Risø-R-1240(EN)

Isolated Systems with Wind Power
Results of Measurements in Egypt

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Abstract The present report presents results of measurements carried out in Egypt in 1998 as part of joint project between Risø National Laboratory, Denmark and NREA, Egypt supported by the Danish Energy Agency. The topic of the project was to investigate issues in relation to isolated power systems with a large amount of wind energy penetration.

The objective of the measurements were to characterise different types of consumer loads in order to be able to construct load patterns to be used in feasibility studies where the available data often will be incomplete, not available or not existing. This will especially be true if there is no existing power system.

Measurements have been carried out at five different sites. Three of the sites were in Hurghada. The Hurghada power system is rather large, the focus at these sites where therefore to measure particular types of load. The three types measured were a hotel load, a shopping mall load and a residential load. The last two measurement sites where at village systems: one large system and one with only power ca. five hours per day. For all the sites loads and power quality have been measured. The results show that the load profiles are quite different at the different sites. The residential load is the most extreme load since variability from day to day is small and it has some very low and very high values compared with the average value. The power quality at the different sites was adequate even at the small village sites. The results are however, influenced by the fact that the load is almost constant.

The load profiles have been used to investigate the impact different load profiles on the technical and economic performance of a wind diesel system in the feasibility phase. The impact has also been compared to the impact of the energy consumption development forecast. The results indicate that when the profile has low values for a long time each day the impact on fuel consumption and profit is significant. However, if the load profile is not so extreme the development of the energy consumption is more important. Since development of the load often is very rapid at relevant sites emphasis should be put at determining this rather than the load profile.

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Preface

The project has been financed by the Danish Ministry of Energy under the energy research programme (EFP97), jour. no. 1363/0022.

Presently, studies of isolated systems with wind power have mostly been case-oriented. Thus it has been difficult to extend results from one project to another, not least due to the strong individuality that has so far characterised such systems and their implementation. Therefore, a main objective of the present project is to develop and present a more unified and generally applicable approach for assessing the technical and economical feasibility of isolated power supply systems with wind energy. As a part of the project the following tasks were carried out: Review of literature, field measurements in Egypt, development of an inventory of small isolated systems, overview of end-user demands, analysis of findings and development of proposed guidelines.

The project is reported in one main report and four topical reports, all of them issued as Risø reports:

Isolated Systems with Wind Power
- Main Project Report (Risø R-1256)
- Implementation Guideline Report (Risø R-1257)
- Review of Relevant Studies of Isolated Systems (Risø R-1109)
- Results of Measurements from Egypt (Risø R-1240)
- Inventory of Isolated Systems in Egypt (Risø, I-1703)

This is the Main Report Risø-R-1256, summing up the activities and findings of the project and outlining an Implementation Strategy for Isolated Systems with Wind Power, applicable for international organisations such as donor agencies and development banks.

This is the Measurement Report Risø-R-1240, presenting the results of the measurement and analysis of load patterns and power quality for five different consumer groups in Egypt together with an example of the application of the results in a system performance analysis.

Glossary

COE	Cost of energy
CT	Current Transformer
DGS	Diesel Generator Set
IEC	International Electro-technical Commission
LAC	Levelized annual costs
LCA	Lifecycle Cost Analysis
LPC	Levelized production cost
P	Active Power
Q	Reactive Power
RE	Renewable Energy
THD	Total Harmonic Distortion
VOE	Value of Energy
WD	Wind-diesel
WTG	Wind Turbine Generator

1 Introduction

The present report covers part of the activities carried out in the framework of the project "Isolated Systems with Wind Power" supported by the Danish Energy Agency under the programme EFP97. The project was carried out by Risø National Laboratory and NREA, Egypt.

The part of the project described in this report covers measurements carried out in Egypt on various types of power systems. The objectives of the measurements where to obtain information on the actual power quality of real power systems of different types and sizes and to establish load profiles to be used in future design of power systems with wind power.

The measurements were carried out during 1998 at five different locations:

- Small Village System: Wadi Tal, Sinai
- Medium Town System: Ras Sudr, Sinai
- Particular Load in Large System 1: Hotel
- Particular Load in Large System 2: Shopping Mall
- Particular Load in Large System 3: Residential Area

For each location the measurement period was 1-2 months. Data were sampled at 0.1Hz. The signals measured included active and reactive power, voltage and current, and harmonic distortion.

For each of the systems the collected data has been analysed and compared in order to generalise the results to the extent possible. The load profiles have also been used to assess the influence of load patterns in the prediction by computer simulation of the performance of power systems with a large amount of wind power capacity.

2 Measurements

2.1 General overview

The objectives for executing the measurements are to establish a foundation for the description of the loads of an isolated system in order to be able to design an isolated power system with wind power in terms of (a) sizing of components (diesel generators and wind turbines), (b) determination of operating strategy and (c) prediction of the performance in terms of e.g. fuel consumption and utilisation of wind power. Another objective has been to measure the actual power quality of such systems in order to be able to have a documented base case for the performance requirements when installing wind power in isolated systems.

The approach has been to measure different types of loads and to measure on different types of power systems. The load has been divided in several categories including domestic, shopping/office, light industry, hotels etc. The reasoning behind this is that it should then be possible based on these types of loads to aggregate the total load of a system based on the demographic data like number of inhabitants, number of shops etc. The impact of the size of the power system is also very important to establish. This includes knowledge of the steps in load and the actual power quality (frequency and voltage quality).

2.2 Selection of sites

The sites have been selected in order to meet the above mentioned objectives. This has resulted in the selection of three sites in Hurghada for the illustration of different types of load and selection of two sites in Sinai to investigate the behaviour in small and medium sized power systems.

In order to investigate the difference between various types of loads three sites were selected in Hurghada. The three sites were:

- Hotel (Three Corner Village Hotel)
- Shopping Centre/Office (Three Corner Shopping Mall)
- Residential area

The power system at Hurghada has rather recently been connected to the national grid, and therefore it cannot serve as an example of an independent grid. The measurement of the characteristics of such grids has been done at two sites in Sinai:

- Ras Sudr, a medium sized system (approx. 4MW and 8000 inhabitants)
- Wadi Tal, a small village (75 kW and 200 inhabitants).

These sites were selected based on inspection of several sites. The criteria for selecting the sites were several including size, collaboration of local utility/operator and location/infrastructure.

The measurements do not give an exhaustive picture of the various types of loads and system behaviour but they give indications of the real life situation in terms of load shapes, load changes and power quality. They can be seen as a step in the direction of establishing a more general foundation for the design of isolated hybrid systems.

In each case the measurements were done by measuring at the outgoing cable of a transformer. The measurement system consisted of a Voltech PM300 power analyser with three current clamps, direct measurement of voltage and a datalogger in the form of a laptop computer with dedicated software.

2.3 Description of sites

Hurghada, West Coast of Red Sea: 3 Corner Village Hotel

3 Corner Village hotel is a medium sized 2-3 star hotel. It has approx. 150 rooms some with air-condition and TV. It is located in Hurghada at the seashore and it is one of the older hotels there. It has two restaurants and a small shop.

The hotel has its own 500kVA transformer for power supply. The measurement system was connected directly at the terminators at the secondary side of this transformer. All three phase voltages were measured relative to ground as well as all three line currents.

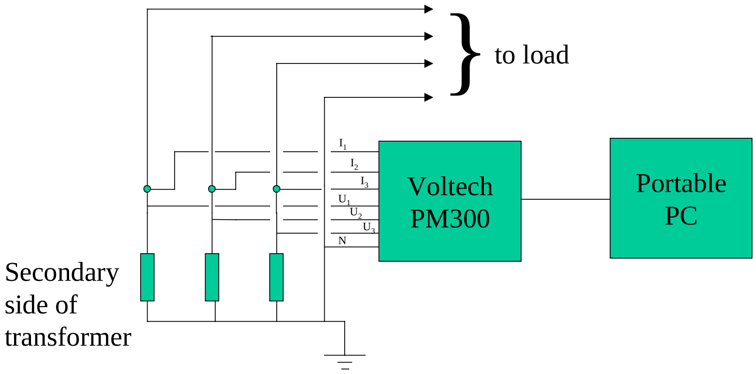


Figure 1 Connection of measurement system

A Voltech PM300 was used to calculate relevant signals such as RMS-values of voltages and currents, active and reactive power and distortion. The complete list of signals is in app. A.

The site was the first site of the measurement campaign of the project. It was carried out during Feb-May 1998.

Hurghada: 3 Corner Shopping Mall

The 3 Corner Shopping Mall is close to the hotel. It is a small mall with approx.15 shops and with office space in the floors above. The building is rather new. The offices are air-conditioned. The building has it own 500kVA transformer. The measurement system was connected and set up in the same way as at the hotel.

The measurements were carried out during June-July 1998.

Hurghada: Residential Area

The residential area is located in the city centre of Hurghada. The area is dominated by houses but the are also a few small shops. The measurement system was connected to a 500KVA transformer. The installation and setup was identical to the previous ones.

The measurements were carried out during July-August1998.

Ras Sudr

Ras Sudr is a small town situated on the Red Sea Coast of Sinai approx. 100km South of Suez. It has 8000 households. The main economic activity of the area is tourism. Several hotels are located along the cost line. There is also some industrial activity related to oil handling. There is quite some building construction of both housing and hotels in the area.

The power system is an autonomous grid with a single power station situated in the town. The power is distributed using a 11kV and 22 kV overhead lines. The power station has several gensets due to the rapid growth of the load, but currently the town is only using two rather new MAN diesel gensets of 2MWe each. The power station is connected to the distribution company through two 11kW cables. The bus bar for distributing the power is situated at the distribution company.

Wadi Tal

Wadi Tal is a small bedouin village situated on Sinai approx. 50km south of Ras Sudr and a few kilometres inland. The village has approx. 400 inhabitants living in 50 households. There is a primary school and a small hospital. The main need for power is for lighting. There is power available from ca. 16.00h to 22.00h every day. Power is generated at the local power station, which is not grid connected. The grid is a 400V grid connecting each house. There are only a few hundred meters of grid.

Two gensets are available, but only one at a time can be connected. The power station is operated by the head of the village or the school teacher. Operation consists of starting and stopping the genset, refuelling the day tank, checking oil and changing filters. If a diesel set breaks down the cable is connected to the terminals of the other generator. Fuel is delivered in barrels and is paid for by the villagers. During the one month measurement period the system was operated as normal.

2.4 Data screening

For each of the five measurement sites data showing the power quality and characterising the load is presented. The main focus is on the voltage quality and on the active power demand, but also the frequency and the reactive load is analysed. The analysis has been performed with the objective of characterising the load type in order to be able to use it in the analysis of future systems. The original data is sampled with 10 sec intervals. The samples are then averaged using a 10 min averaging period.

The measurement period and the procedure are slightly different from site to site and this information is therefore indicated in the section for each site.

Hurghada: 3 Corner Village Hotel

This is the initial measurement site and it is one of three sites in Hurghada. The measurements were carried out for a relatively long period (more than three months), but only data after the trip in beginning of April 1998 has been used in the analysis since as part of the trip the measurements were inspected and it was found the due to the neutral not being connected the data on the voltage were not valid.

The measurement system was checked each day and data files were changed. Only few problems were experienced during the period.

Table 1 Key data for 3 Corner Village Hotel measurements

Item	**Description**
Load type	Hotel
Grid type	Interconnected
Start date	98.03.06
Stop date	98.05.22
Average load	89 kW
Standard deviation of load	34 kW
Min 10 min load	28 kW
Max 10 min load	236 kW

Initially graphs are shown indicating the power quality at the point of measurement.

