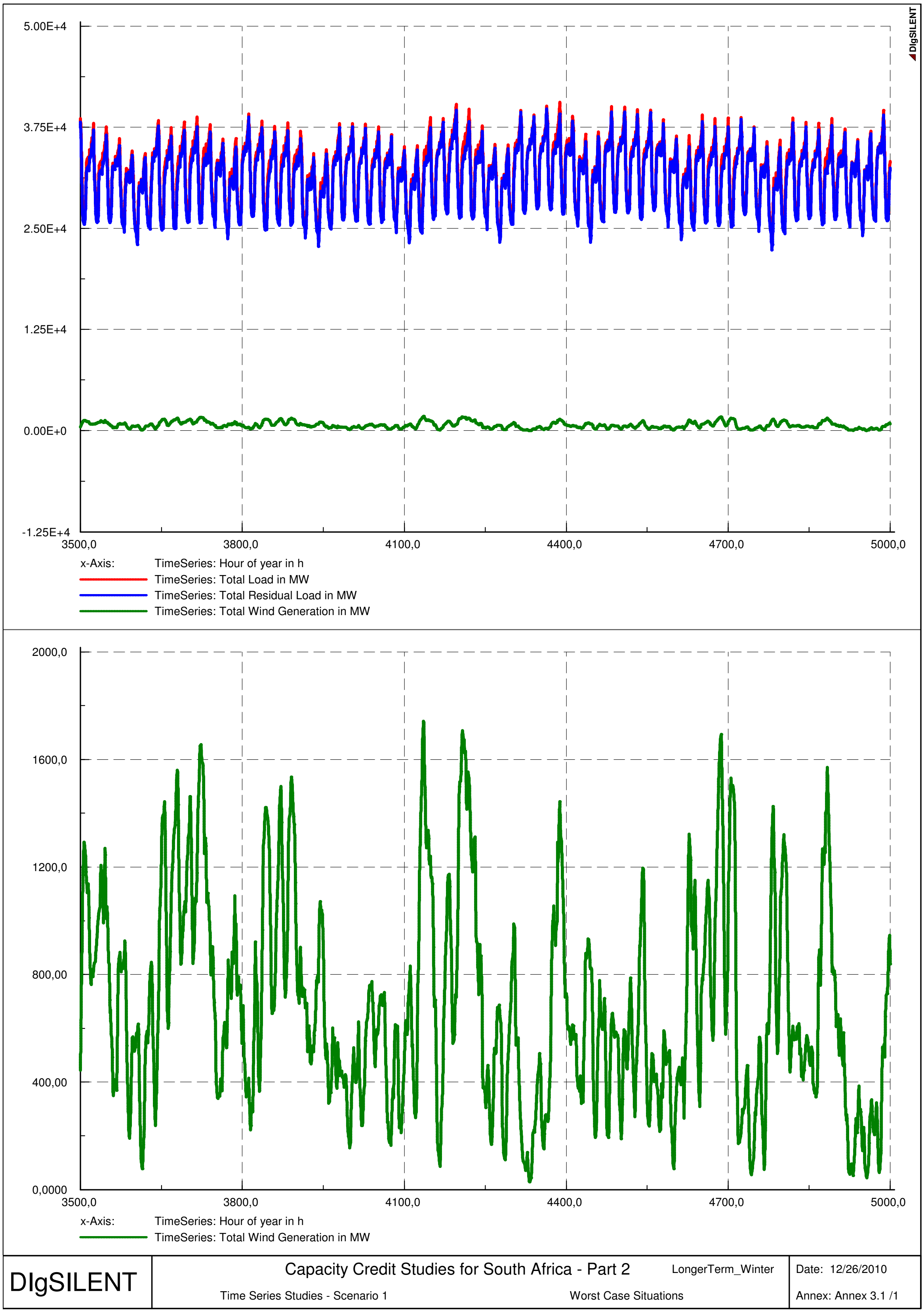


Figure 26: Hourly Average of Wind Generation in South Africa during summer - Scenario 3

Annex 3: Results of Time Series Assessment

Annex 3-1: Worst Case Situations and Duration Curves, Scenario 1 – 2015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3800,0
4100,0
4400,0
4700,0
5000,0
x-Axis: TimeSeries: Hour of year in h
TimeSeries: Total Load in MW
TimeSeries: Total Residual Load in MW
TimeSeries: Total Wind Generation in MW
2000,0
1600,0
1200,0
800,00
400,00
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3800,0
4100,0
4400,0
4700,0
5000,0
x-Axis: TimeSeries: Hour of year in h
TimeSeries: Total Wind Generation in MW
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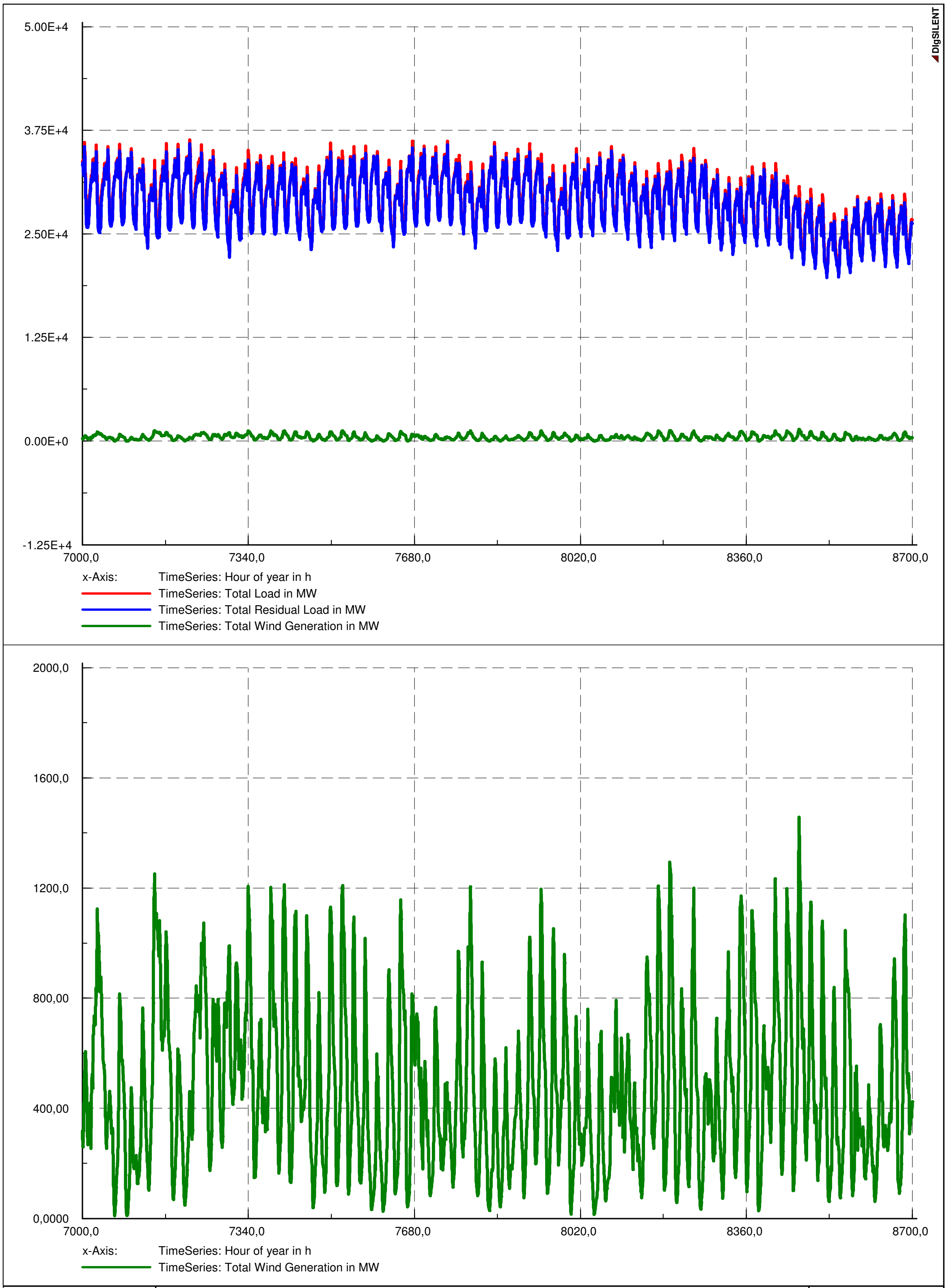
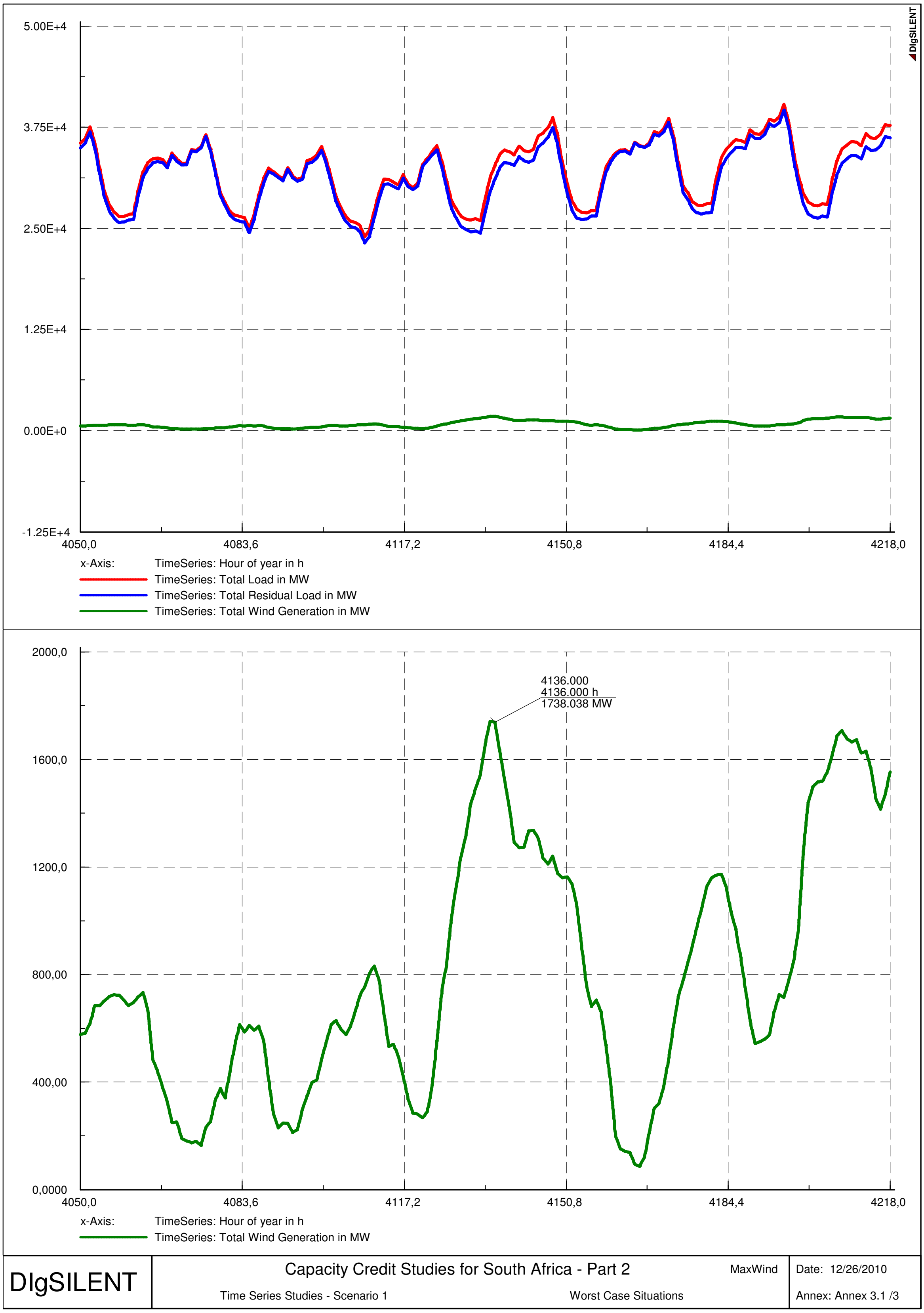
Capacity Credit Studies for South Africa - Part 2
LongerTerm_Winter
Date: 12/26/2010
Time Series Studies - Scenario 1
Worst Case Situations
Annex: Annex 3.1 /1