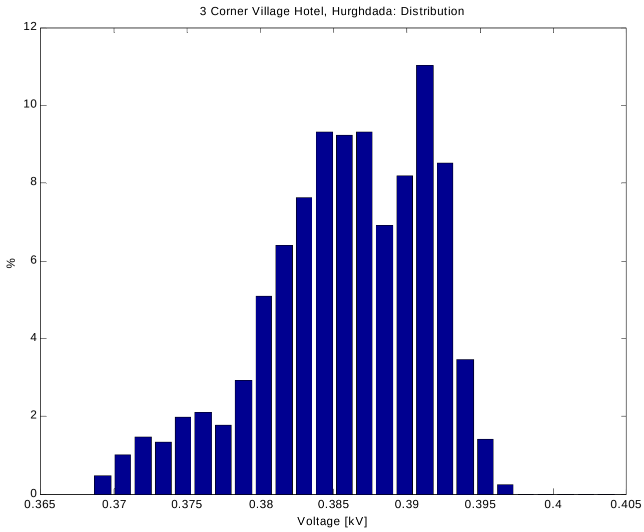


Figure 2 Distribution of 10 min average voltage values

It is seen in Figure 2 that the voltage fluctuations are quite small, and Figure 3 shows that the level of Total Harmonic Distortion (THD) is also on a low level. The voltage fluctuations taken as changes from one 10 min average value to the next is small which is to be expected in a large grid. In Figure 5 the grid frequency is shown and it is seen that also the frequency variations are small.

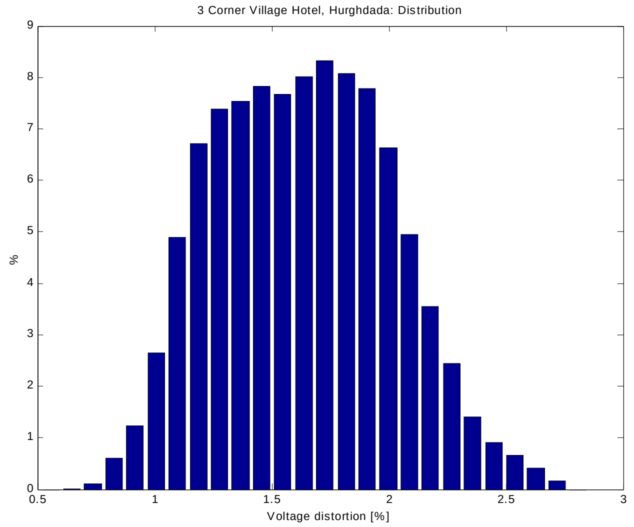


Figure 3 Distribution of 10 min average voltage THD distortion values

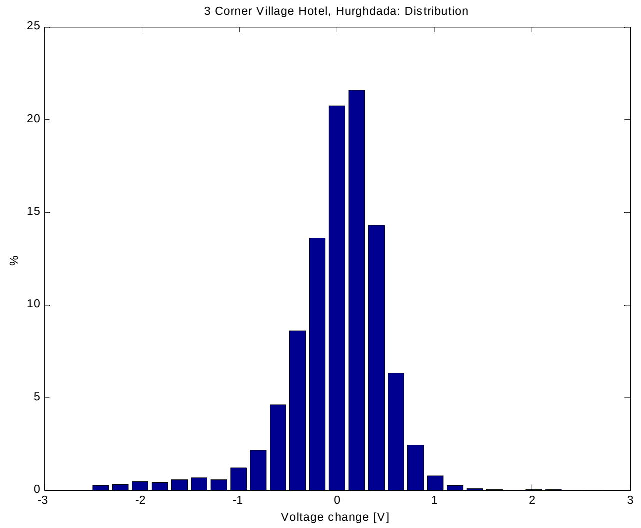


Figure 4 Change of voltage from one 10 min value to the next, absolute as well as relative to the initial voltage

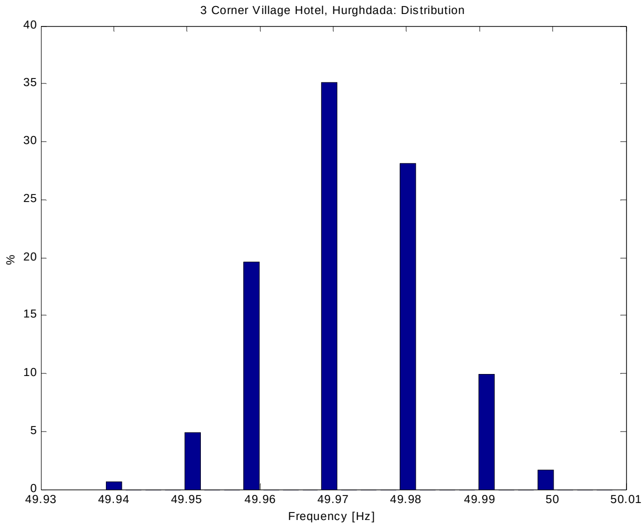


Figure 5 Distribution of 10 min average grid frequency values

The figure also shows the resolution of the frequency measurement.

In Figure 6 the daily average load and the minimum and maximum 10 min average load for the whole period are shown. It is noticed that the daily average as well as the minimum and maximum varies significantly. The ratio between maximum daily average and minimum daily average is 2.5.

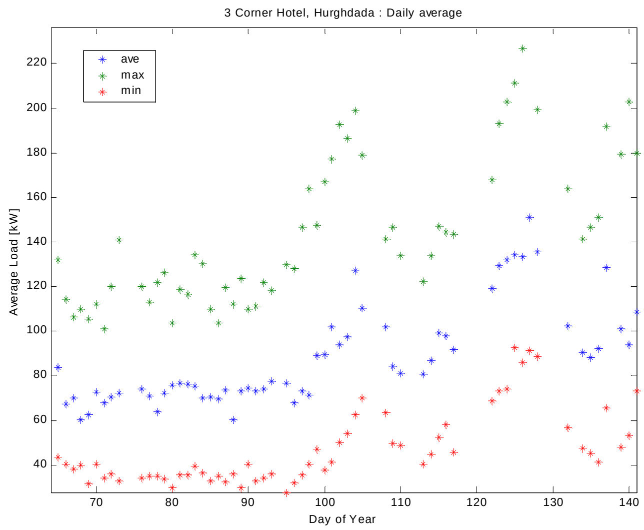


Figure 6 Daily average load and maximum and minimum 10 min average for each day.

The variation of the maximum and minimum with the average is shown in Figure 7 as ratios between maximum and minimum, respectively, and the average. The minimum varies almost proportional to the average whereas the maximum shows a larger variation.

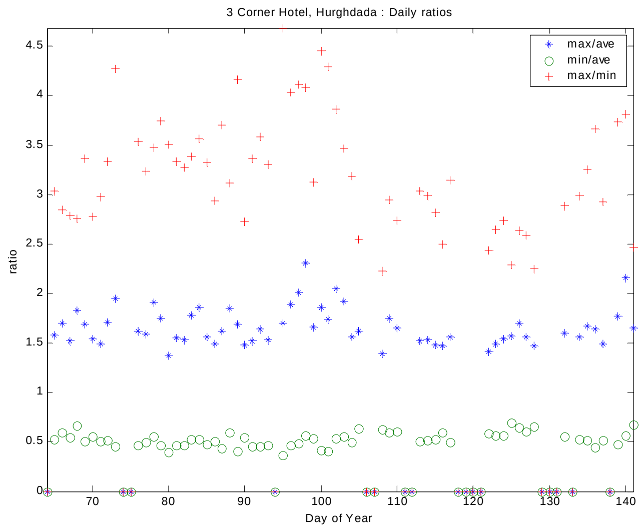


Figure 7 Ratio between maximum and average daily load, minimum and average daily load and maximum and minimum load for each day. All based on 10 min average values.

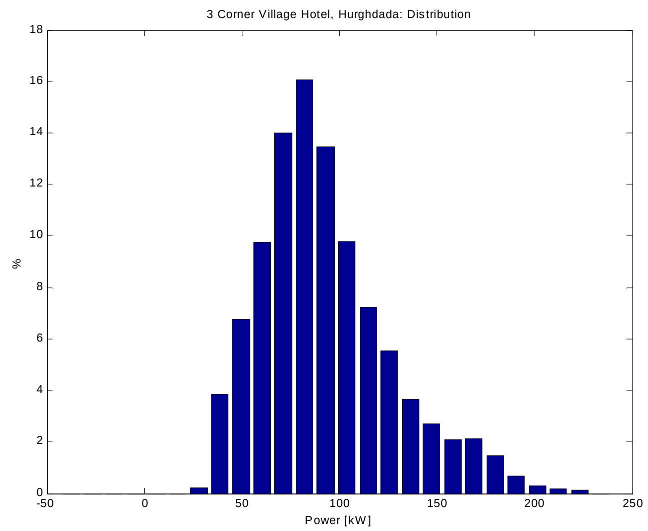


Figure 8 Distribution of 10 min average active power values

Figure 8 shows the distribution of the 10 min average power values. The distribution is not symmetrical and it has a tail towards the higher loads. The same characteristics are noticed for the reactive power.

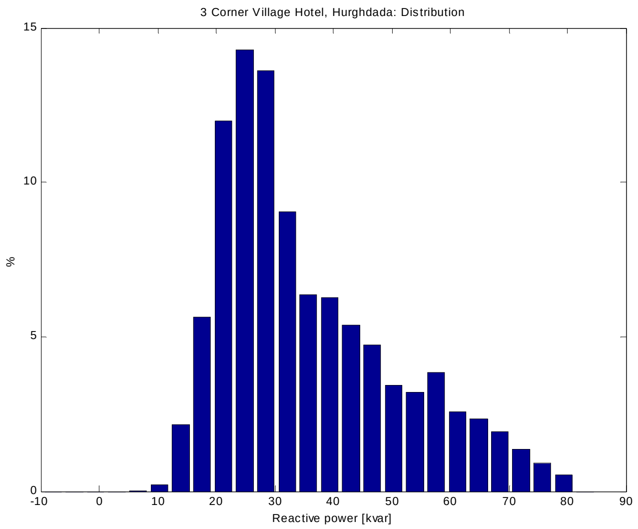


Figure 9 Distribution of 10 min average reactive power consumption values

This is confirmed by the co-variation of the active and reactive power shown in Figure 10. It is also noticed that the point cloud is quite wide. This might be due to the rather large number of loads with different characteristics and the variation in the number of guests.