DIgSILENT	Capacity Credit Studies for South Africa - Part 2	LongerTerm_Summer	Date: 12/26/2010
	Time Series Studies - Scenario 1	Worst Case Situations	Annex: Annex 3.1 /2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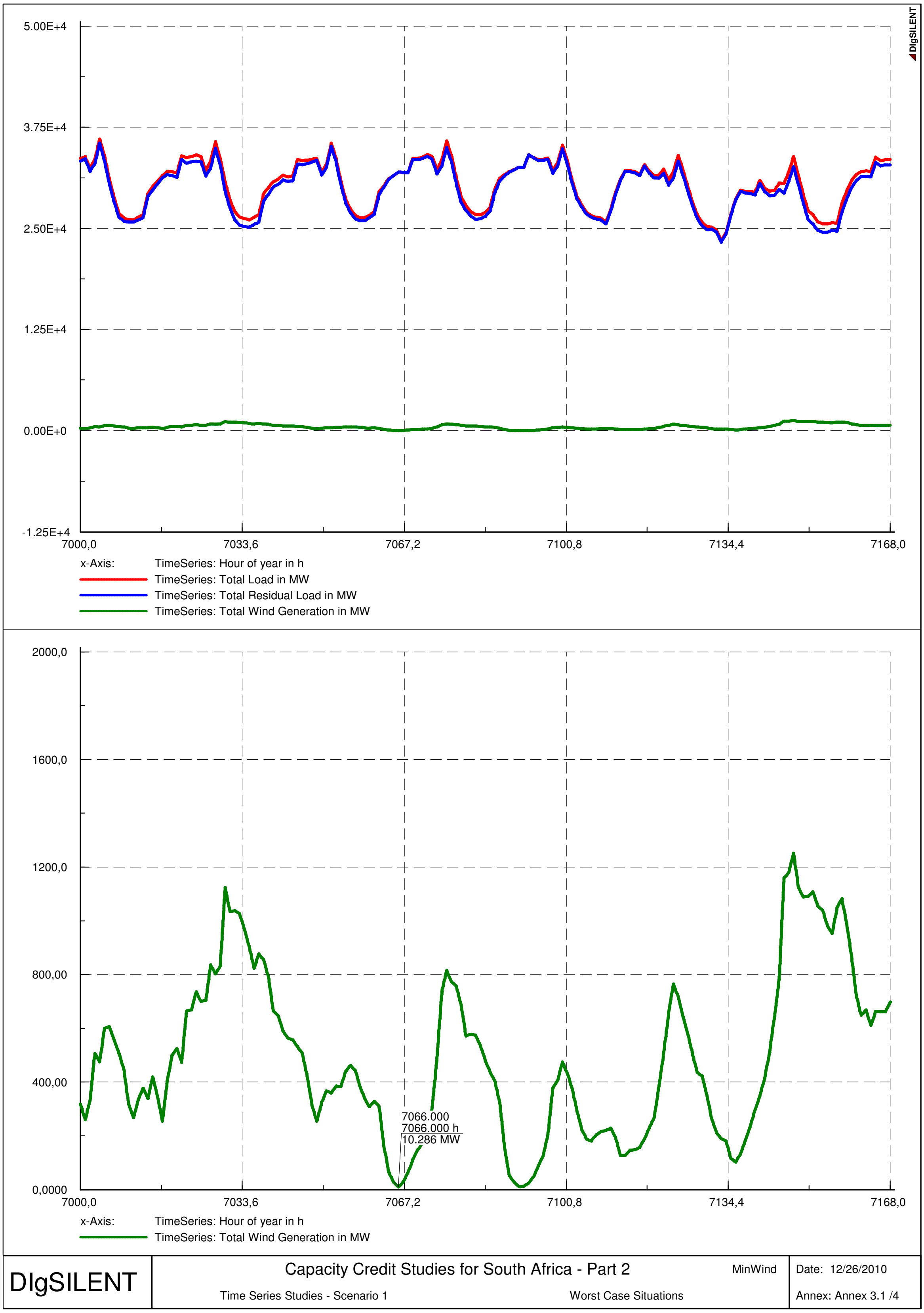
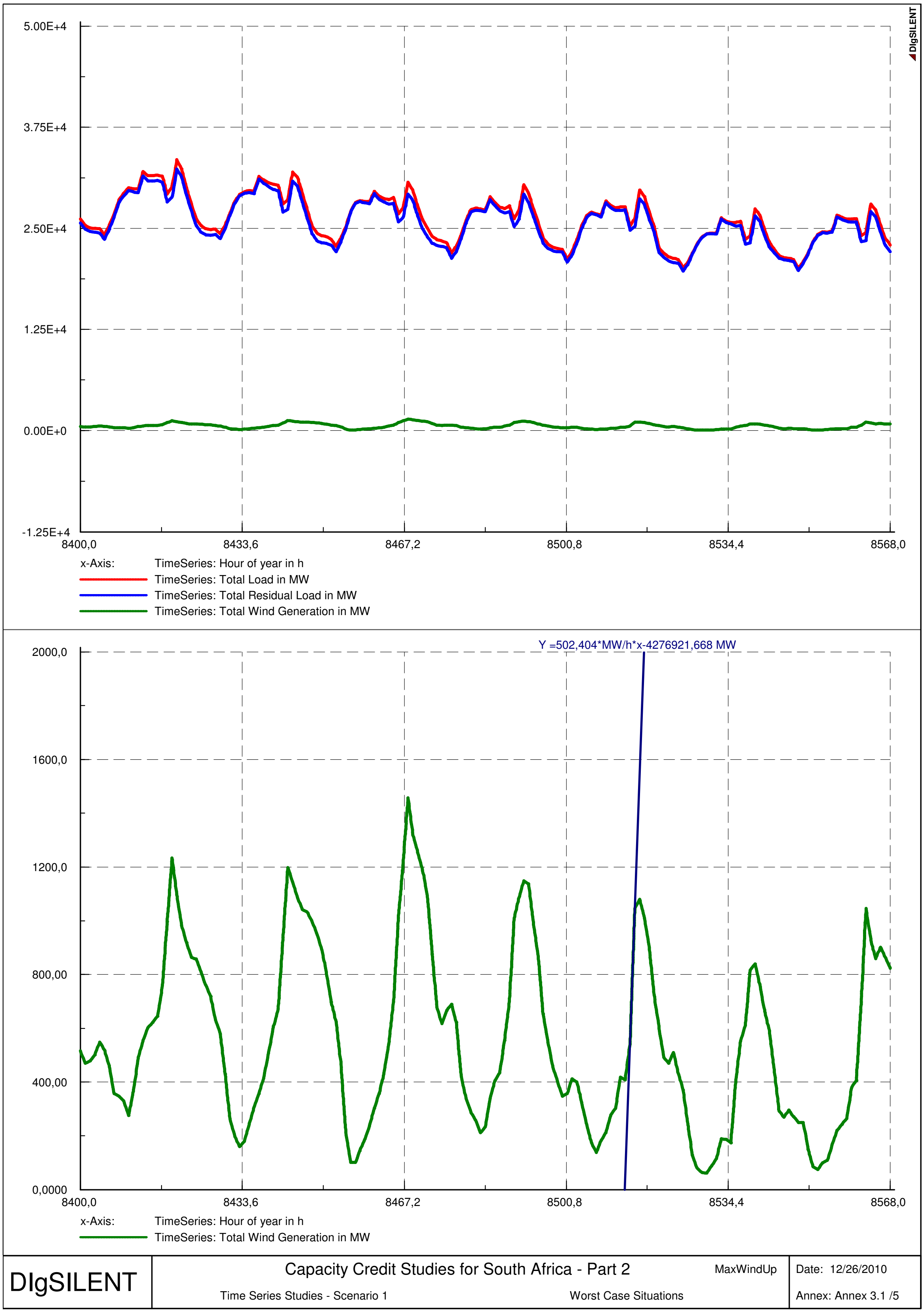
5.00E+4
3.75E+4
2.50E+4
1.25E+4
0.00E+0
-1.25E+4
4050,0
4083,6
4117,2
4150,8
4184,4
4218,0
x-Axis: TimeSeries: Hour of year in h
TimeSeries: Total Load in MW
TimeSeries: Total Residual Load in MW
TimeSeries: Total Wind Generation in MW
2000,0
1600,0
1200,0
800,00
400,00
0,0000
4136.000
4136.000 h
1738.038 MW
4050,0
4083,6
4117,2
4150,8
4184,4
4218,0
x-Axis: TimeSeries: Hour of year in h
TimeSeries: Total Wind Generation in MW
DIgSILENT
Capacity Credit Studies for South Africa - Part 2
MaxWind
Date: 12/26/2010
Time Series Studies - Scenario 1
Worst Case Situations
Annex: Annex 3.1 /3



DIgSILENT | Capacity Credit Studies for South Africa - Part 2 | MinWind | Date: 12/26/2010

Time Series Studies - Scenario 1 | Worst Case Situations | Annex: Annex 3.1 /4



DIgSILENT

Capacity Credit Studies for South Africa - Part 2

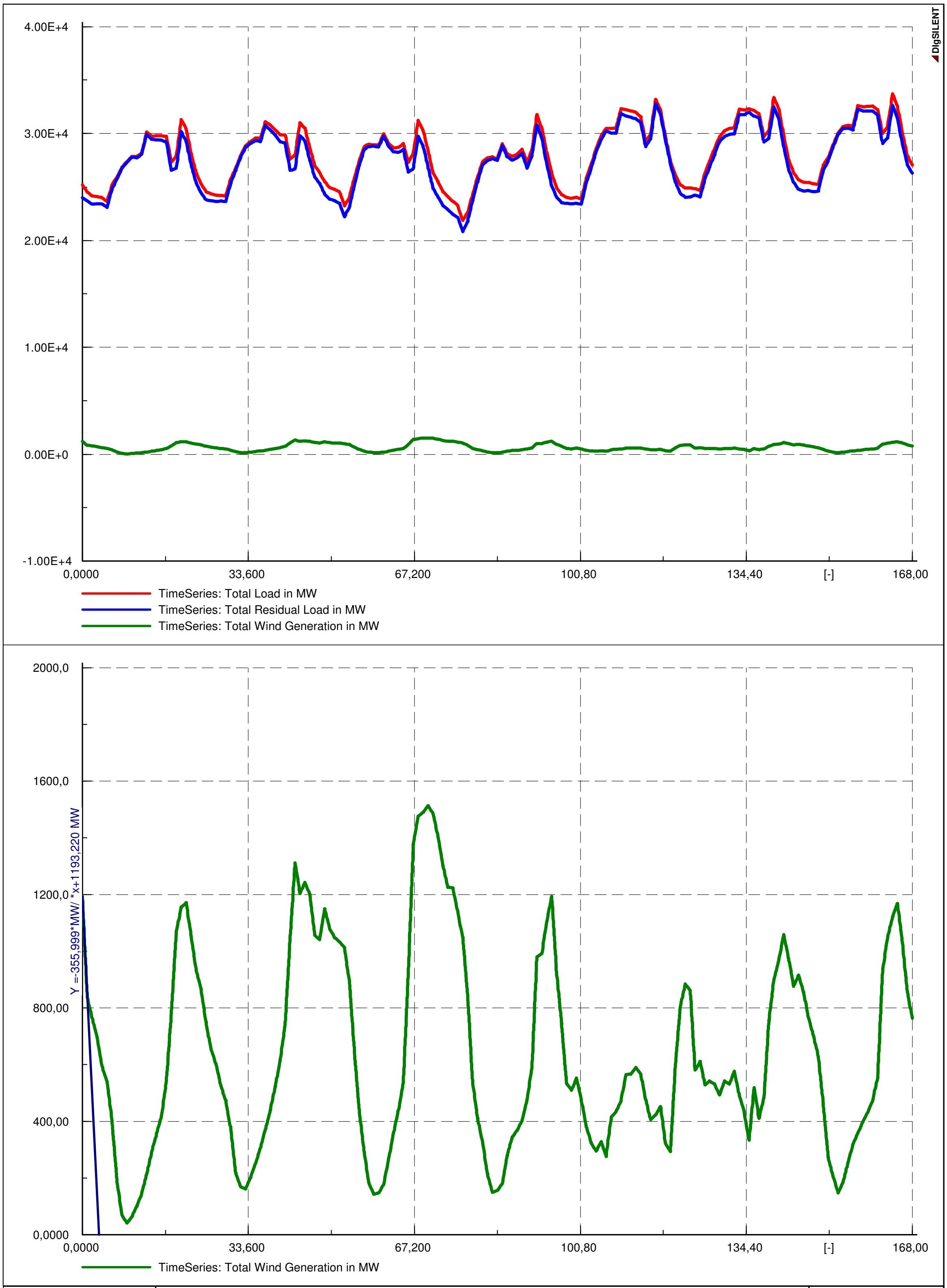
MaxWindUp

Date: 12/26/2010

Time Series Studies - Scenario 1

Worst Case Situations

Annex: Annex 3.1 /5



DIgSILENT

Capacity Credit Studies for South Africa - Part 2

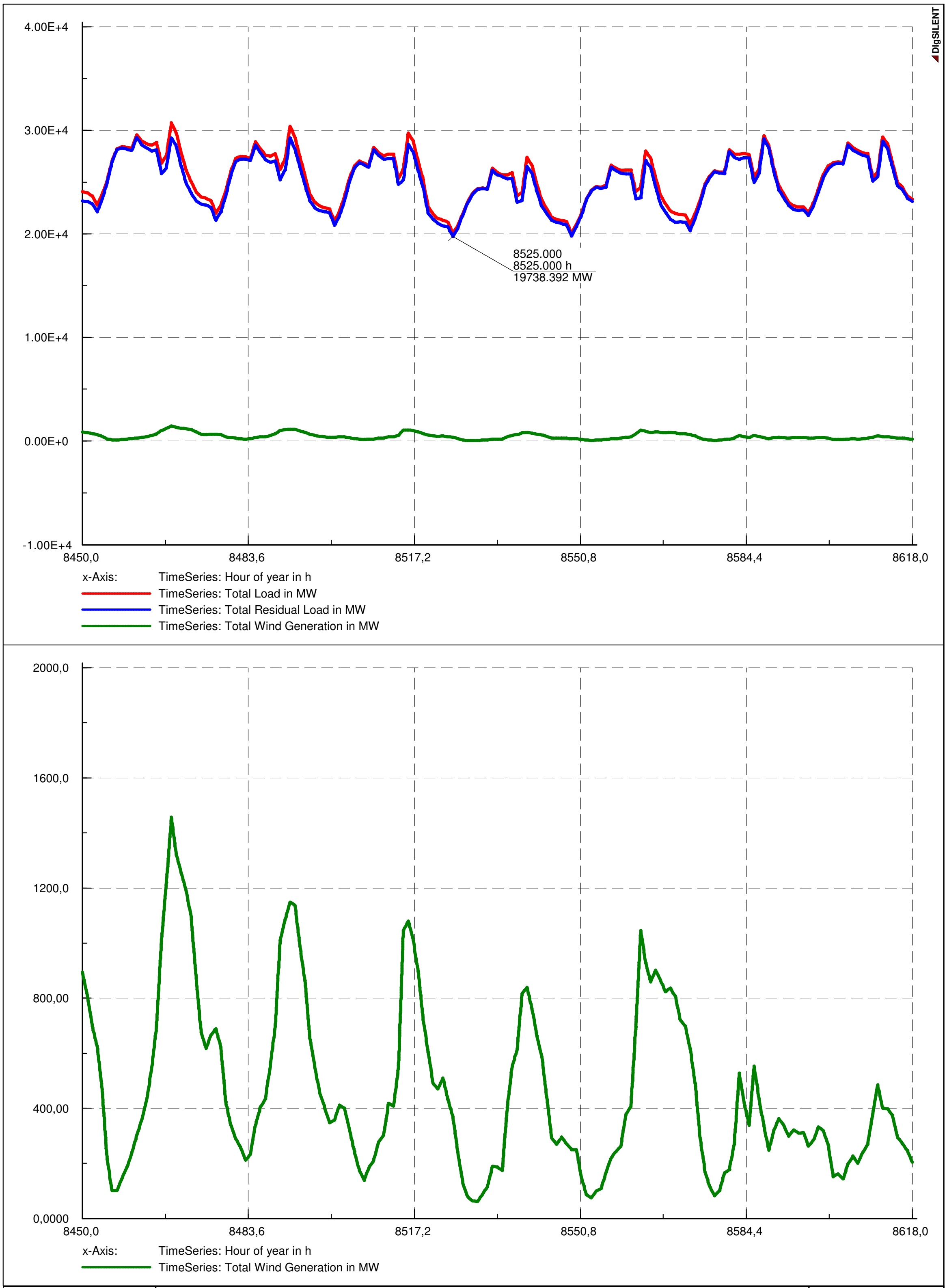
MaxWindDown

Date: 12/26/2010

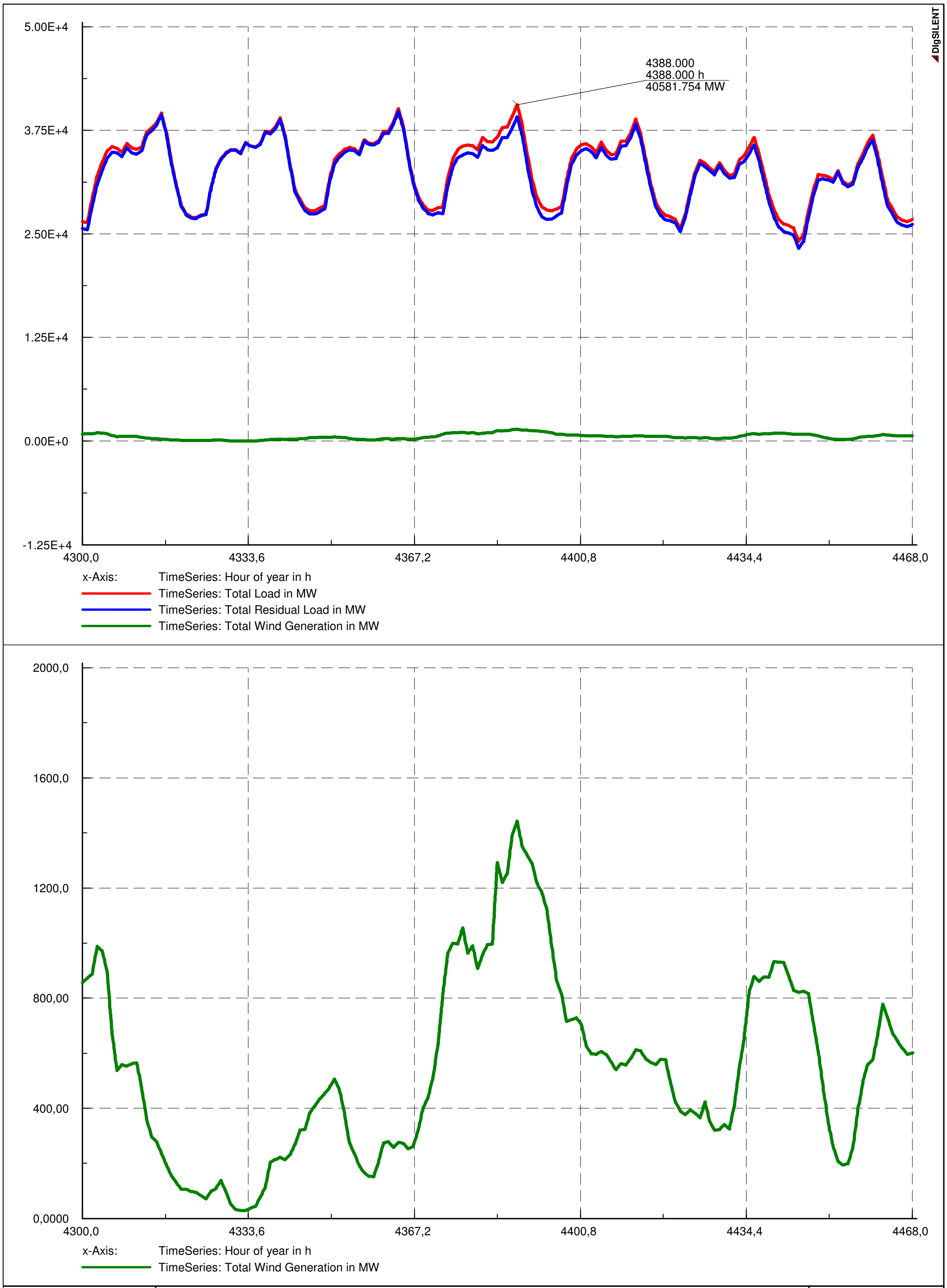
Time Series Studies - Scenario 1

Worst Case Situations

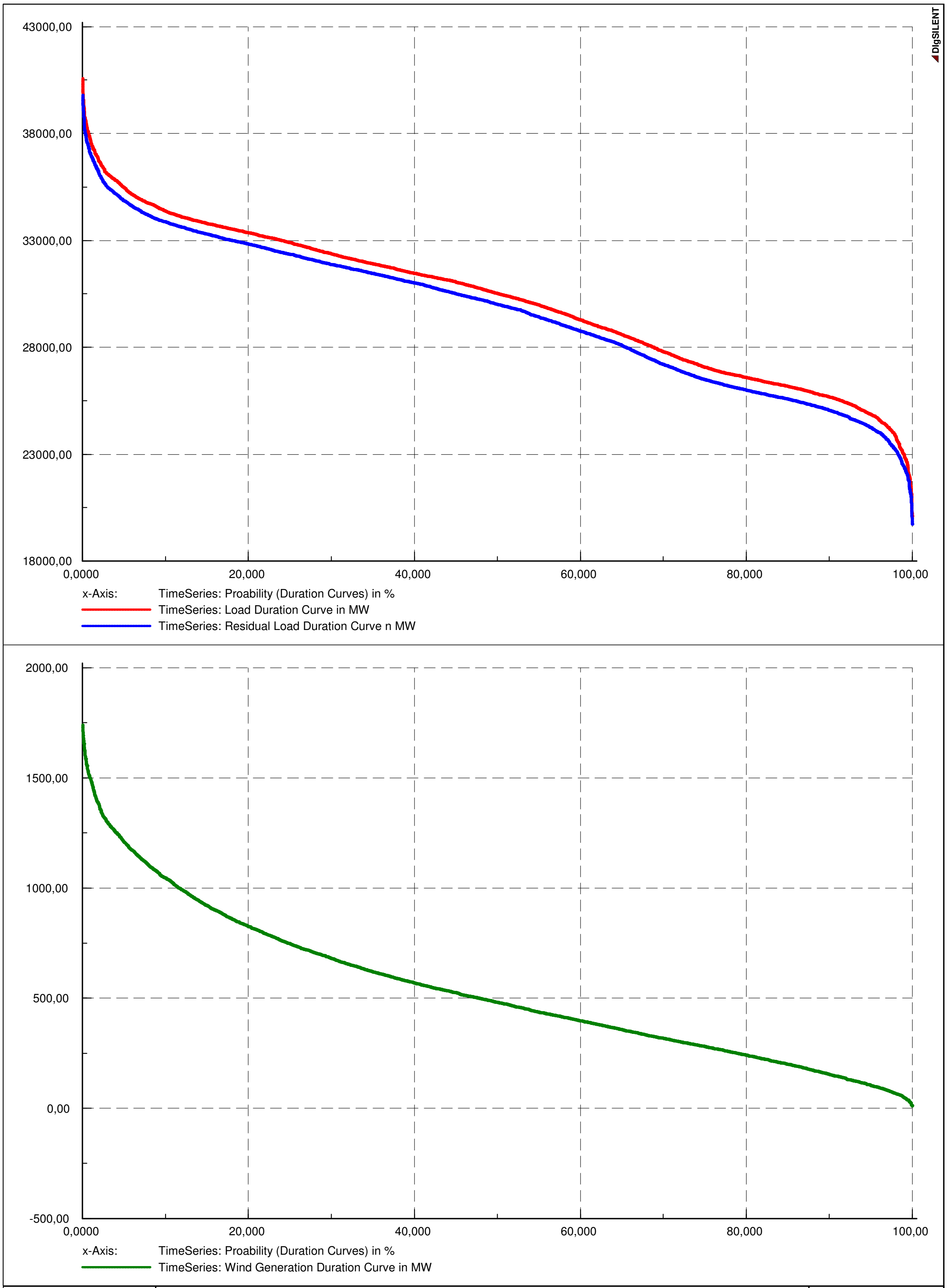
Annex: Annex 3.1 /6



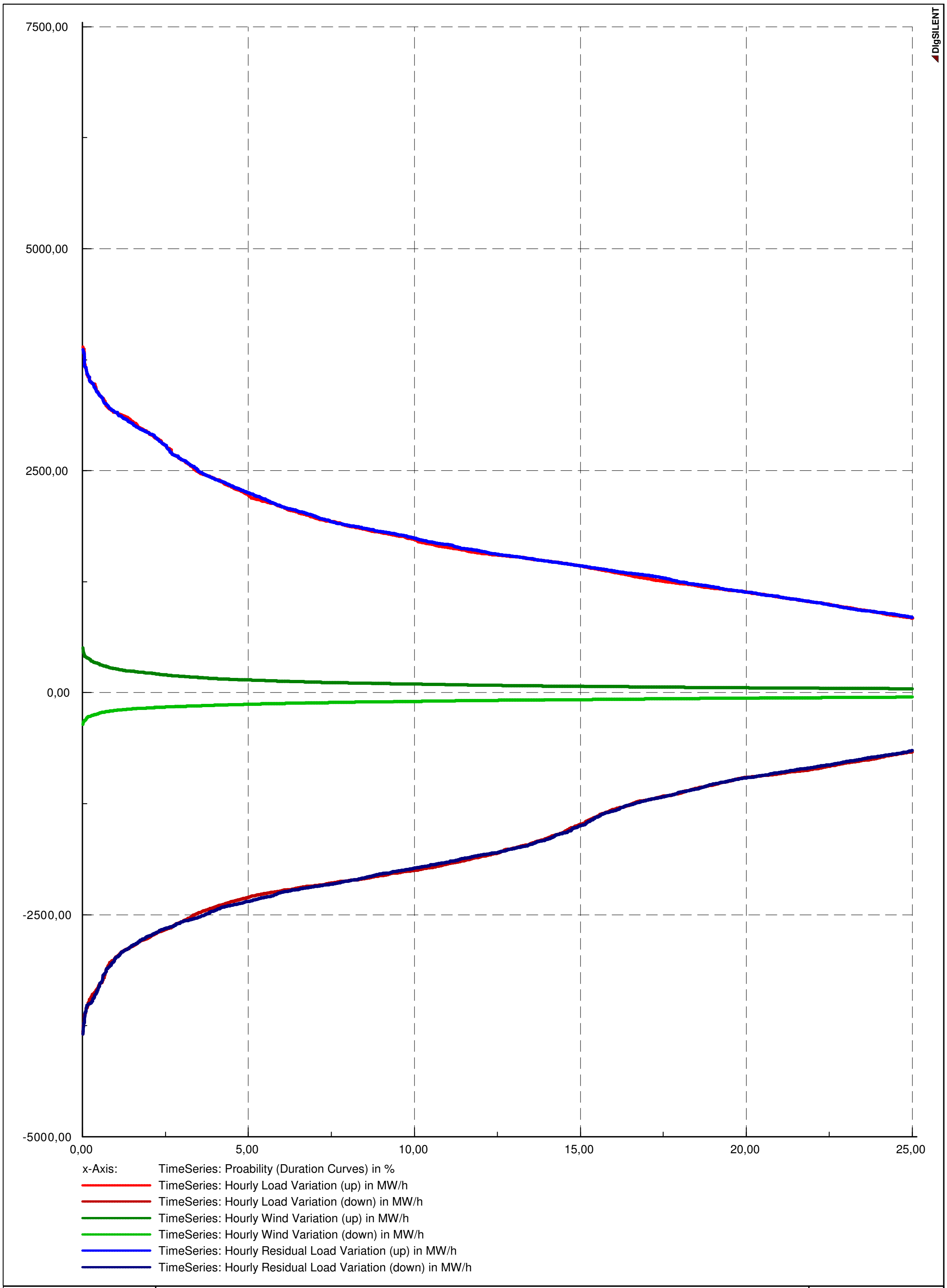
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MinResLoad	Date: 12/26/2010
	Time Series Studies - Scenario 1	Worst Case Situations	Annex: Annex 3.1 /7



DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MaxLoad	Date: 12/26/2010
	Time Series Studies - Scenario 1	Worst Case Situations	Annex: Annex 3.1 /8