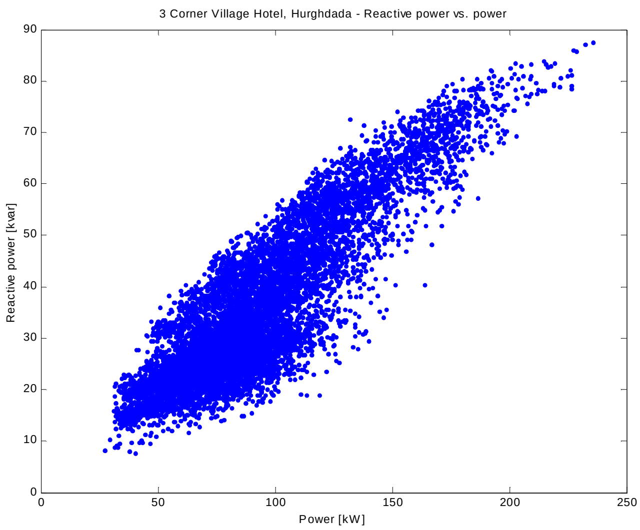
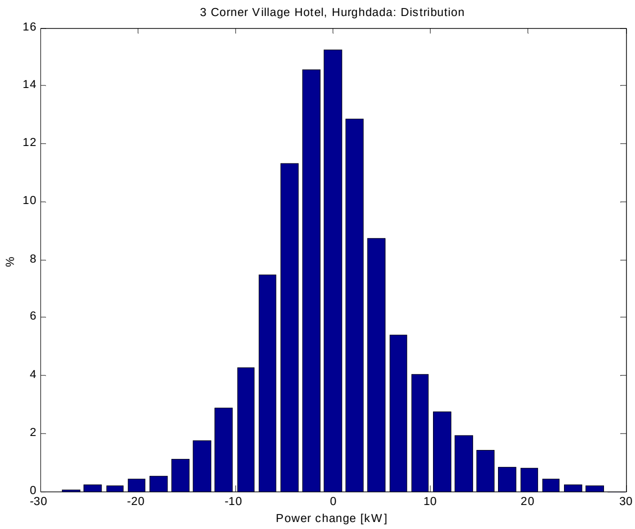


Figure 10 Reactive power consumption as a function of active power production



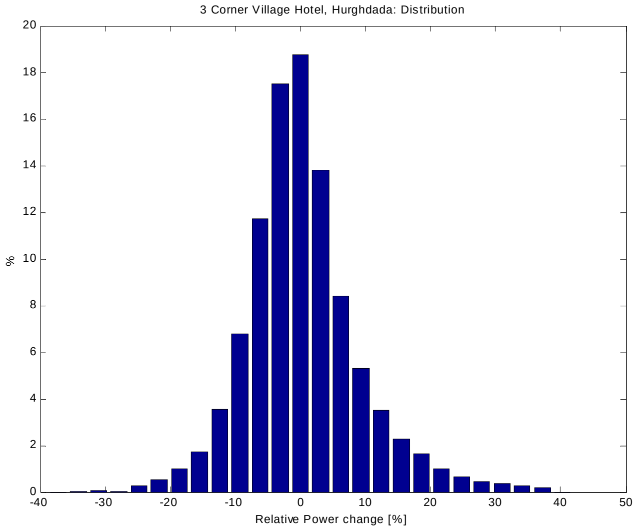
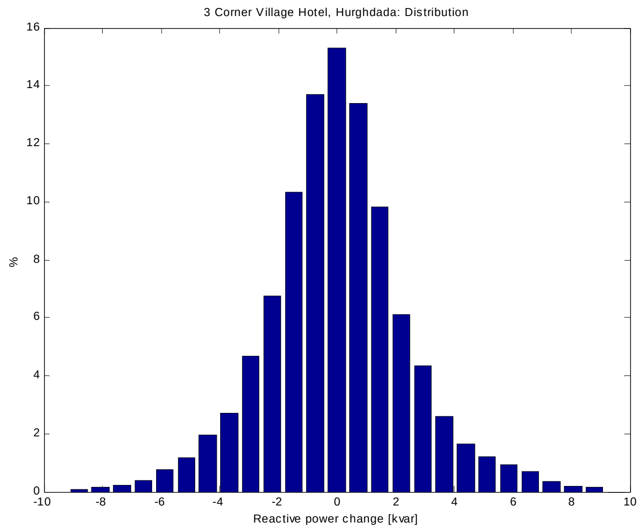


Figure 11 Change of active power from one 10 min value to the next, absolute as well as relative to the initial power

An important characteristics for loads in isolated systems is the temporal variation of the loads. Here it is shown as the variation of the 10 min average from one period to the next. This is shown in Figure 11and Figure 12 for the active and reactive power, respectively. For the load at the hotel the distribution of changes is almost symmetrical which means that positive and negative changes in load occurs with the same magnitude and frequency. It is also seen that the majority of the changes are between +-10% and that changes above 20% only occurs very rarely.



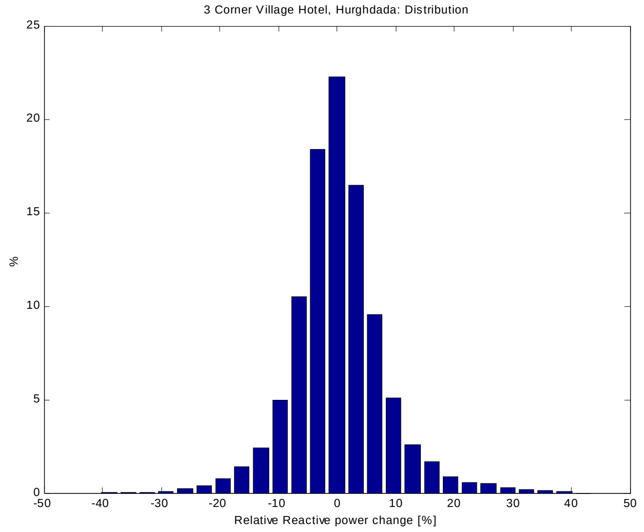


Figure 12 Change of reactive power from one 10 min value to the next, absolute as well as relative to the initial reactive power

The daily load profile is important for the performance assessment of a wind diesel system. Figure 13 and Figure 14 show the active and reactive power profiles for each day of the week, respectively. Since the measurements are from Egypt, Friday is the day off. However, there is not a significant difference between the load on Fridays and on the other days although Friday is one of the lower profiles.

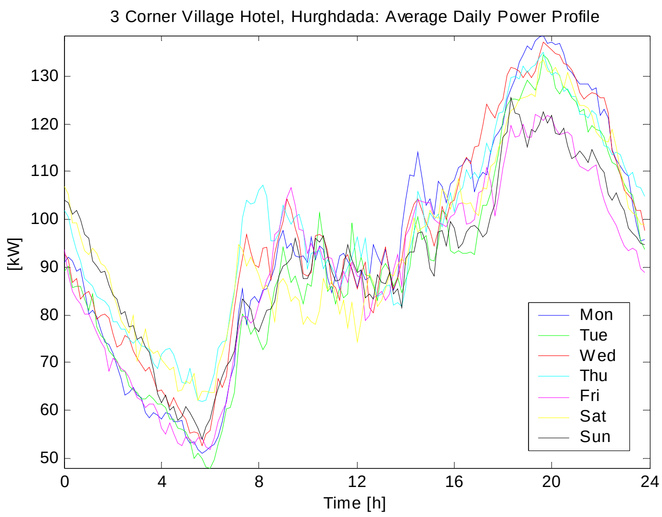


Figure 13 Average daily active power profile for each day of the week

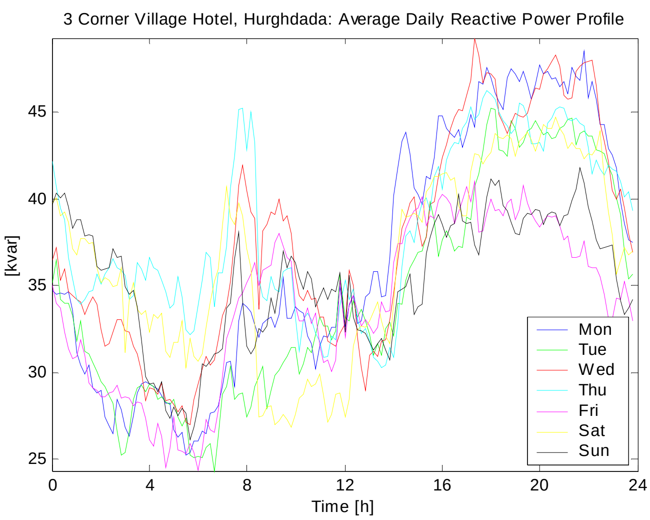


Figure 14 Average daily reactive power profile for each day of the week

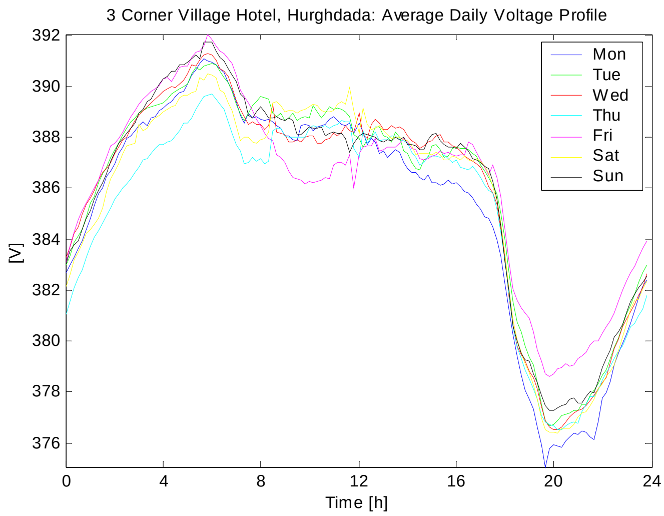


Figure 15 Average daily voltage profile for each day of the week

Figure 16 Average daily voltage THD profile for each day of the week

The voltage quality measures also do follow the load profile as shown in Figure 15 and Figure 16.

All the above profiles are averages for the total period. The next figures show the time series for each day group by the day of the week. This illustrates the variation within Mondays etc. and can be compared with the variation between the weekdays in Figure 13 and Figure 14. It is clearly seen that the variation within each day of the week is large compared with the variation between days of the week.

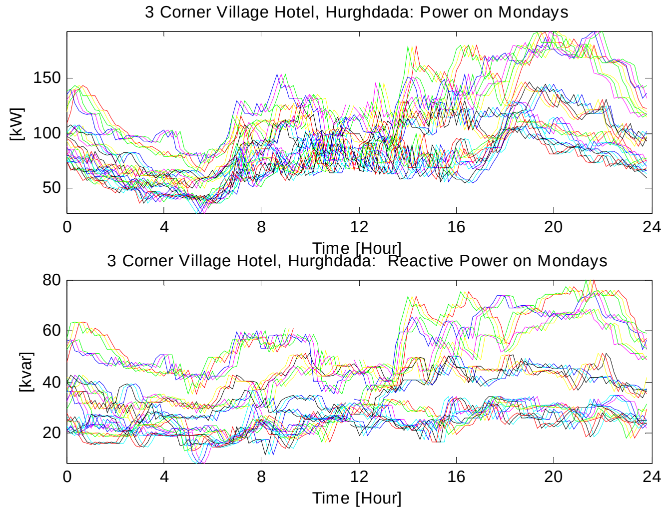


Figure 17 Daily active and reactive power profile for each Monday in the data set

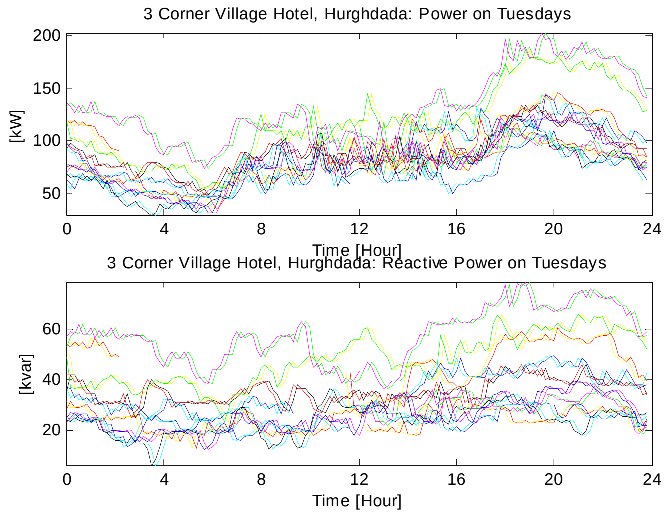


Figure 18 Daily active and reactive power profile for each Tuesday in the data set

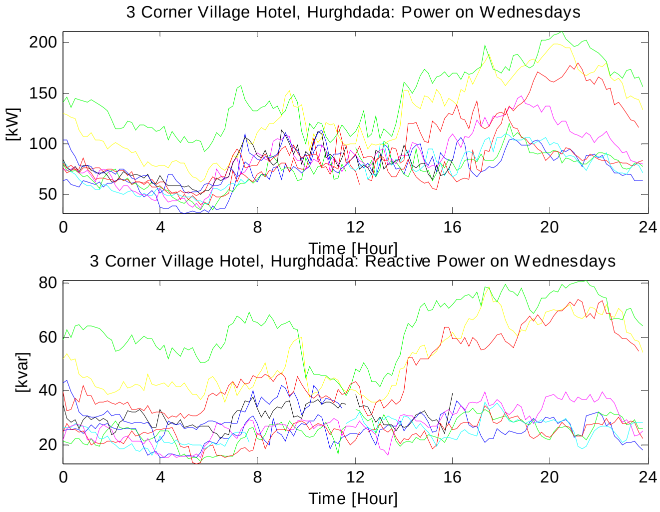


Figure 19 Daily active and reactive power profile for each Wednesday in the data set