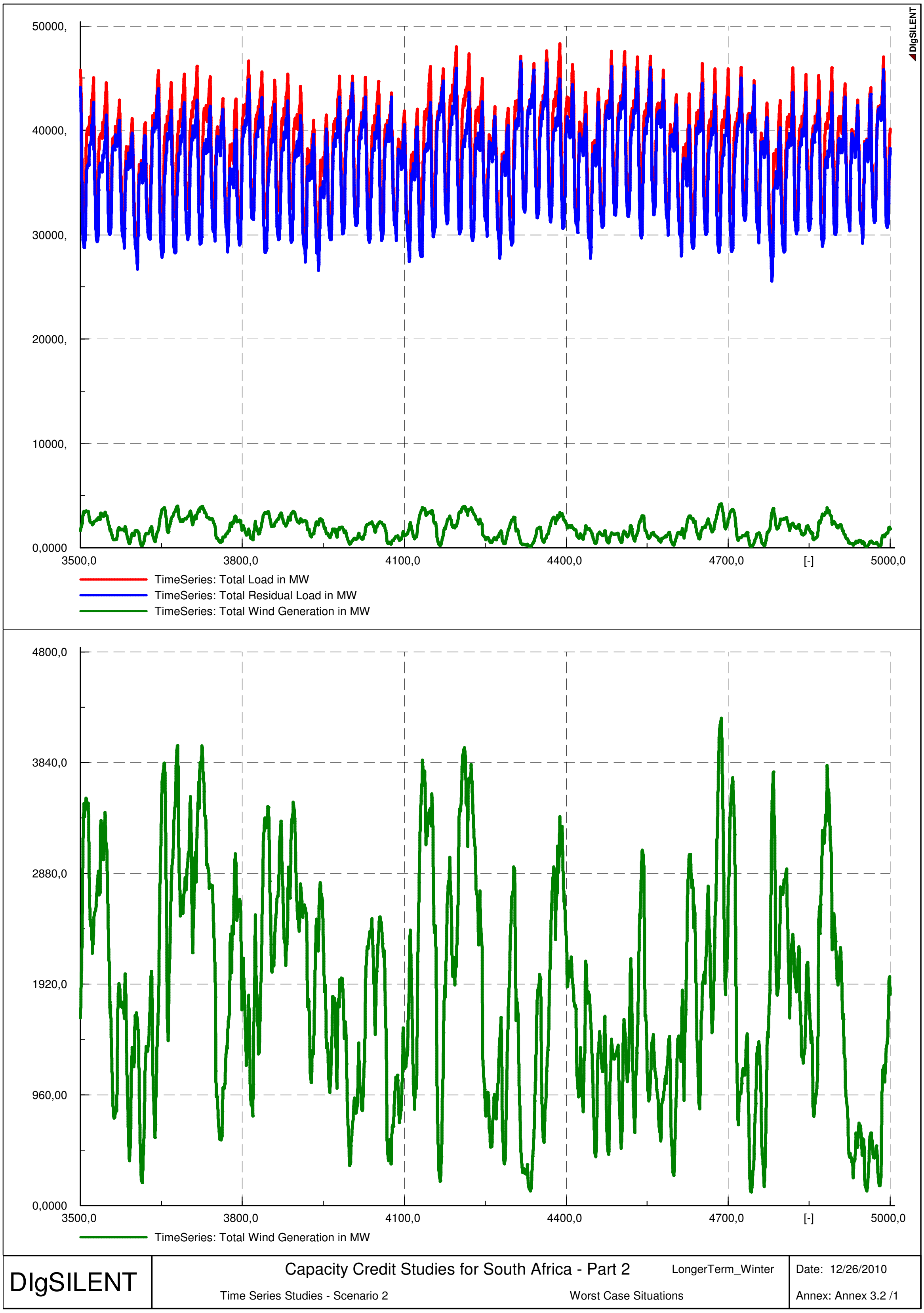


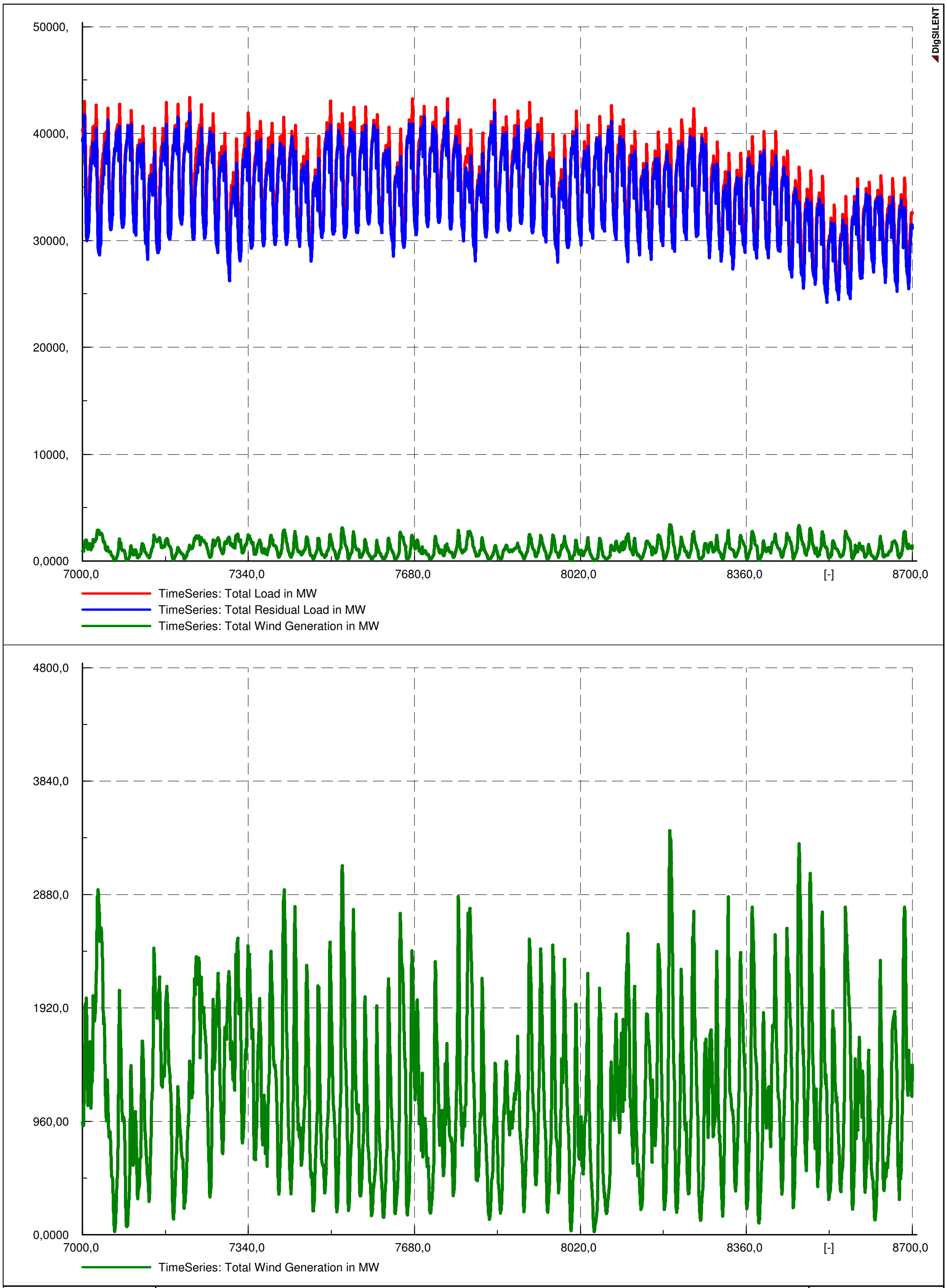
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	Duration	Date: 12/26/2010
	Time Series Studies - Scenario 1	Worst Case Situations	Annex: Annex 3.1 /9



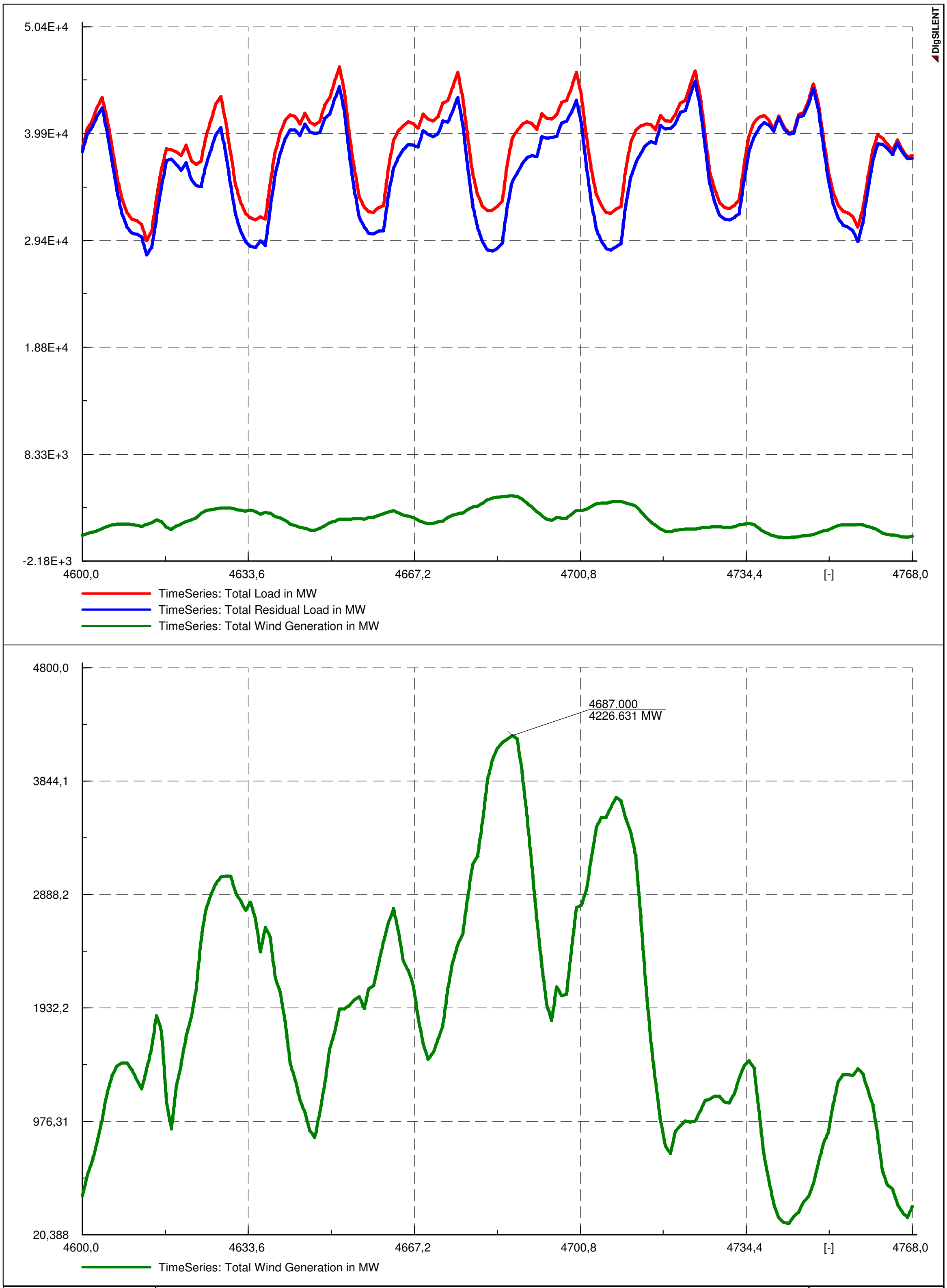
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	Duration_Variations	Date: 12/26/2010
	Time Series Studies - Scenario 1	Worst Case Situations	Annex: Annex 3.1 /10

Annex 3-2: Worst Case Situations and Duration Curves, Scenario 2 – 2020

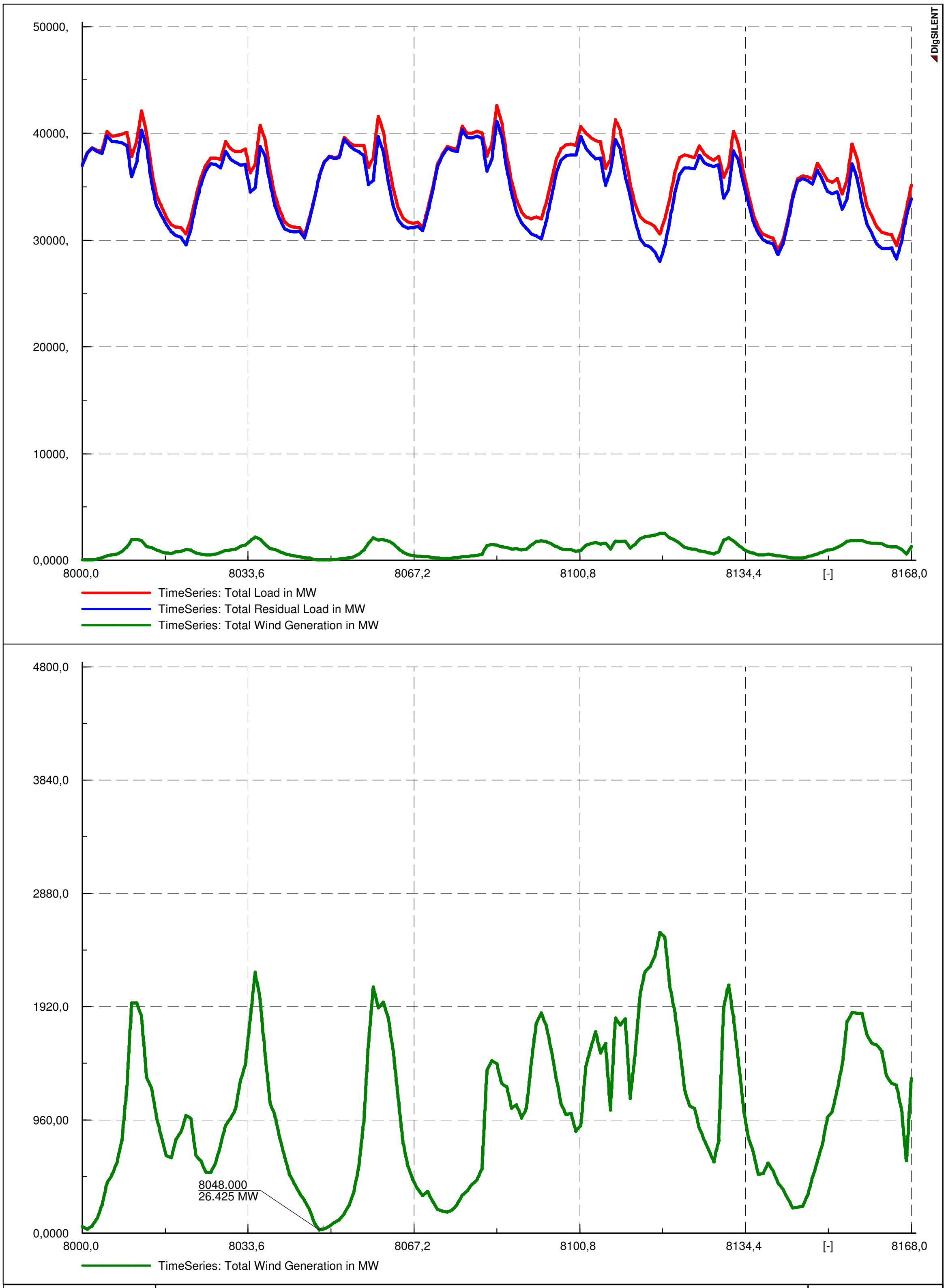

DIgSILENT
50000,
40000,
30000,
20000,
10000,
0,0000
3500,0
3800,0
4100,0
4400,0
4700,0
[-]
5000,0
TimeSeries: Total Load in MW
TimeSeries: Total Residual Load in MW
TimeSeries: Total Wind Generation in MW
4800,0
3840,0
2880,0
1920,0
960,00
0,0000
3500,0
3800,0
4100,0
4400,0
4700,0
[-]
5000,0
TimeSeries: Total Wind Generation in MW
DIgSILENT
Capacity Credit Studies for South Africa - Part 2
LongerTerm_Winter
Date: 12/26/2010
Time Series Studies - Scenario 2
Worst Case Situations
Annex: Annex 3.2 /1



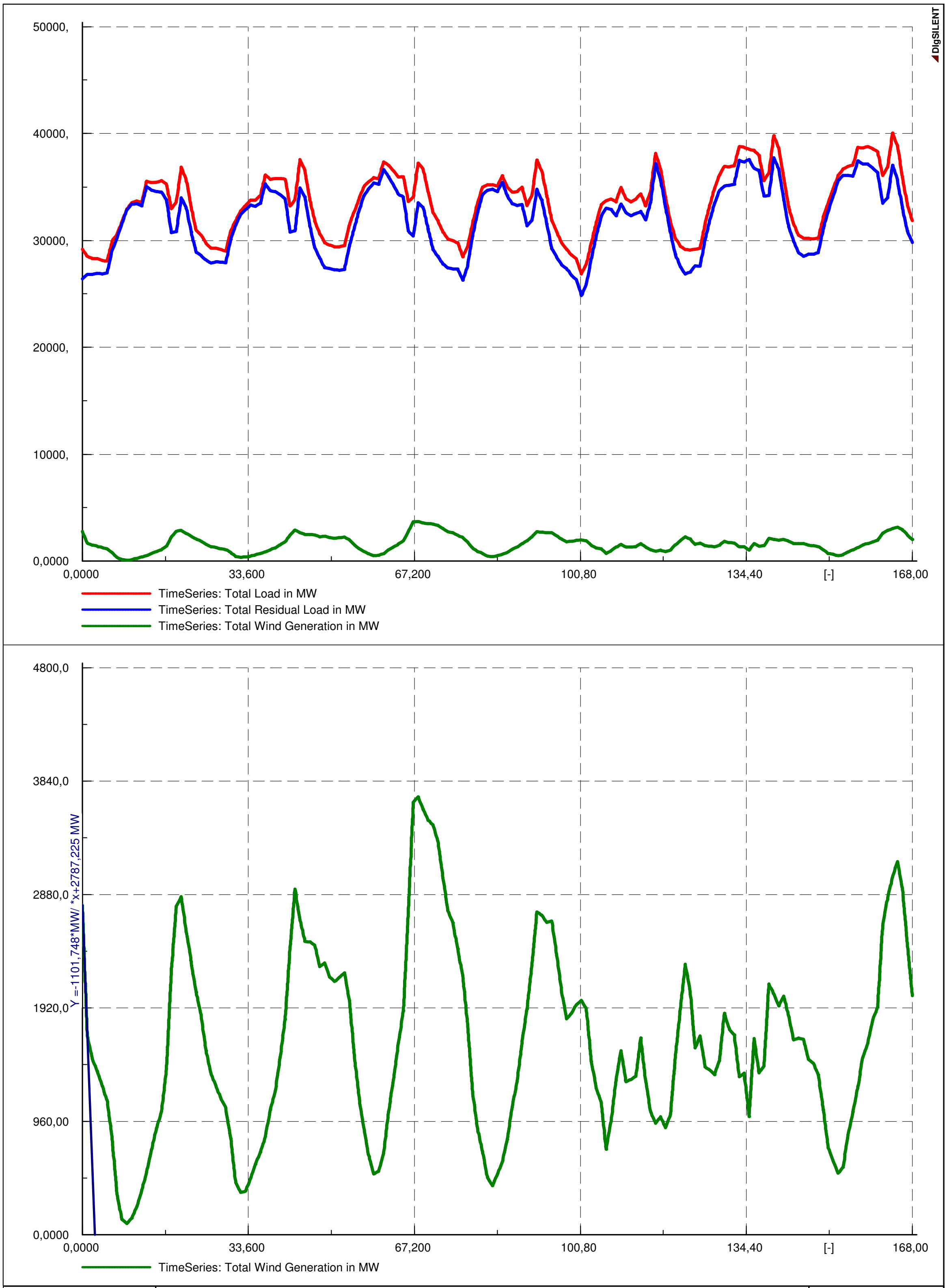
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	LongerTerm_Summer	Date: 12/26/2010
	Time Series Studies - Scenario 2	Worst Case Situations	Annex: Annex 3.2 /2



DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 2	MaxWind Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.2 /3



DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 2	MinWind Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.2 /4