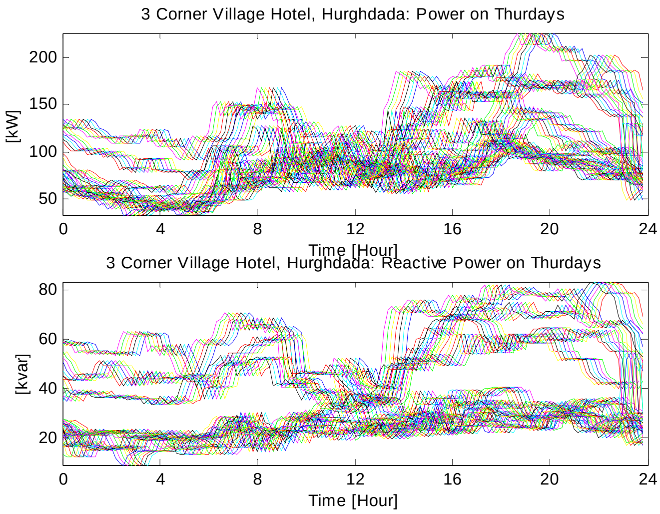


Figure 20 Daily active and reactive power profile for each Thursday in the data set

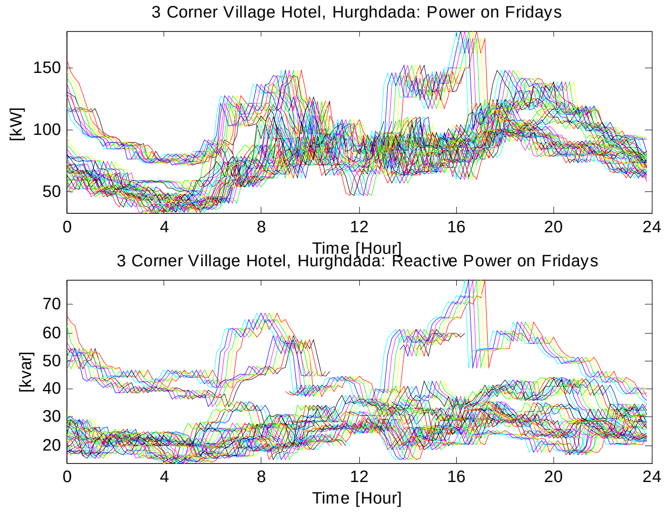


Figure 21 Daily active and reactive power profile for each Friday in the data set

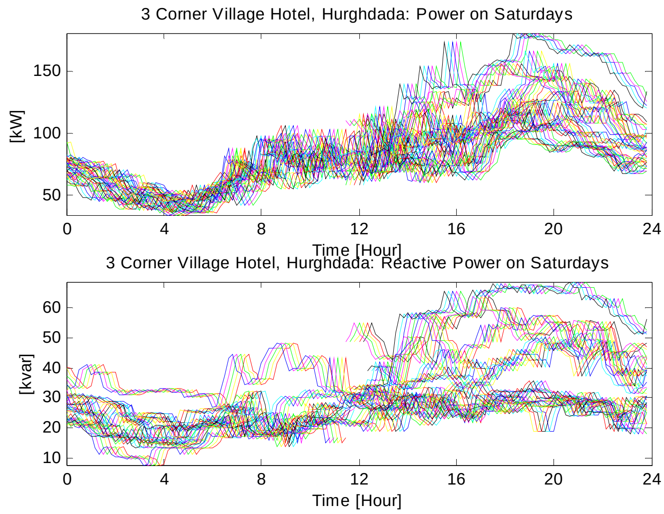


Figure 22 Daily active and reactive power profile for each Saturday in the data set

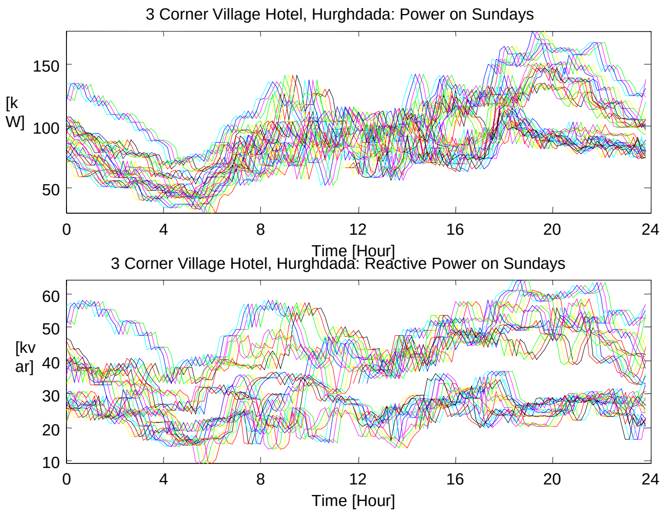


Figure 23 Daily active and reactive power profile for each Sunday in the data set

Hurghada: 3 Corner Shopping Mall

The 3 Corner Shopping Mall is the second measurement site also situated in Hurghada.

The measurement system was checked each day and data files were changed. Only few problems were experienced during the period.

Table 2 Key data for 3 Corner Village Hotel measurements

Item	**Description**
Load type	Shop/office
Grid type	Interconnected
Start date	98.07.11
Stop date	98.08.15
Average load	161 kW
Standard deviation of load	38 kW
Min 10 min load	76 kW
Max 10 min load	286 kW

Initially graphs are shown indicating the power quality at the point of measurement.

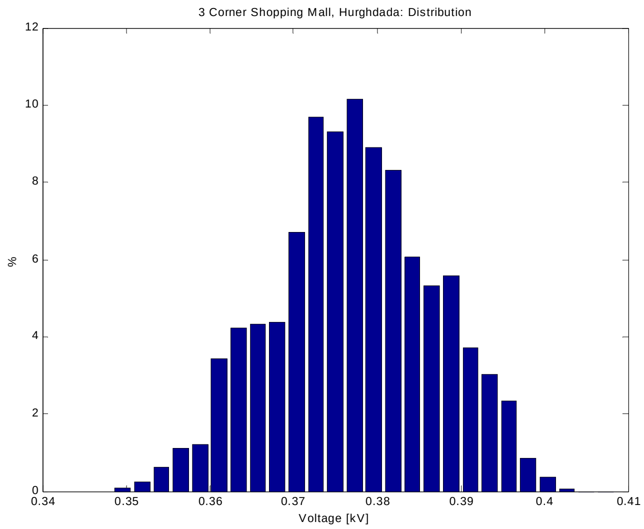


Figure 24 Distribution of 10 min average voltage values

The distribution of the voltage is shown in Figure 24. The voltage range is wide considering that the system is connected to a large grid. It is also significantly higher than for the two other measurement sites in Hurghada.

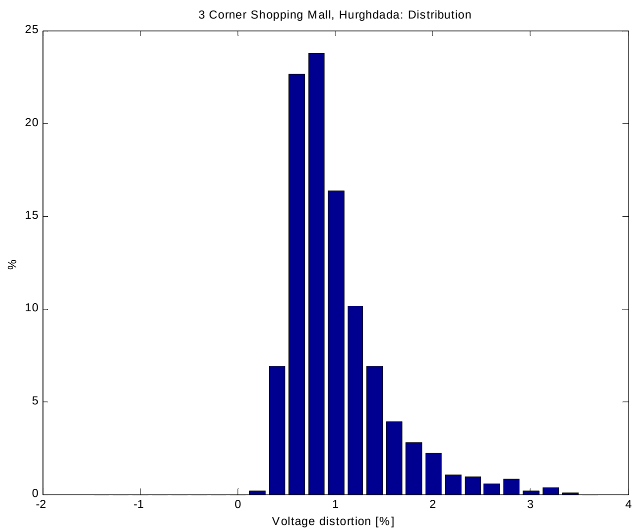


Figure 25 Distribution of 10 min average voltage THD distortion values

The harmonic distortion as shown in Figure 25 corresponds with the other measurements and is at a low level.

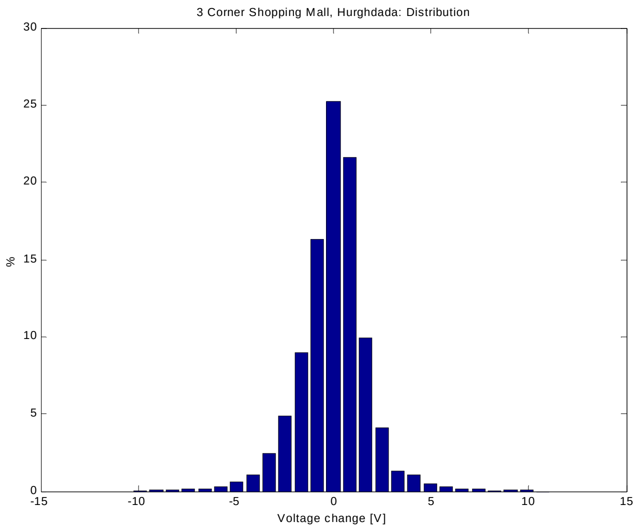


Figure 26 Change of voltage from one 10 min value to the next, absolute as well as relative to the initial voltage

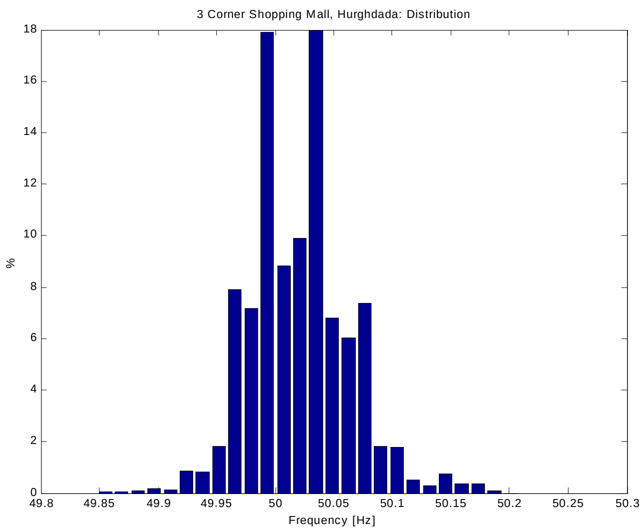


Figure 27 Distribution of 10 min average grid frequency values

The change in voltage from one 10 min average to the next, Figure 26 and the distribution of the grid frequency, Figure 27, also indicate that the mode of operation is more like an isolated grid with rather large fluctuations of both voltage and frequency.

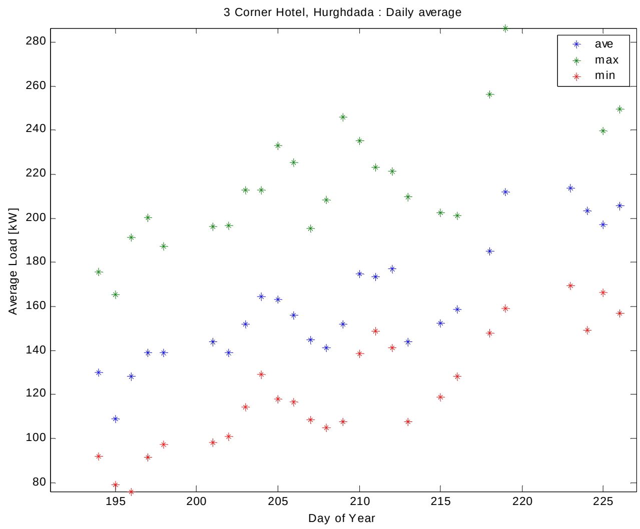


Figure 28 Daily average load and maximum and minimum 10 min average for each day.

The daily average power consumption shows considerable variation throughout the measurement period, Figure 28. The average increases to almost twice the initial value. The minimum and maximum 10 min average values also vary, but their ratios to the daily average are quite constant, Figure 29.

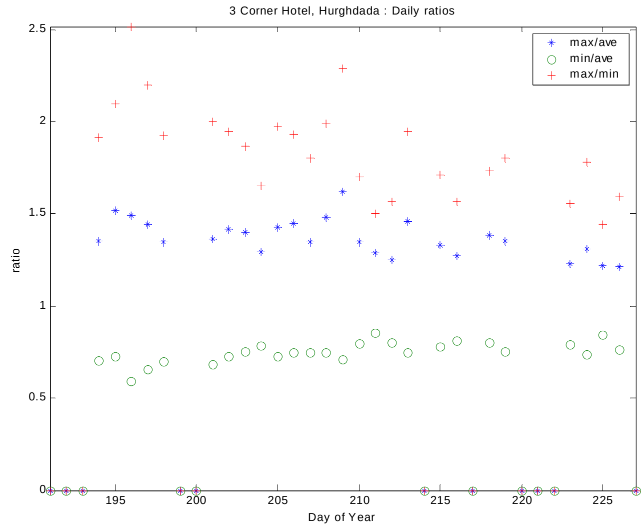


Figure 29 Ratio between maximum and average daily load, minimum and average daily load and maximum and minimum load for each day. All based on 10 min average values.

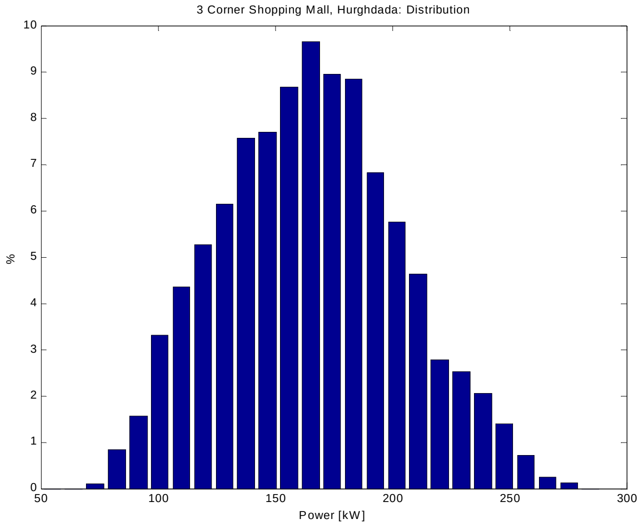


Figure 30 Distribution of 10 min average active power values

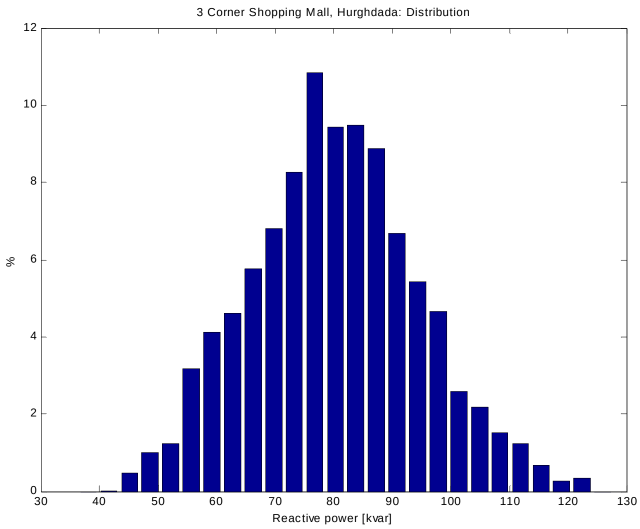


Figure 31 Distribution of 10 min average reactive power consumption values

The distribution of the 10 min active and reactive power values is quite wide and triangular, Figure 30 and Figure 31. This means that one value of the load is the most common value, but other values are also quite frequent. The distributions of active and reactive power, respectively, are similar.

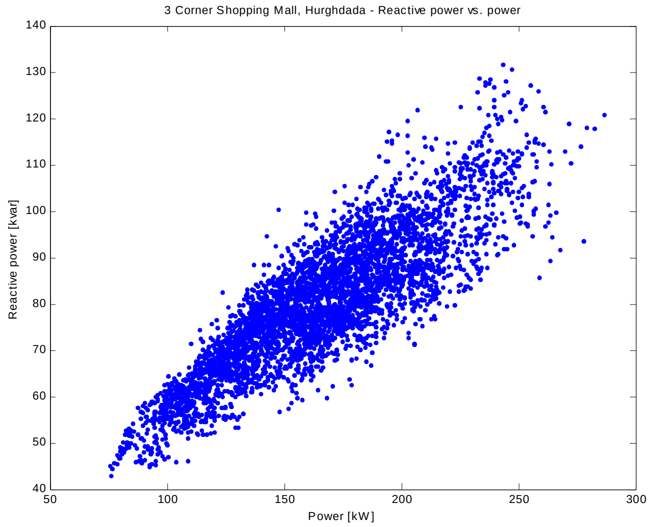
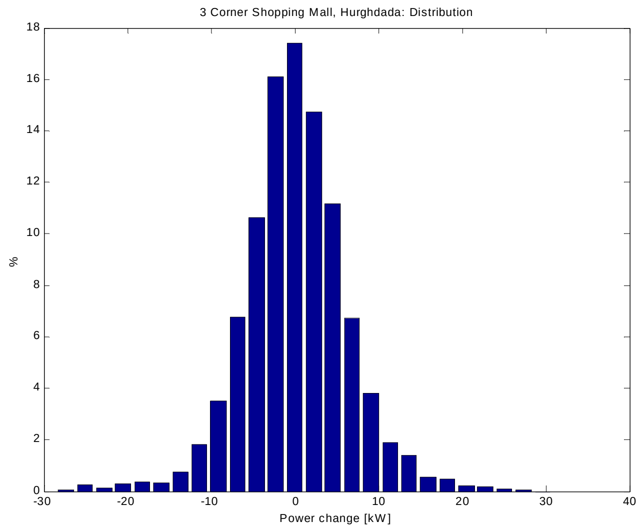


Figure 32 Reactive power consumption as a function of active power production

The reactive power consumption follows the active power consumption, even though the values are somewhat scattered when the load is high, Figure 32. The power factor is reasonable at a value above 0.90.



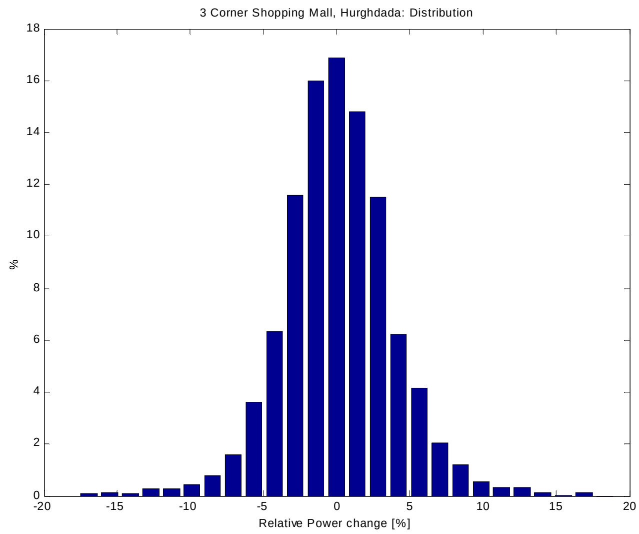


Figure 33 Change of active power from one 10 min value to the next, absolute as well as relative to the initial power

The changes in power and reactive power, respectively, from one 10 min average to the next are shown in Figure 33 and Figure 34. The figures include both absolute change and change relative to the initial level. It is seen that only very few values above 10% occur. The change in load is therefore relatively slow.

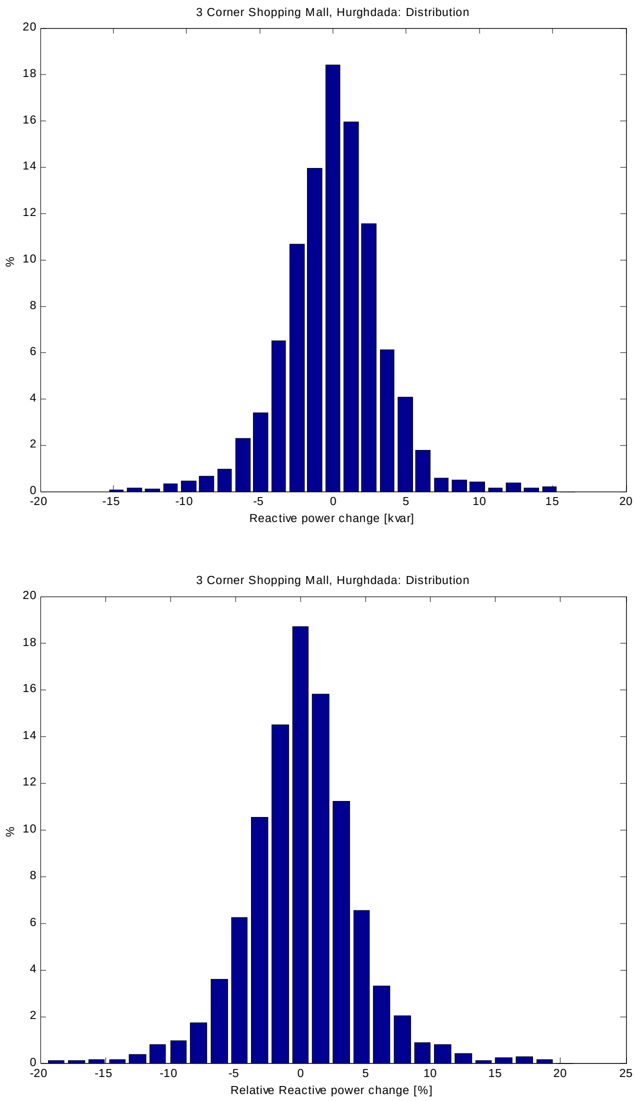


Figure 34 Change of reactive power from one 10 min value to the next, absolute as well as relative to the initial reactive power

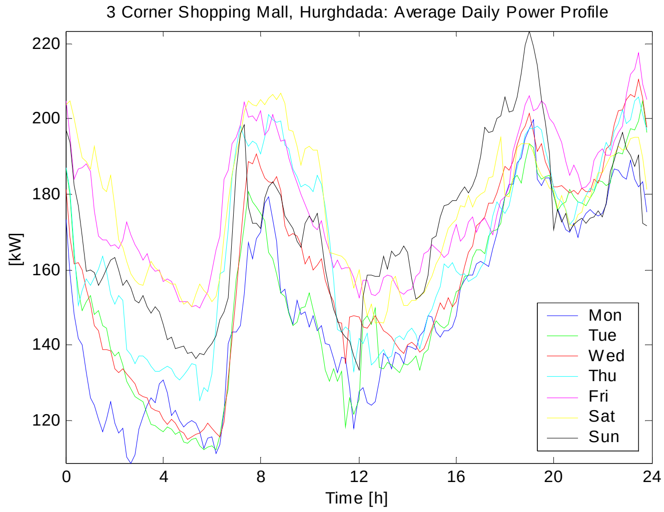


Figure 35 Average daily active power profile for each day of the week

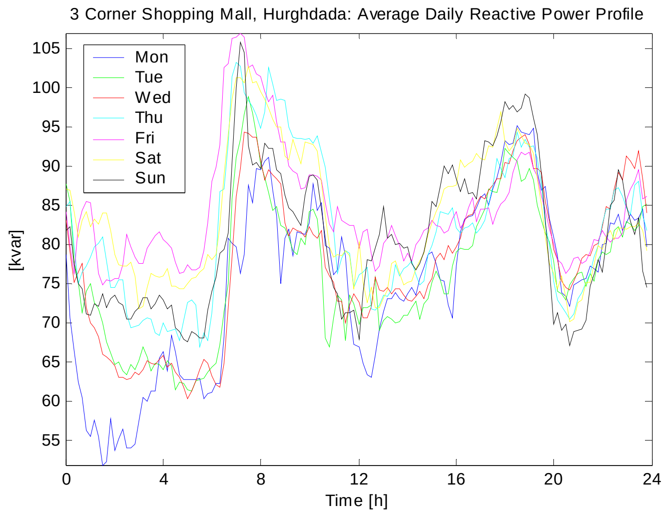


Figure 36 Average daily reactive power profile for each day of the week

The daily load profile shows three peaks, Figure 35. The first peak is due to the activities in the shops during the day. The peak in the evening could be due to the restaurants whereas the peak at midnight is less obvious. It is also noticed that the Friday profile is rather high, especially during the day.