DIgSILENT

Capacity Credit Studies for South Africa - Part 2

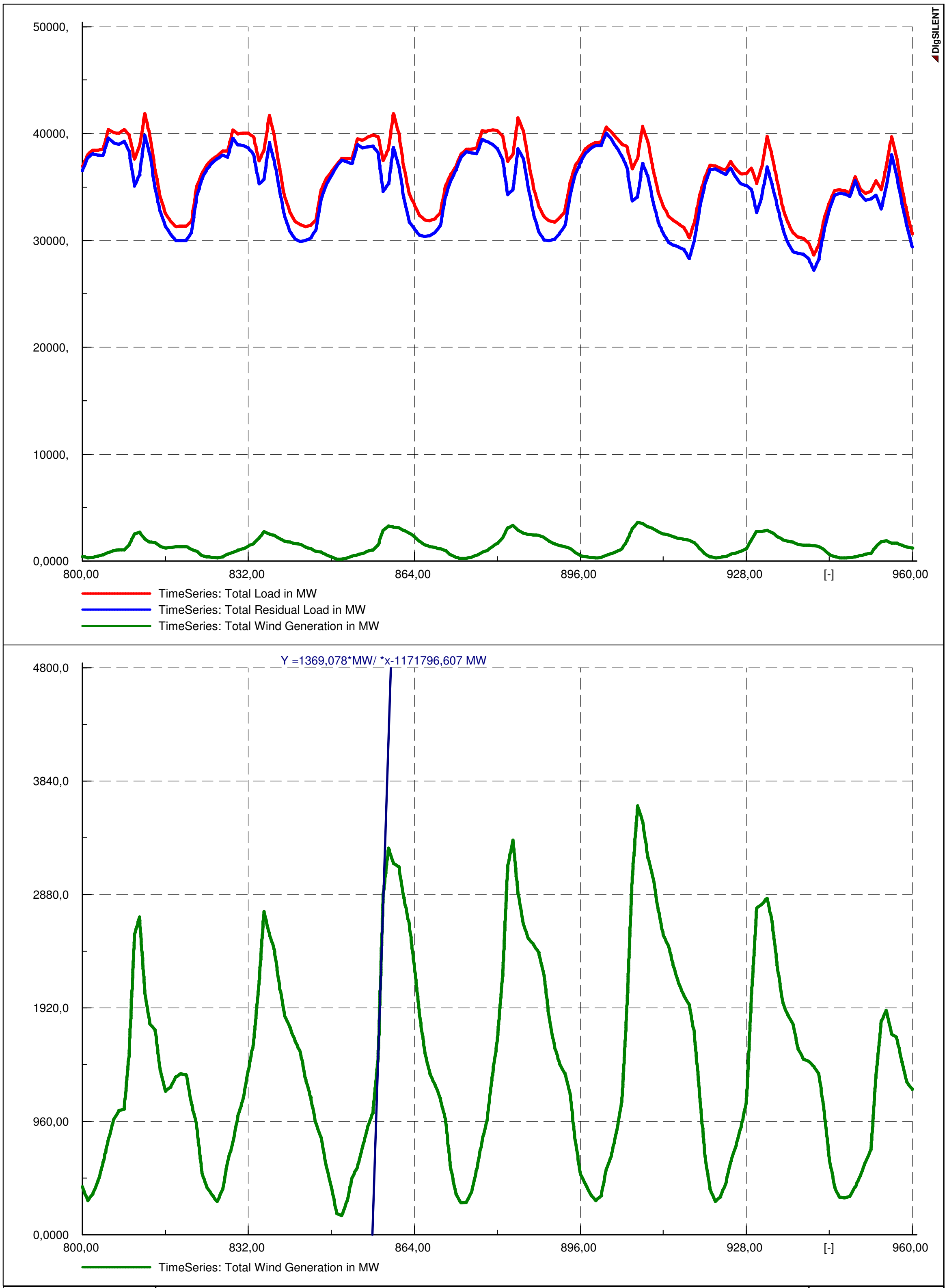
MaxWindDown

Date: 12/26/2010

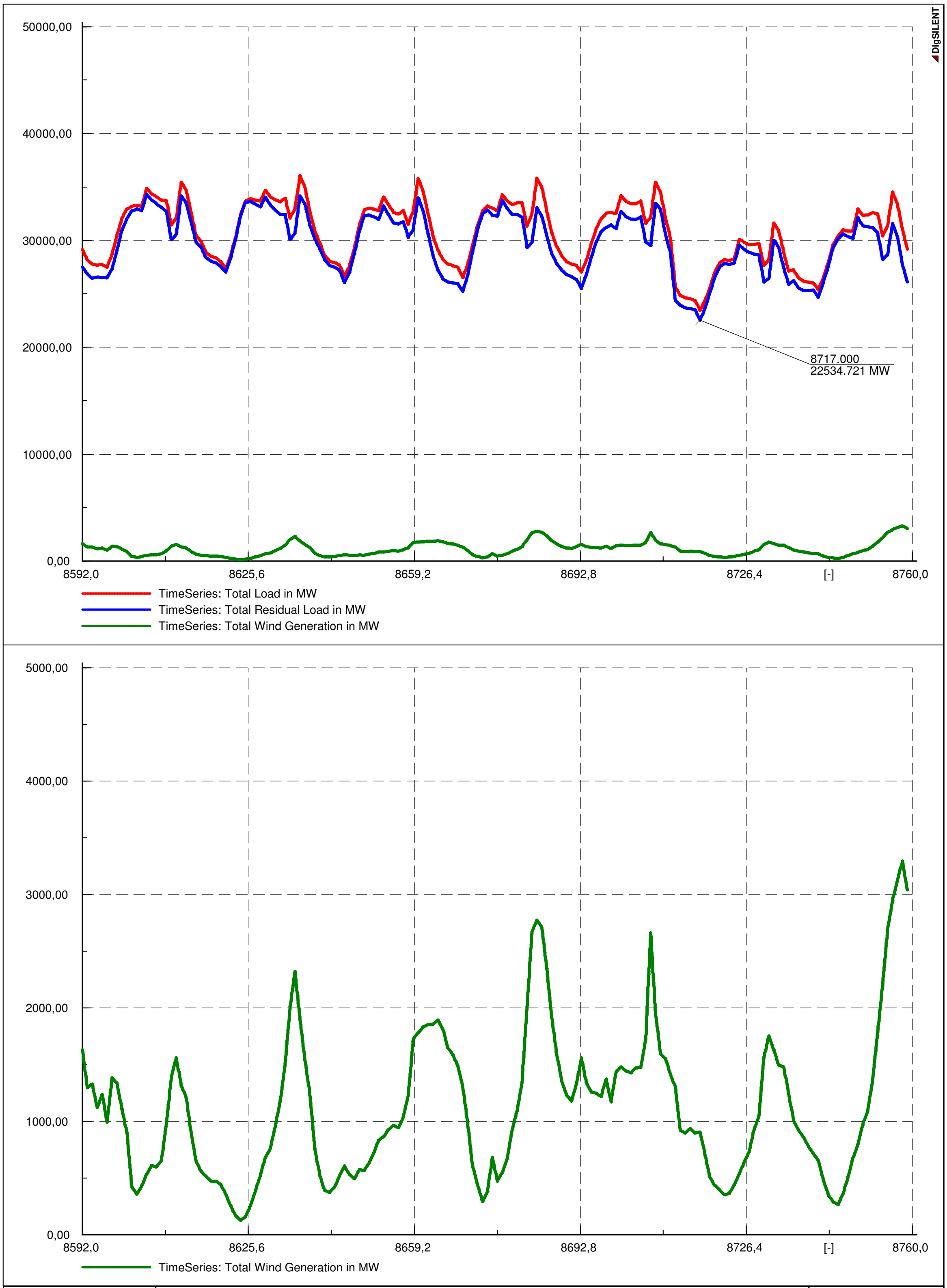
Time Series Studies - Scenario 2

Worst Case Situations

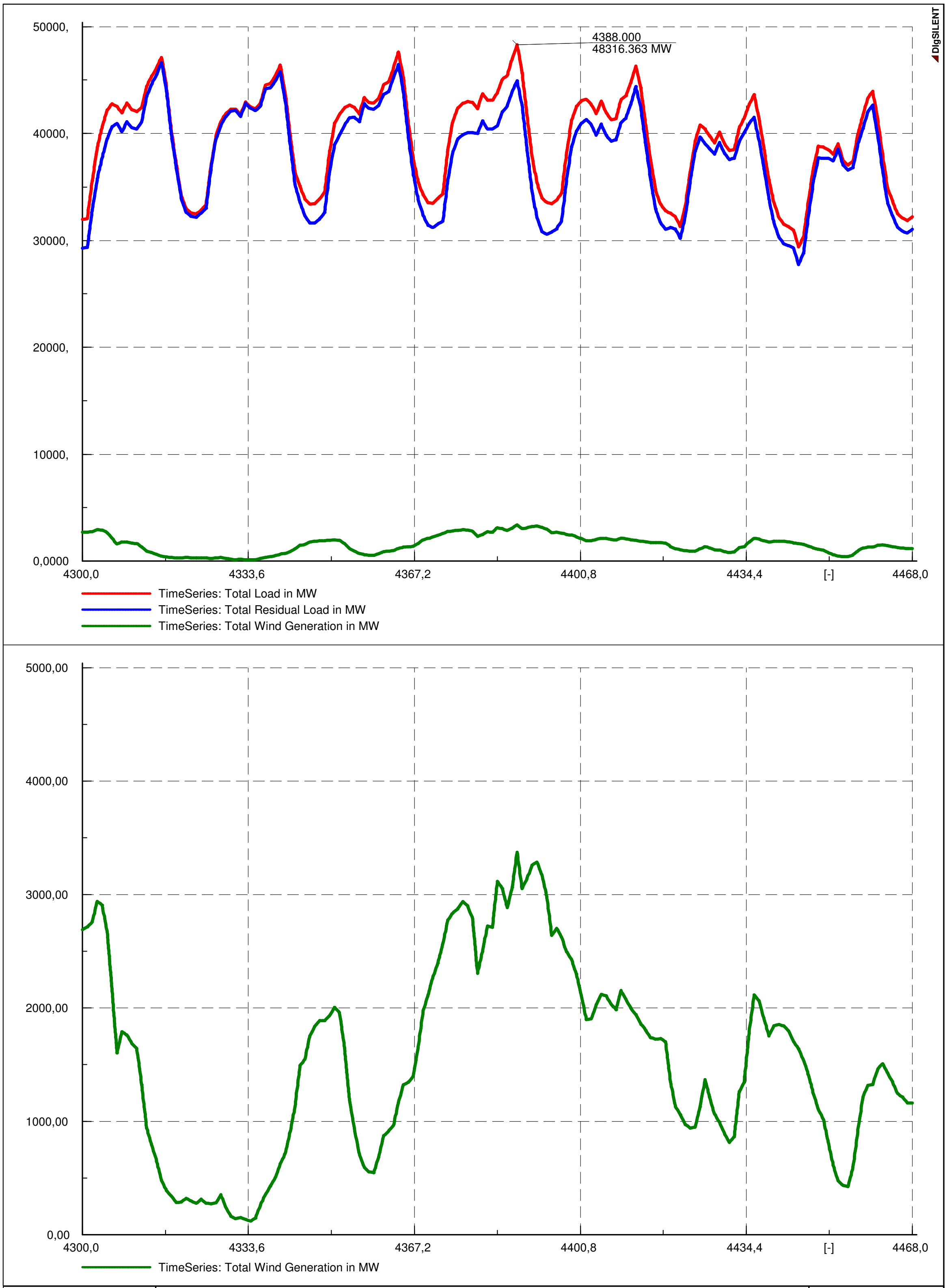
Annex: Annex 3.2 /5



DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 2	MaxWindUp Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.2 /6



DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MinResLoad	Date: 12/26/2010
	Time Series Studies - Scenario 2	Worst Case Situations	Annex: Annex 3.2 /7