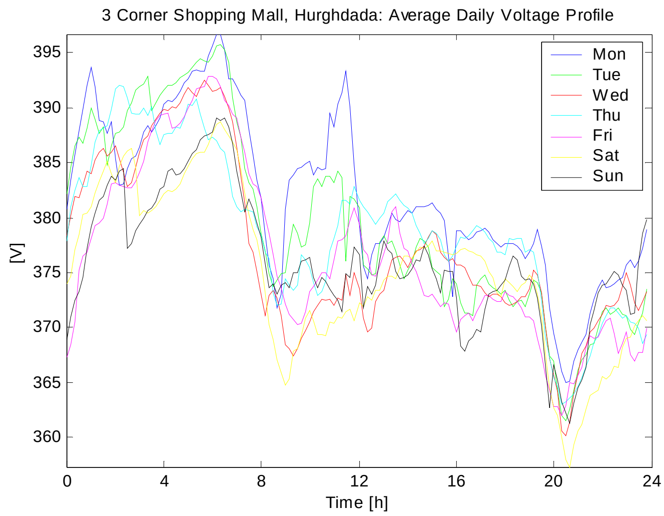


Figure 37 Average daily voltage profile for each day of the week

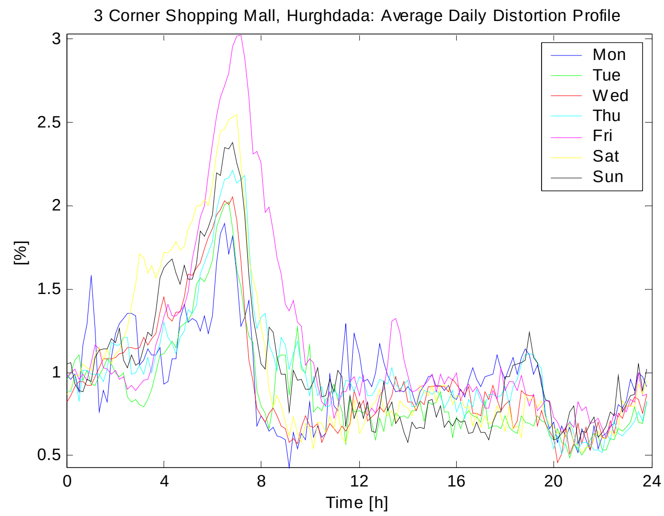


Figure 38 Average daily voltage THD profile for each day of the week

The peak in the THD of the voltage, Figure 38, occurs just before the first peak in the load. It could be caused by the switch-on of the loads in the shops. Apart from this peak the level of THD is low.

The next seven figures, Figure 39-Figure 45, illustrate the variation of the load for each day of the week. From these figures it can be seen that some of the daily profiles are based on very few values e.g. Monday morning, where only one data set is available. It is also seen that the variation between the different curves for each day is significant and that this variation is larger than the variation between the daily average profiles.

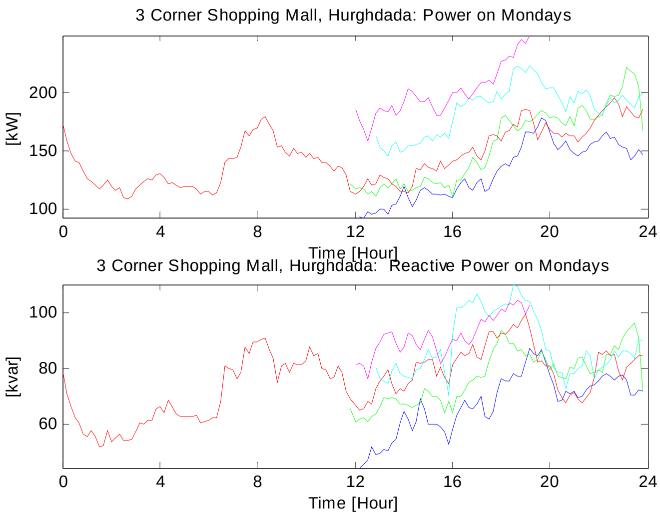


Figure 39 Daily active and reactive power profile for each Monday in the data set

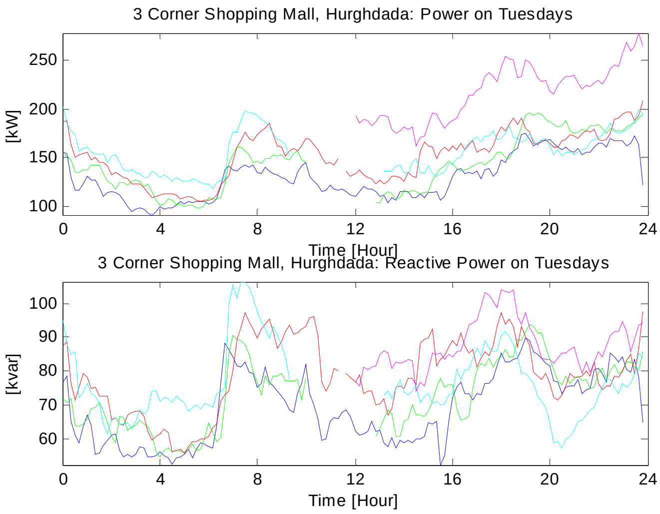


Figure 40 Daily active and reactive power profile for each Tuesday in the data set

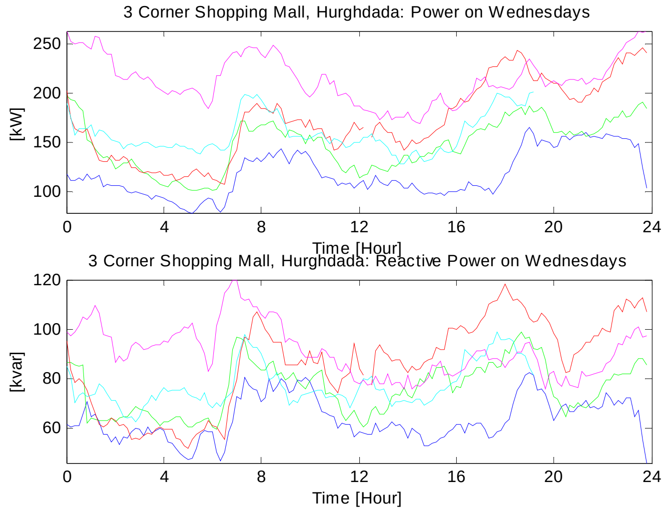


Figure 41 Daily active and reactive power profile for each Wednesday in the data set

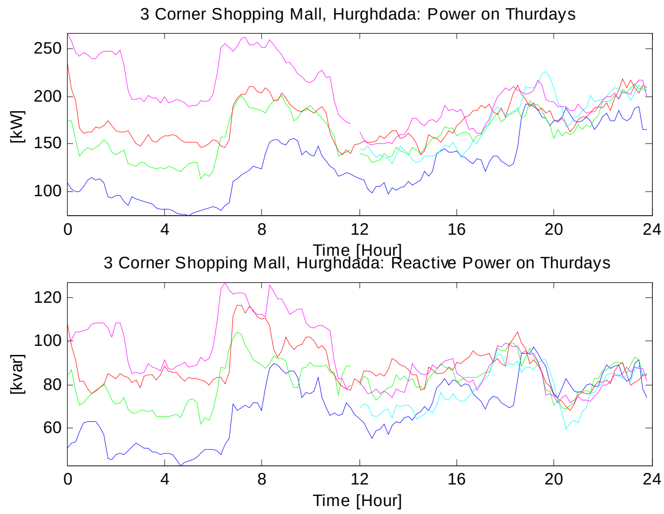


Figure 42 Daily active and reactive power profile for each Thursday in the data set

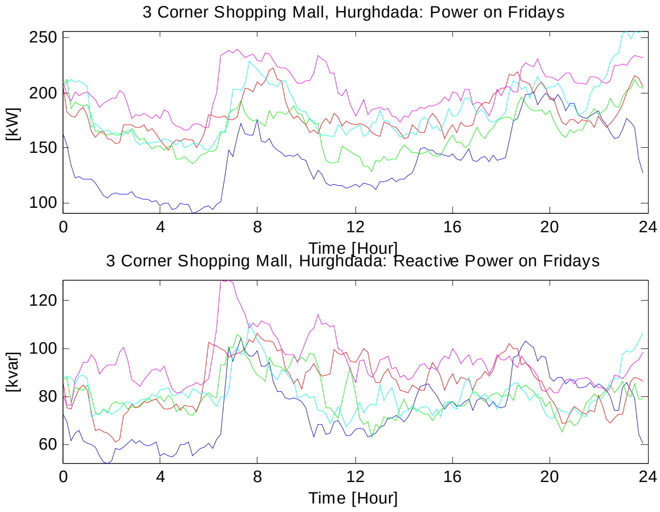


Figure 43 Daily active and reactive power profile for each Friday in the data set

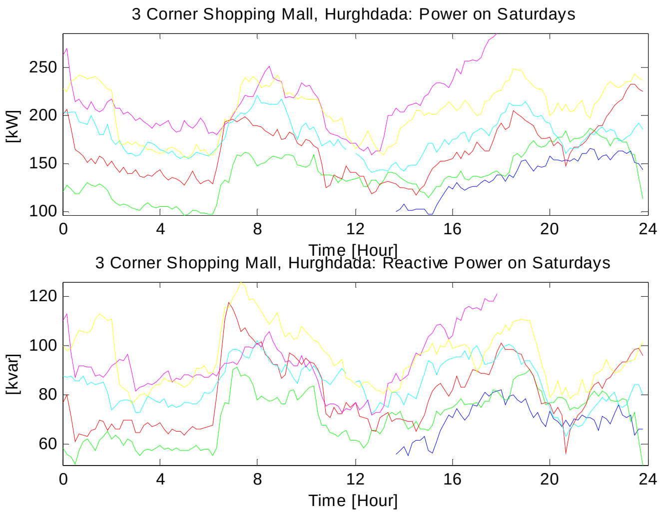


Figure 44 Daily active and reactive power profile for each Saturday in the data set

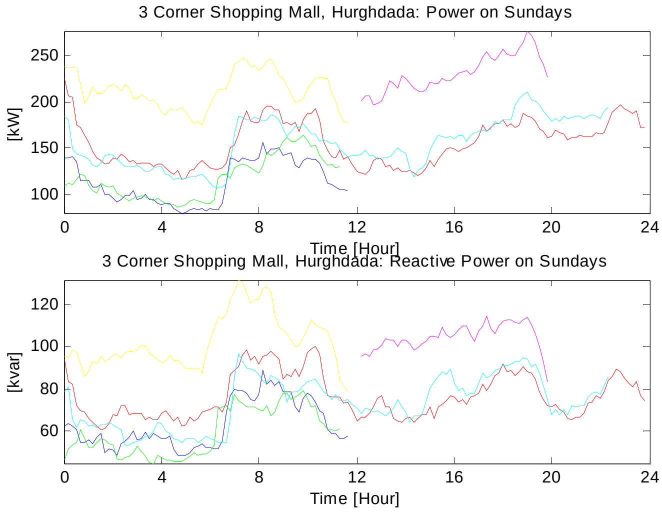


Figure 45 Daily active and reactive power profile for each Sunday in the data set

Hurghada: Residential Area

The third measurement site in Hurghada is in a residential area.

The measurement system was checked each day and data files were changed. Only few problems were experienced during the period.

Table 3 Key data for 3 Corner Village Hotel measurements

Item	**Description**
Load type	Residential
Grid type	Interconnected
Start date	98.05.24
Stop date	98.07.06
Average load	82 kW
Standard deviation of load	45 kW
Min 10 min load	28 kW
Max 10 min load	204 kW

Initially graphs are shown indicating the power quality at the point of measurement.

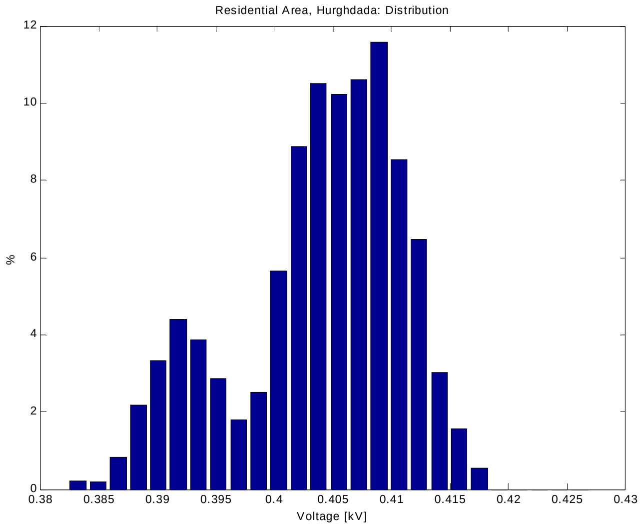


Figure 46 Distribution of 10 min average voltage values

The distribution of the voltage is shown in Figure 46. It shows as expected that the voltage range is quite narrow due to the connection to a large grid. Also, two peaks are noticed. The THD of the voltage does not show any particular features except for a low mean value, Figure 47.

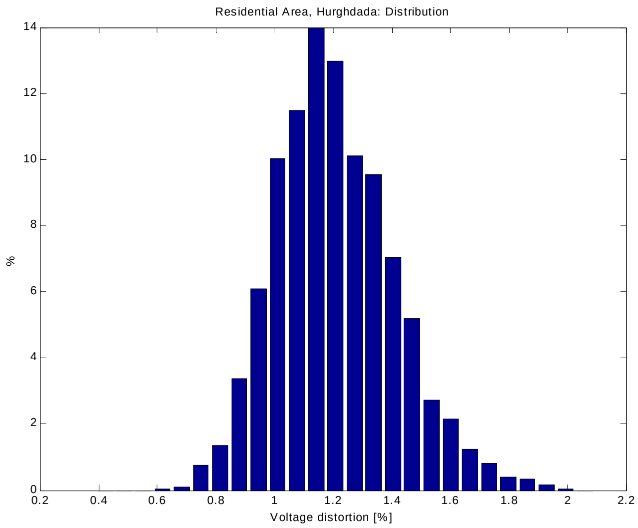


Figure 47 Distribution of 10 min average voltage THD distortion values

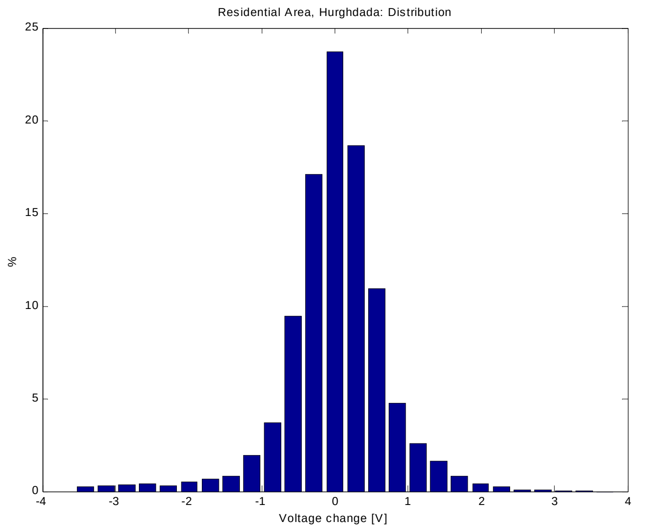


Figure 48 Change of voltage from one 10 min value to the next, absolute as well as relative to the initial voltage

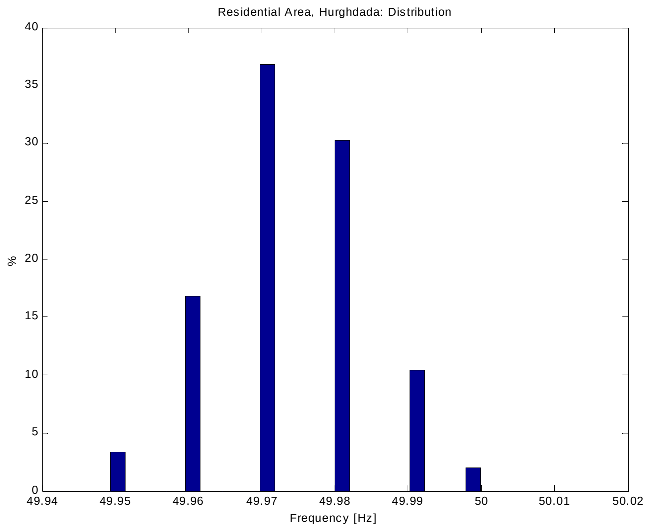


Figure 49 Distribution of 10 min average grid frequency values

As for the distribution of the voltage the change in voltage, Figure 48 and the distribution of the grid frequency, Figure 49, indicate that the system is connected to a large network. Only small variations are observed.

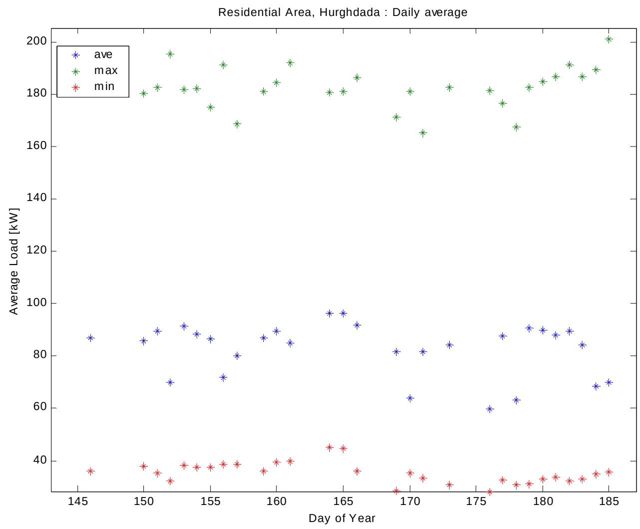


Figure 50 Daily average load and maximum and minimum 10 min average for each day.

Figure 50 indicates several interesting features. The first feature to notice is that the daily average is quite constant throughout the measurement period. It is also noticed that the maximum value for each day is high compared to the average values.

The maximum does also show variation. The minimum value for each day is quite constant like the average value. The ratios are shown in Figure 51. This figure confirms that the minimum and the average vary together and that the maximum value is high compared both to the average and to the minimum.

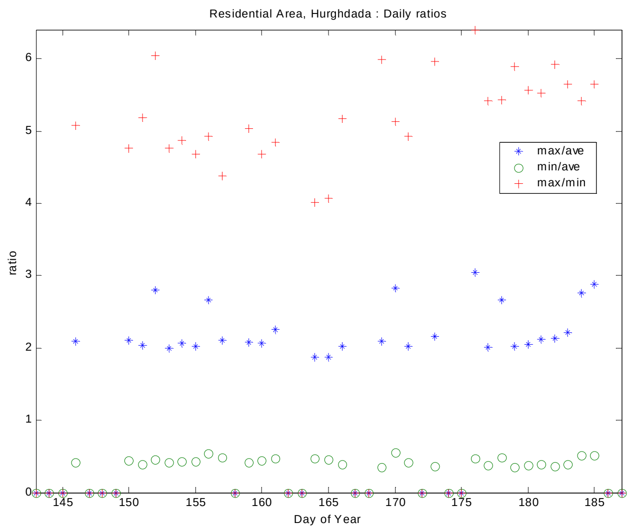


Figure 51 Ratio between maximum and average daily load, minimum and average daily load and maximum and minimum load for each day. All based on 10 min average values.

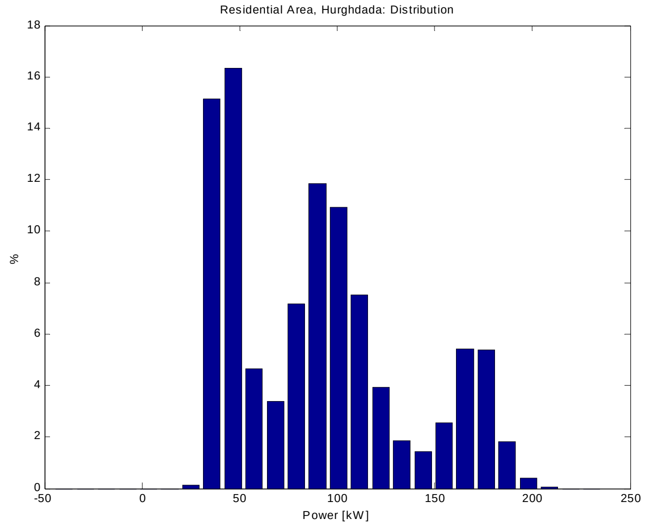


Figure 52 Distribution of 10 min average active power values

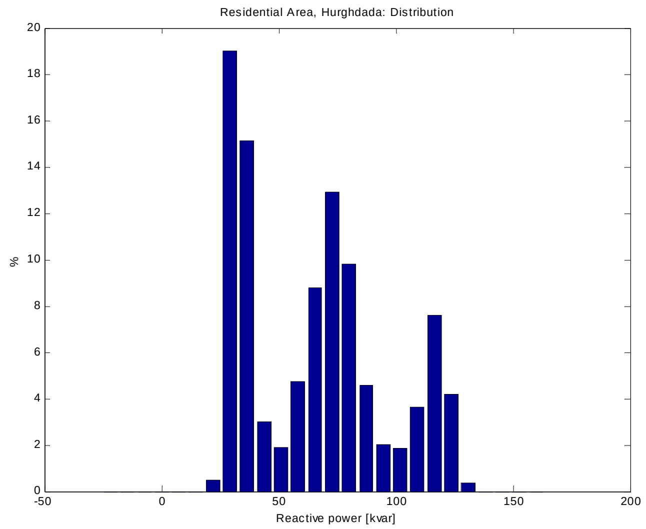


Figure 53 Distribution of 10 min average reactive power consumption values

The distribution of the values of active and reactive power shows some interesting features, Figure 52 and Figure 53. It is clearly seen that the consumption falls mainly at three levels. This is confirmed by looking at the daily load profiles in Figure 57.

Figure 54 shows that the reactive power follows the active power quite closely.