DIgSILENT

Capacity Credit Studies for South Africa - Part 2

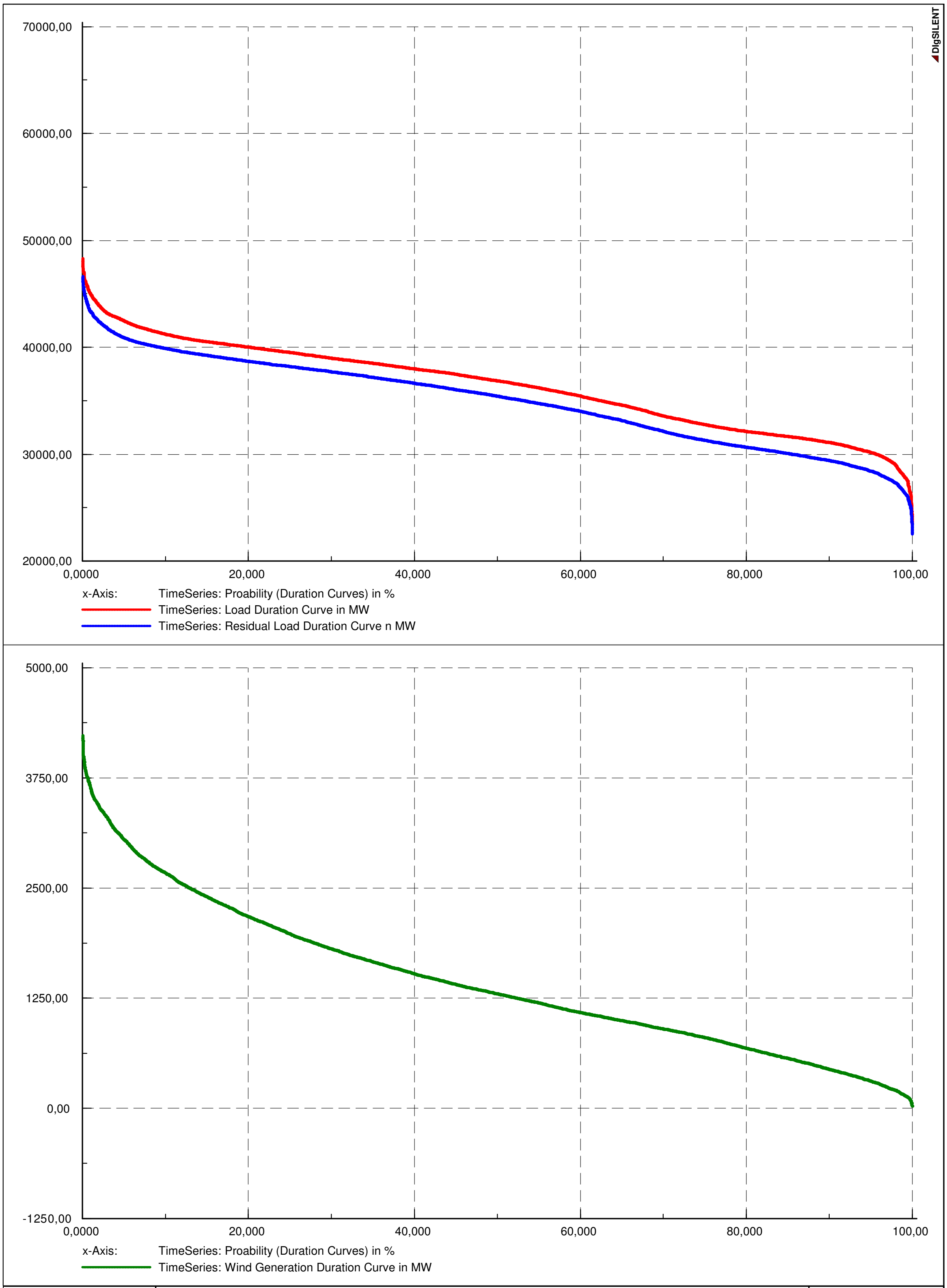
MaxLoad

Date: 12/26/2010

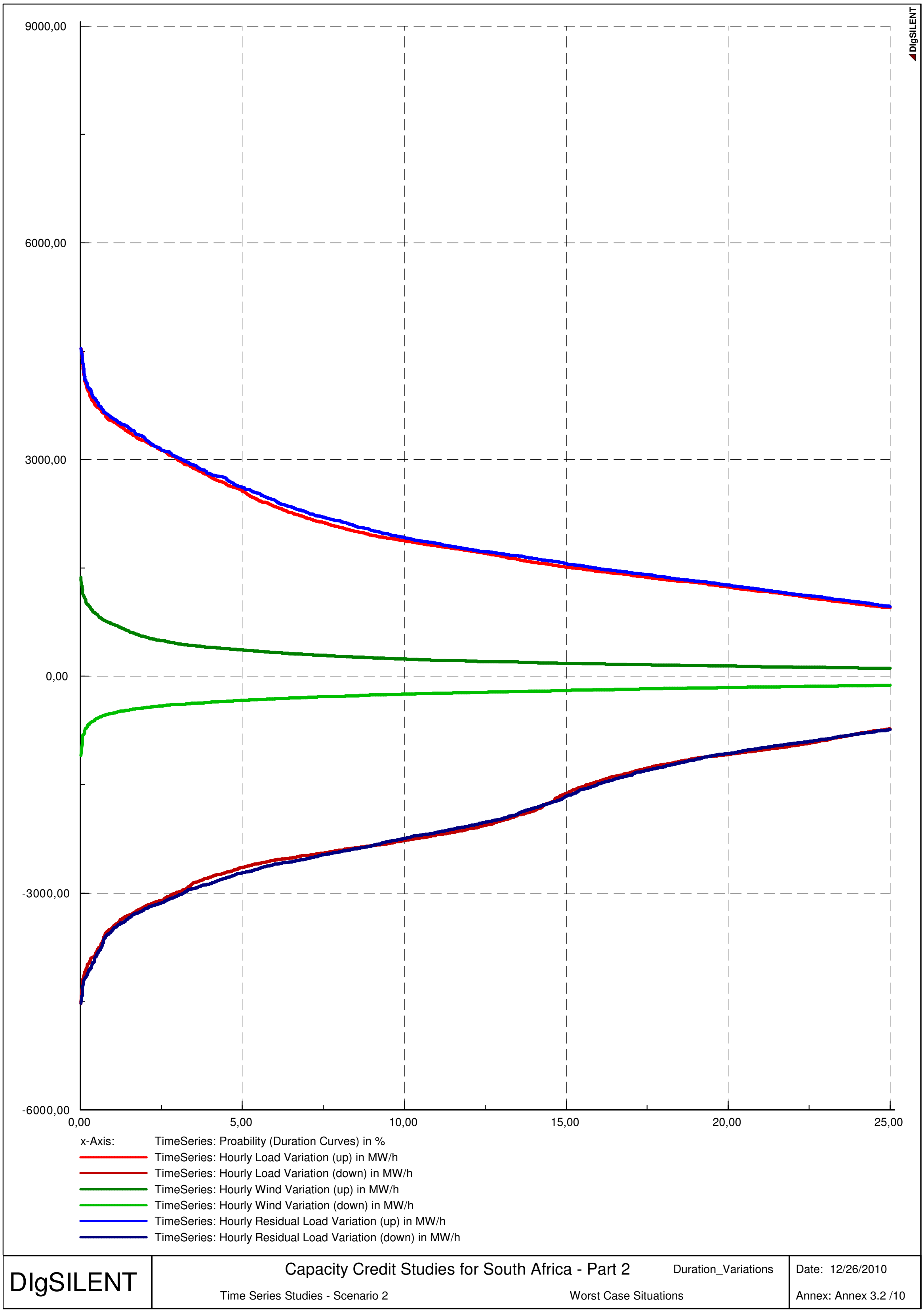
Time Series Studies - Scenario 2

Worst Case Situations

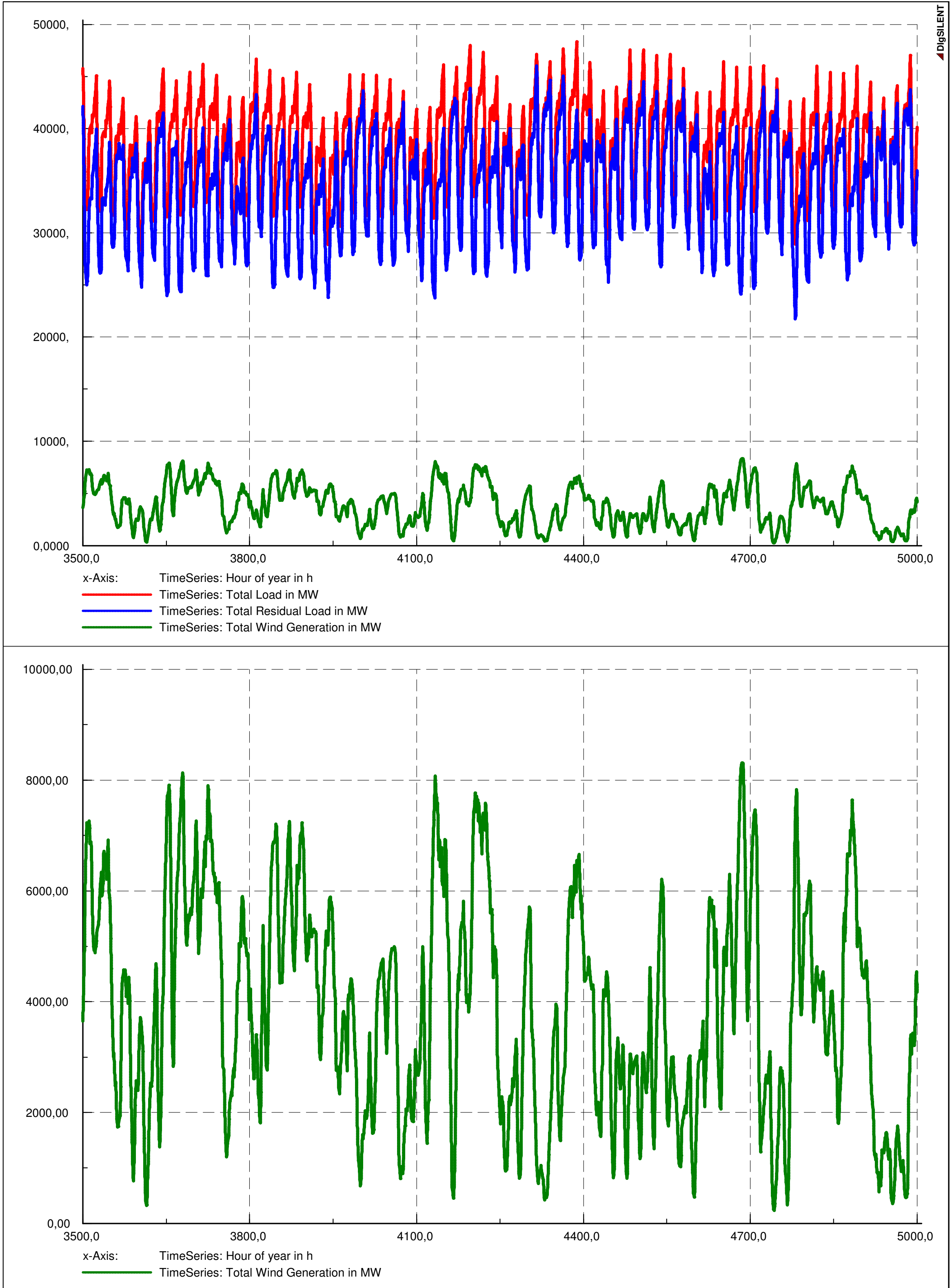
Annex: Annex 3.2 /8



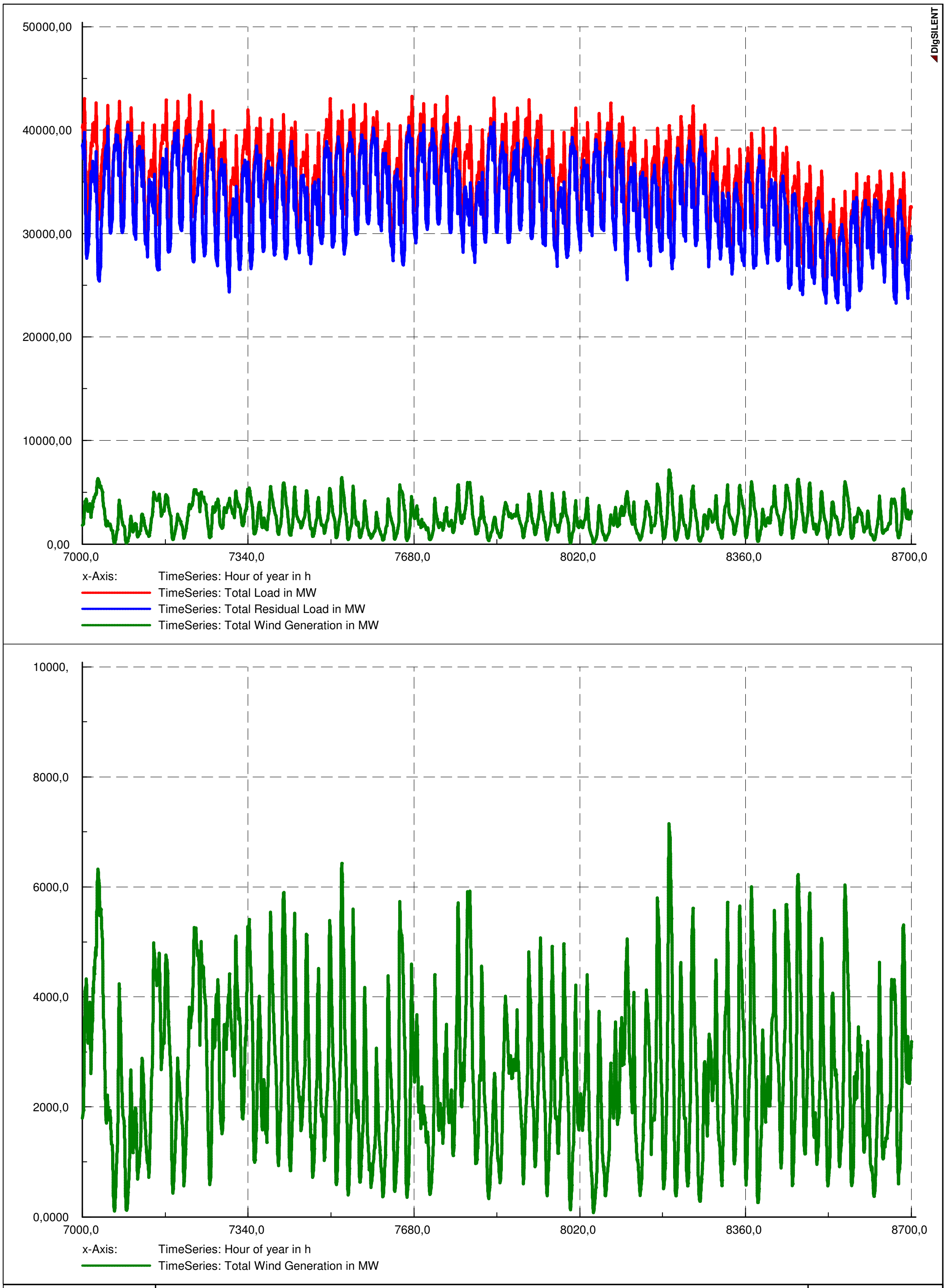
DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 2	Duration Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.2 /9


DIgSILENT
9000,00
6000,00
3000,00
0,00
-3000,00
-6000,00
0,00
5,00
10,00
15,00
20,00
25,00
x-Axis: TimeSeries: Proability (Duration Curves) in %
TimeSeries: Hourly Load Variation (up) in MW/h
TimeSeries: Hourly Load Variation (down) in MW/h
TimeSeries: Hourly Wind Variation (up) in MW/h
TimeSeries: Hourly Wind Variation (down) in MW/h
TimeSeries: Hourly Residual Load Variation (up) in MW/h
TimeSeries: Hourly Residual Load Variation (down) in MW/h
DIgSILENT
Capacity Credit Studies for South Africa - Part 2
Duration_Variations
Date: 12/26/2010
Time Series Studies - Scenario 2
Worst Case Situations
Annex: Annex 3.2 /10

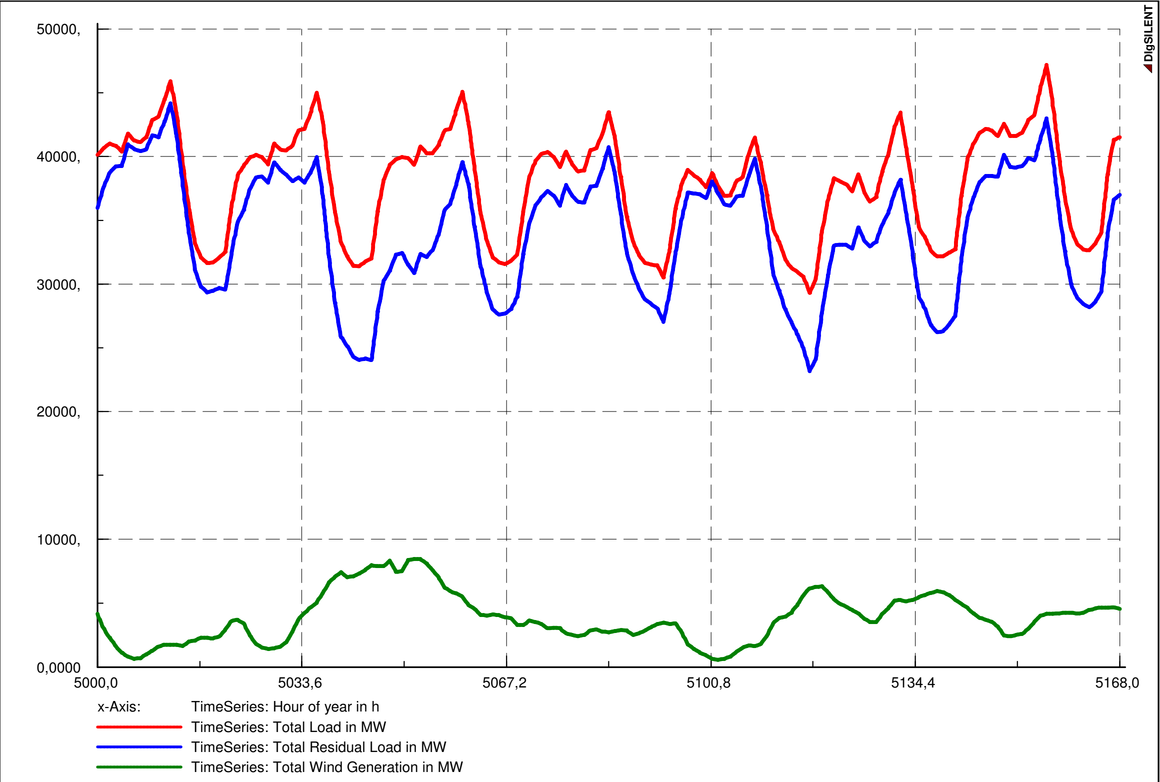
Annex 3-3: Worst Case Situations and Duration Curves, Scenario 3 – 2020

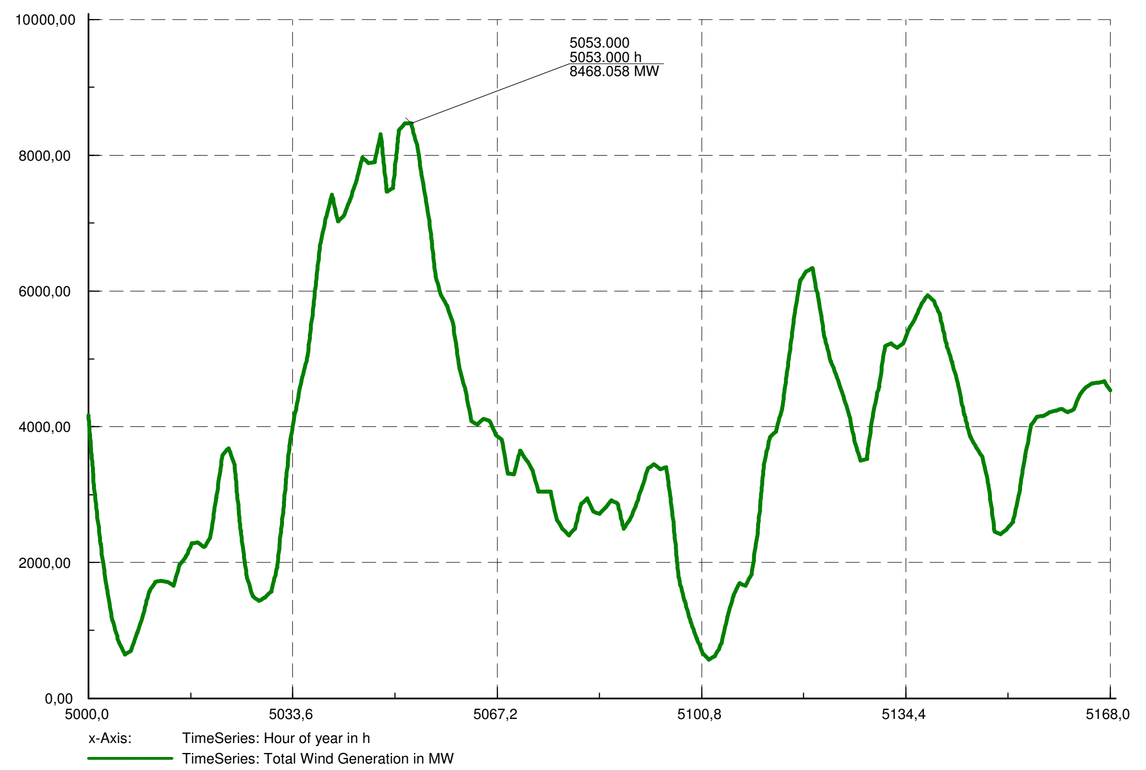


DIgSILENT	Capacity Credit Studies for South Africa - Part 2	LongerTerm_Winter	Date: 12/26/2010
	Time Series Studies - Scenario 3	Worst Case Situations	Annex: Annex 3.3 /1

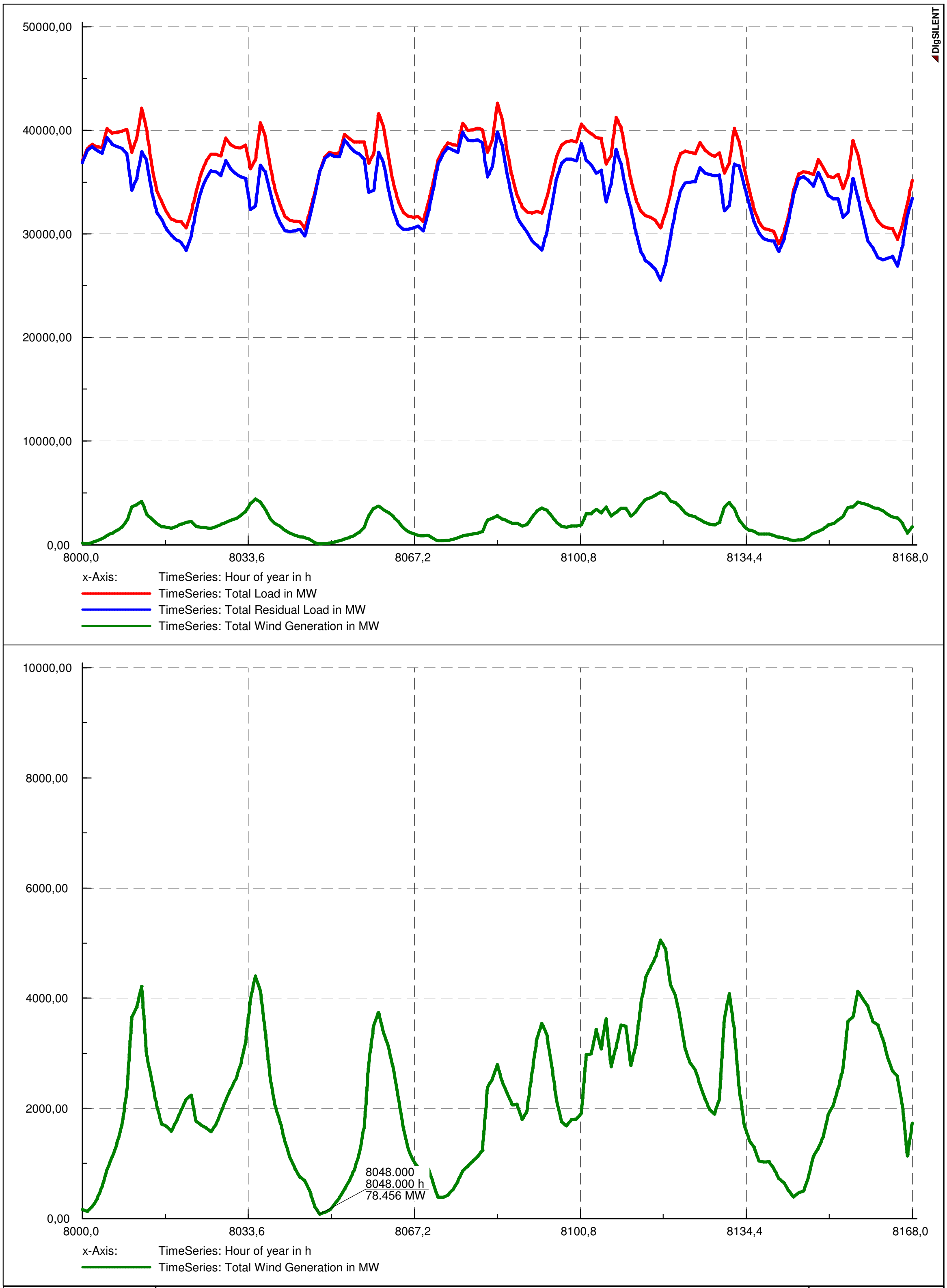


DIgSILENT	Capacity Credit Studies for South Africa - Part 2	LongerTerm_Summer	Date: 12/26/2010
	Time Series Studies - Scenario 3	Worst Case Situations	Annex: Annex 3.3 /2

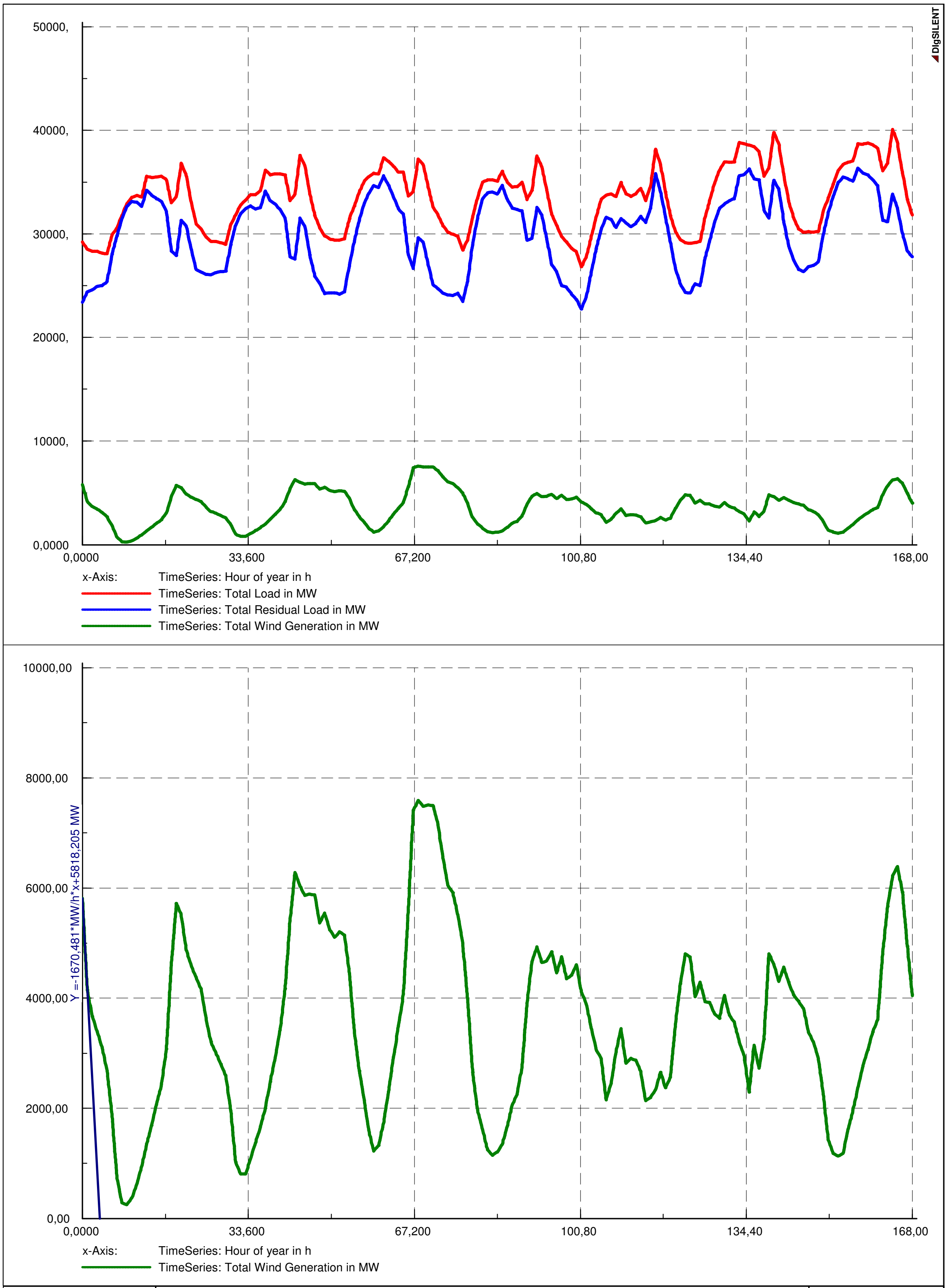




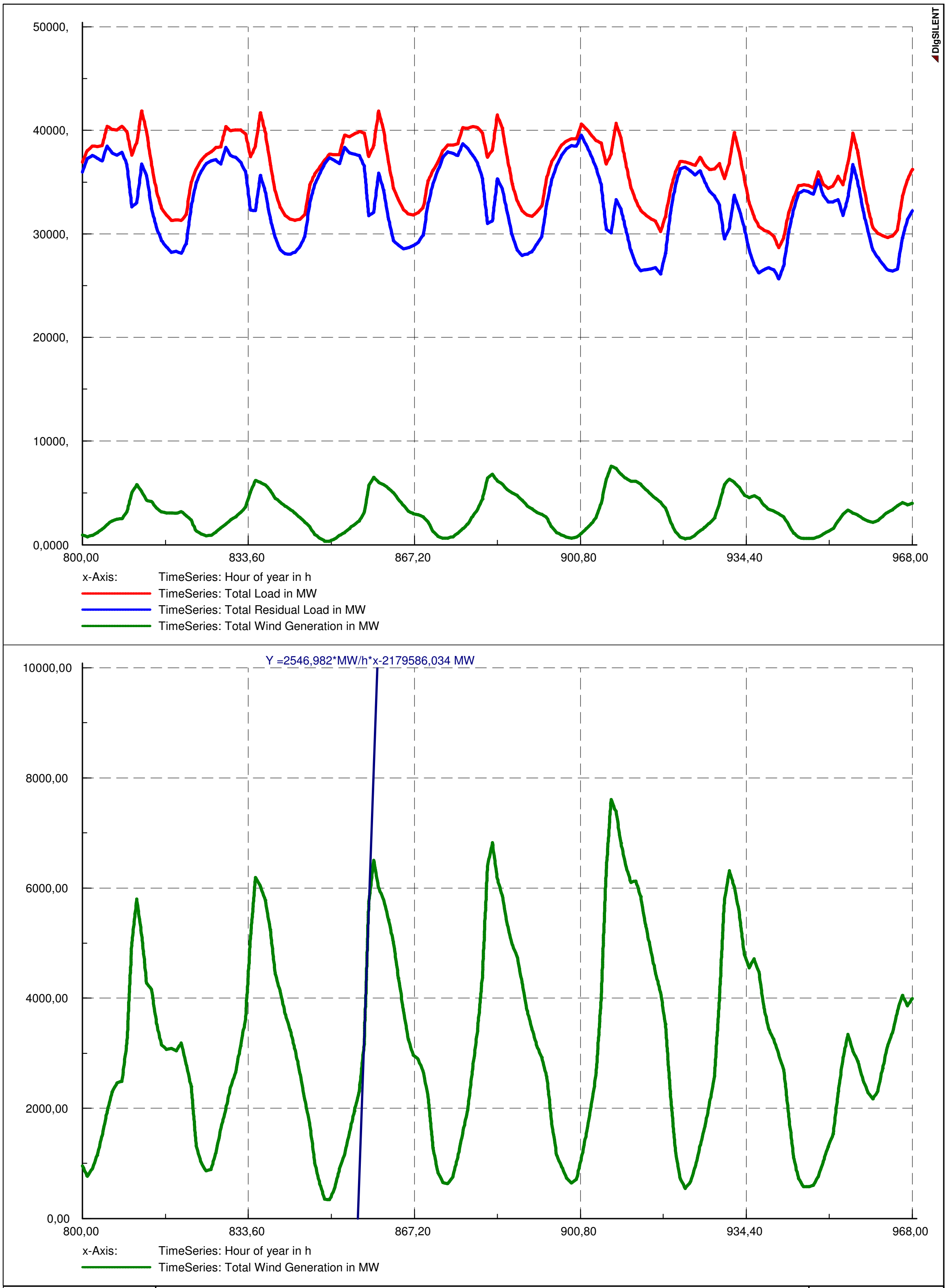
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MaxWind	Date: 12/26/2010
	Time Series Studies - Scenario 3	Worst Case Situations	Annex: Annex 3.3 /3



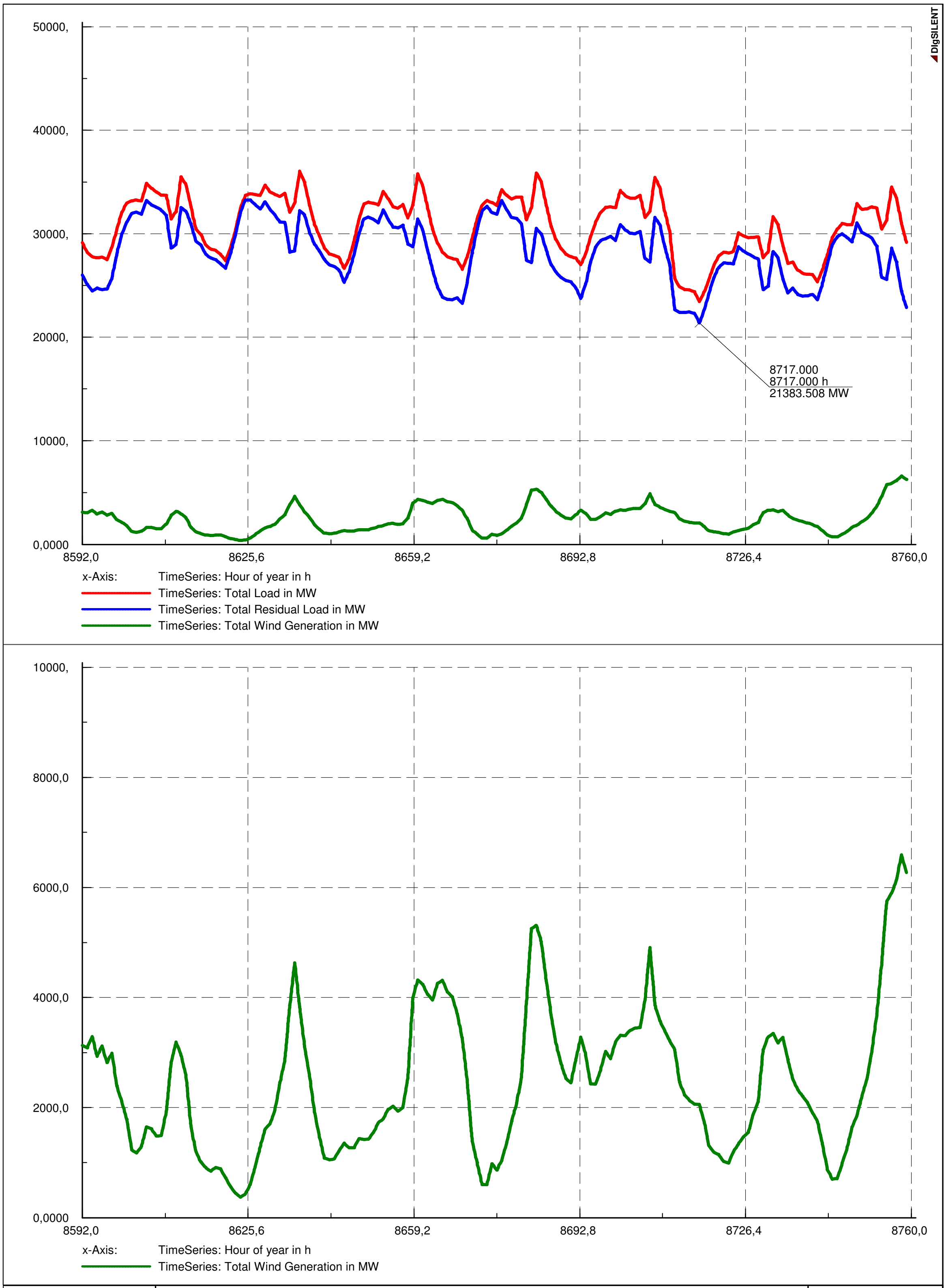
DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 3	MinWind Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.3 /4



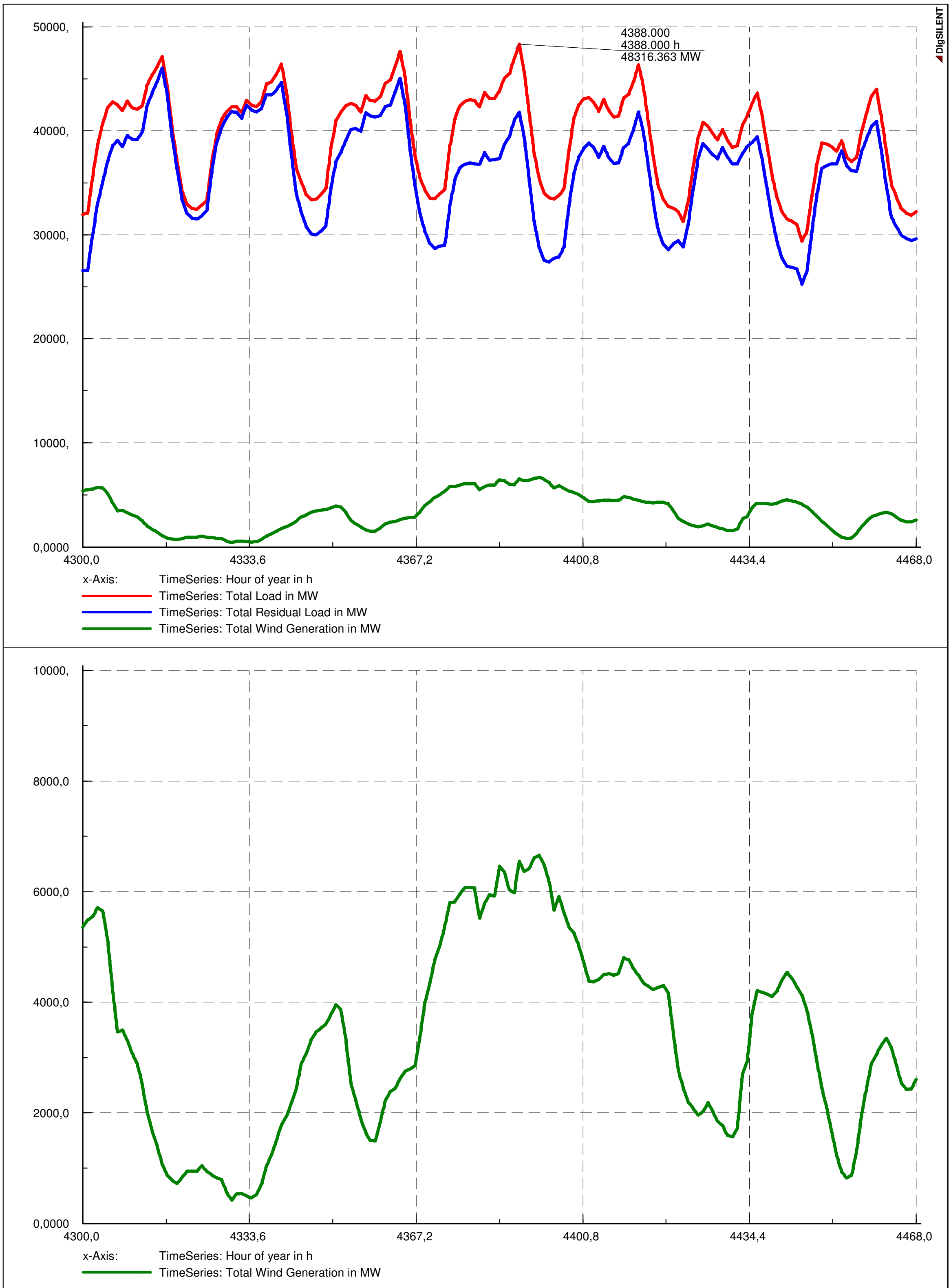
DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 3	MaxWindDown Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.3 /5



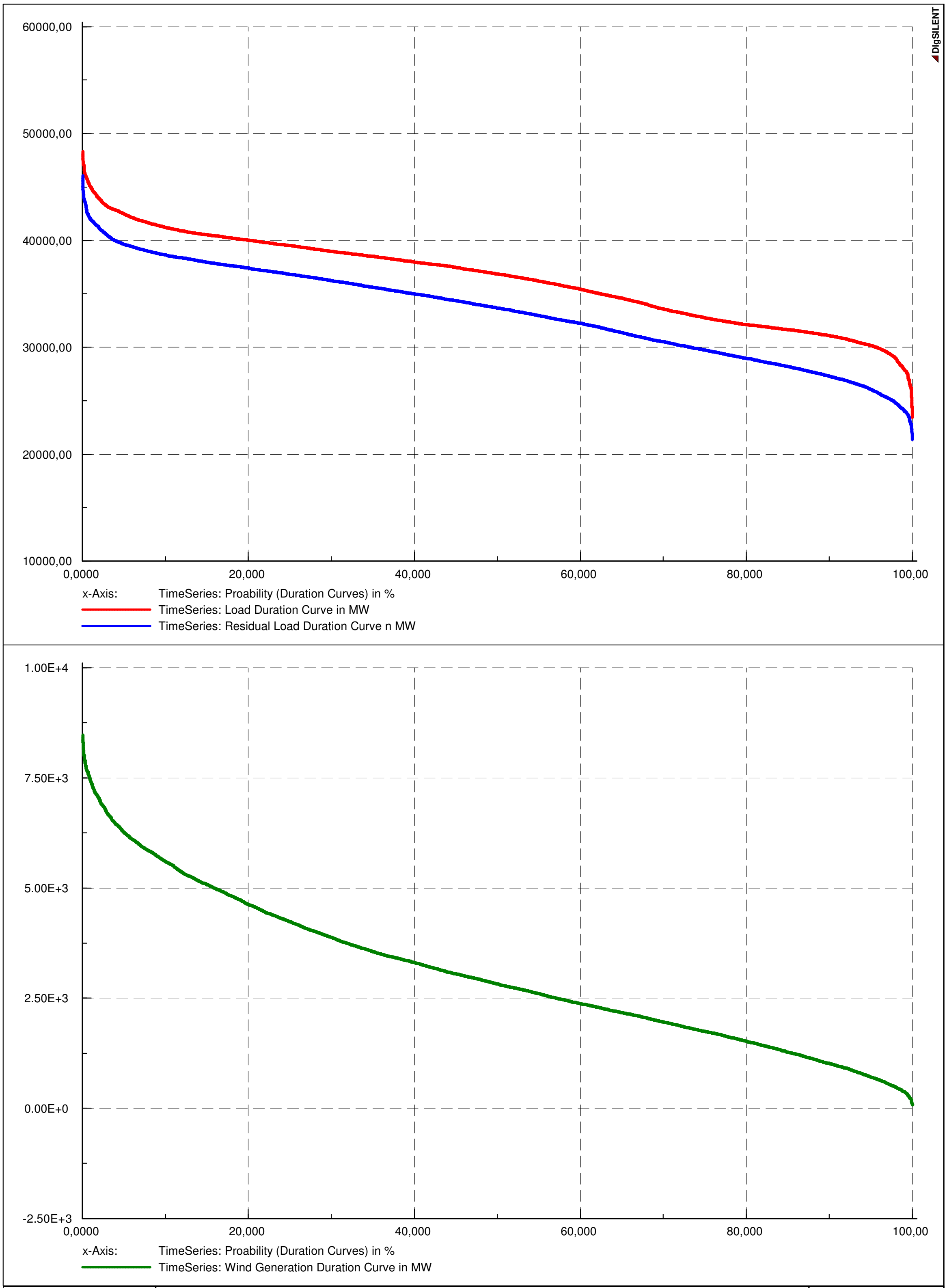
DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MaxWindUp	Date: 12/26/2010
	Time Series Studies - Scenario 3	Worst Case Situations	Annex: Annex 3.3 /6



DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 3	MinResLoad Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.3 /7



DIgSILENT	Capacity Credit Studies for South Africa - Part 2	MaxLoad	Date: 12/26/2010
	Time Series Studies - Scenario 3	Worst Case Situations	Annex: Annex 3.3 /8



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Capacity Credit Studies for South Africa - Part 2

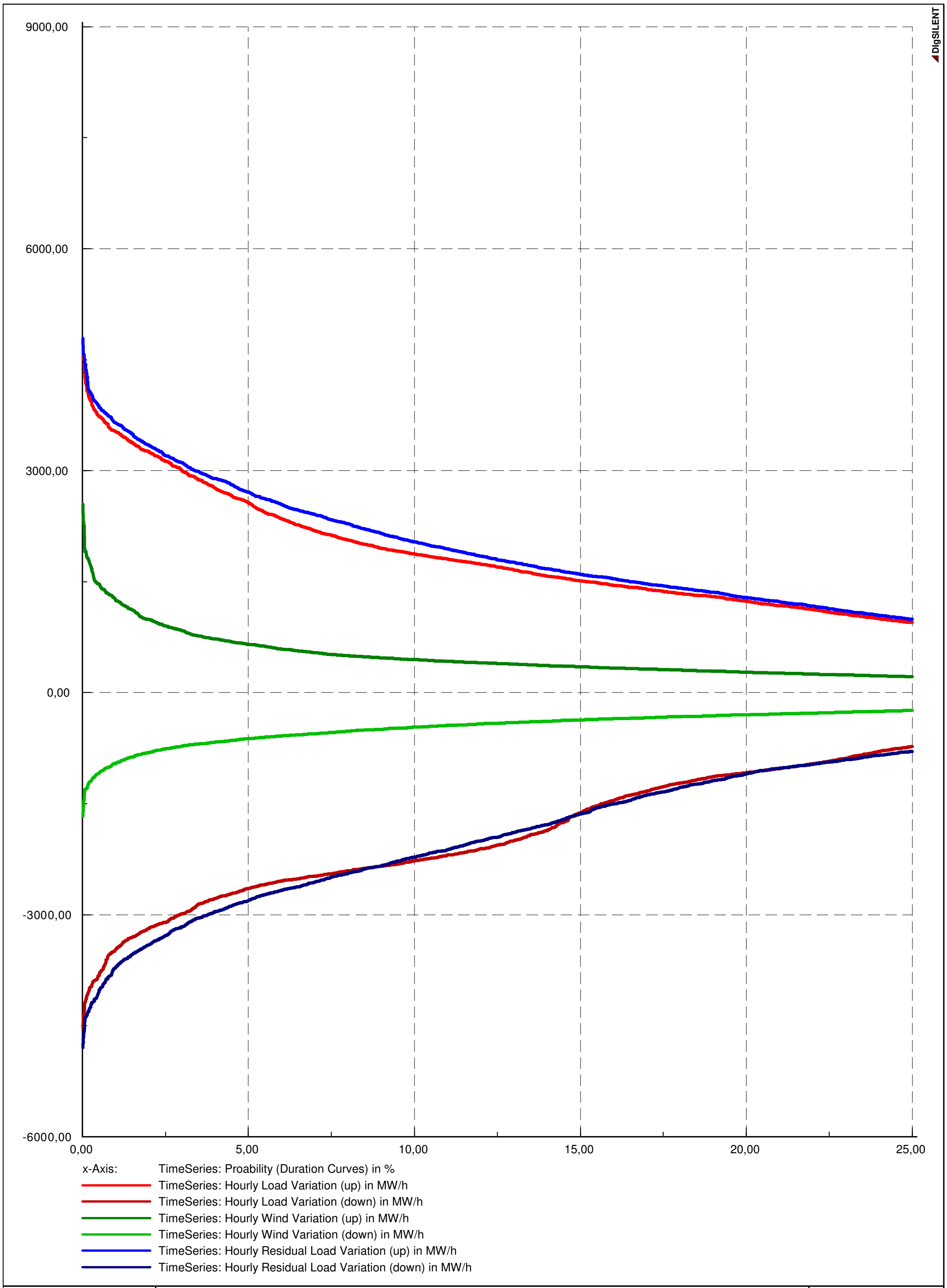
Time Series Studies - Scenario 3

Duration

Worst Case Situations

Date: 12/26/2010

Annex: Annex 3.3 /9



DIgSILENT	Capacity Credit Studies for South Africa - Part 2 Time Series Studies - Scenario 3	Duration_Variations Worst Case Situations	Date: 12/26/2010 Annex: Annex 3.3 /10