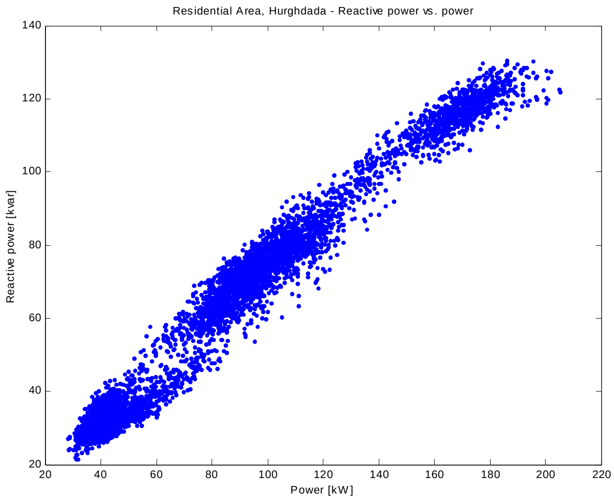


Figure 54 Reactive power consumption as a function of active power production

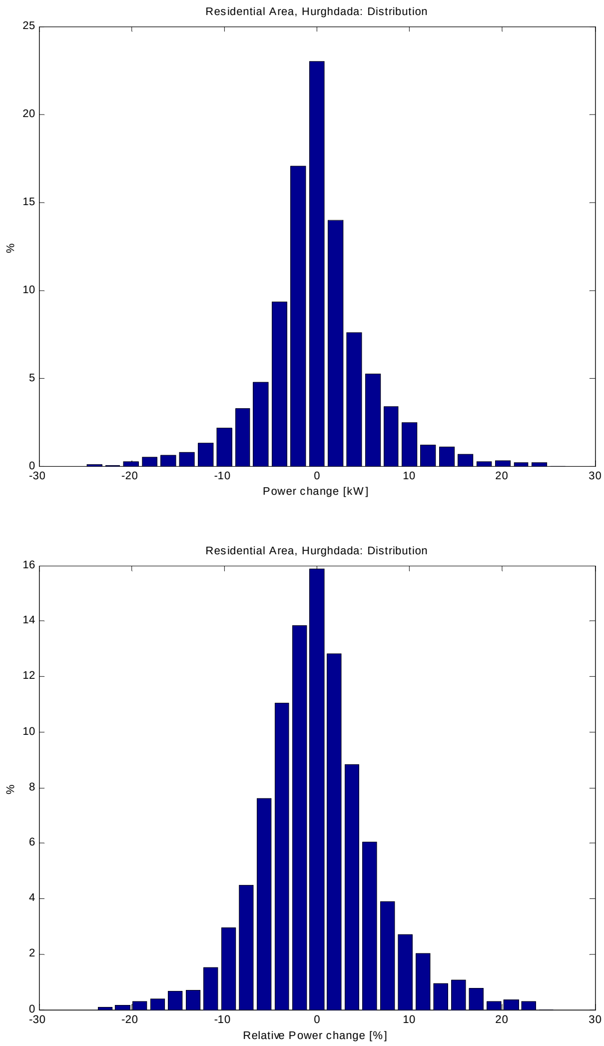
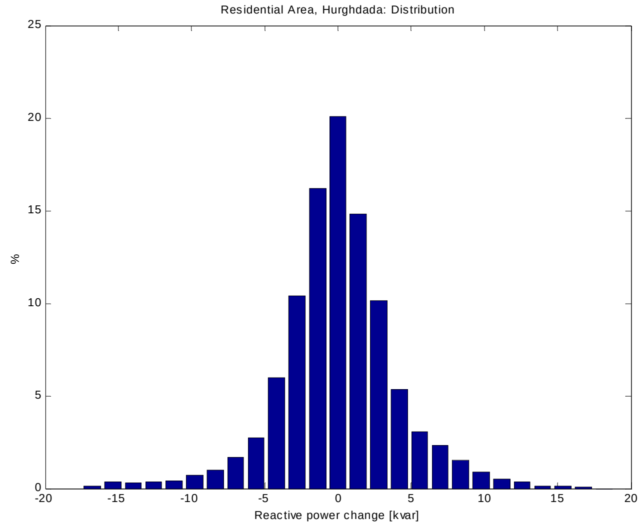


Figure 55 Change of active power from one 10 min value to the next, absolute as well as relative to the initial power

Figure 55 shows that the majority of the power changes from one 10 min average value to the next are below 10% of the initial value, but that approx. 10% of the changes are above 10%. even changes of 20% occurs, but these are rare.



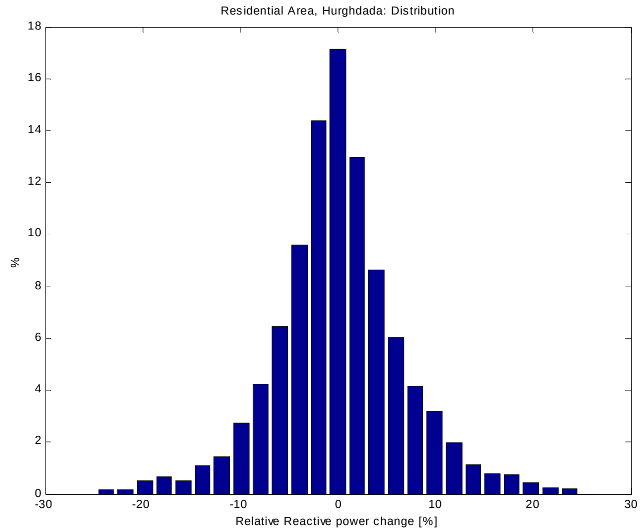


Figure 56 Change of reactive power from one 10 min value to the next, absolute as well as relative to the initial reactive power

The picture for changes in the reactive power is very similar to that of active power with changes concentrated around 0, but with rather long tails.

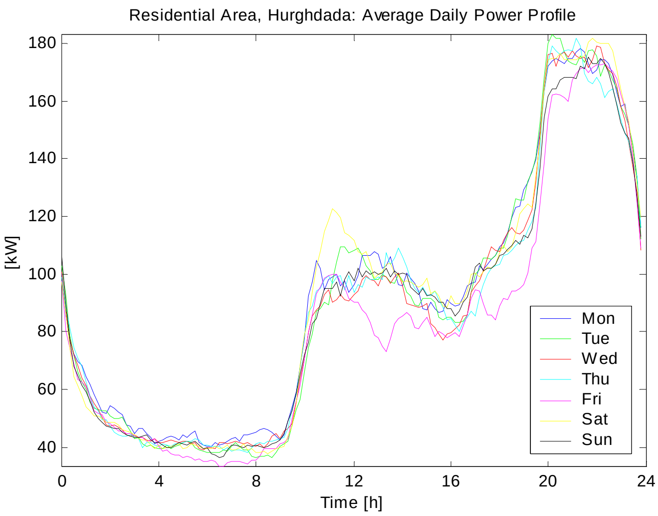


Figure 57 Average daily active power profile for each day of the week

As mentioned above the load has three main levels where it is most of the time. These levels are clearly visible in Figure 57. The first one is the almost constant load during the night. This is followed by a sharp transition to another almost constant level during the day. This level is approx. twice the night level. In the evening the peak load occurs. Again the level is almost constant, but the duration is shorter than the two other load levels. It is almost twice the level of the day load. It is also noticed on the figure that there is not much variation on the level between the week days.

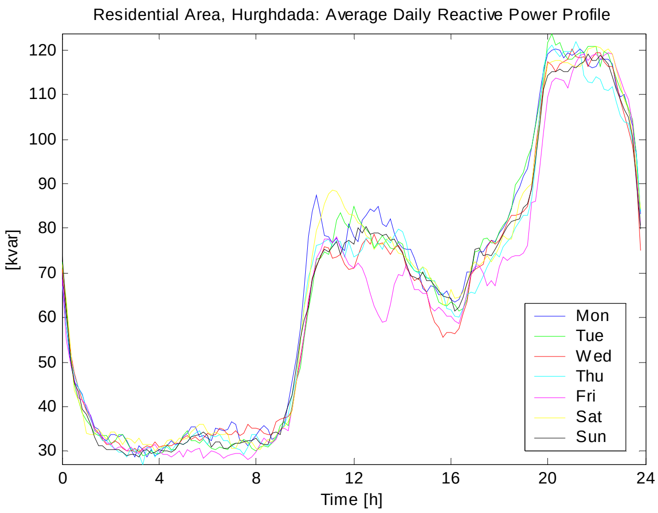


Figure 58 Average daily reactive power profile for each day of the week

As for the previous figures the reactive load follows the active load closely, although there is a drop in the level in the afternoon that is more pronounced than in the active load.

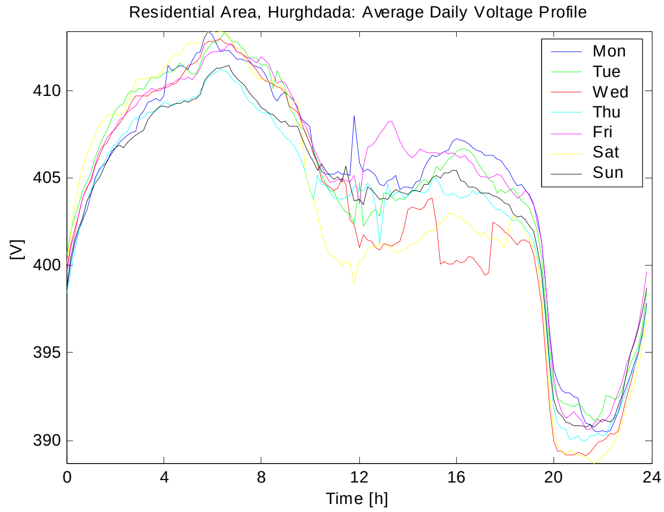


Figure 59 Average daily voltage profile for each day of the week

The voltage profile is shown in Figure 59. It is clearly seen when it is compared to the load profile, that as the load increases the voltage decreases. The profile for the THD of the voltage is shown in Figure 60. Again, the same pattern is seen although the level and variations are quite low.

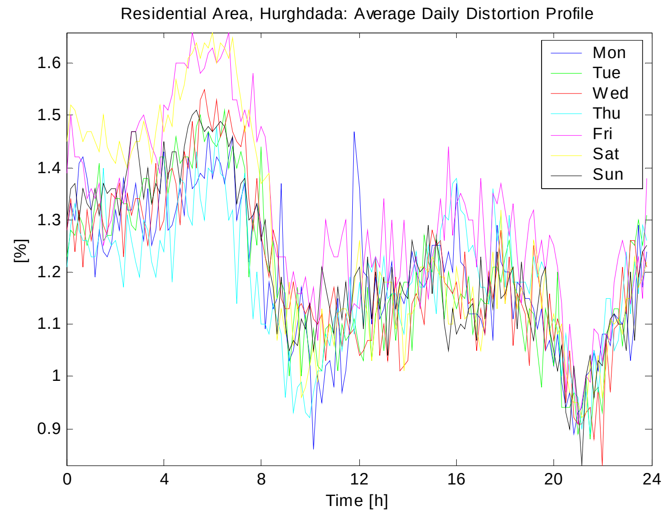


Figure 60 Average daily voltage THD profile for each day of the week

The active and reactive power time series are shown in Figure 61 - Figure 67 with each figure showing the data for a particular day of the week. It is very clearly seen that the variation is small. This is the case both within each day of the week and between the days of the week. This residential load therefore has a very clear load profile with little variation within each hour of the day and between the days of the week.

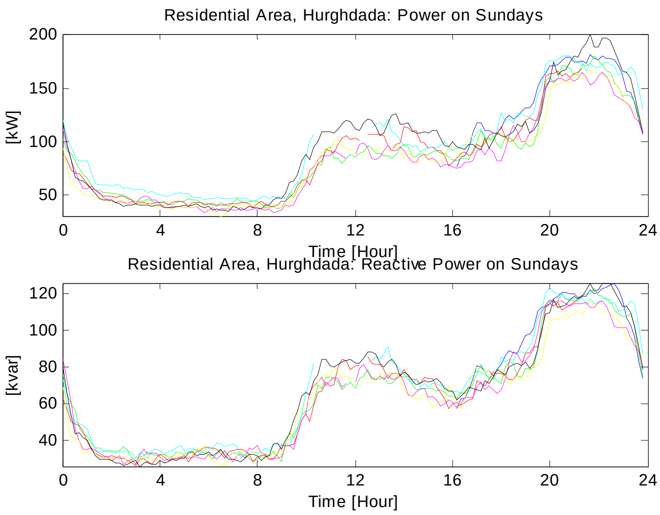


Figure 61 Daily active and reactive power profile for each Monday in the data set

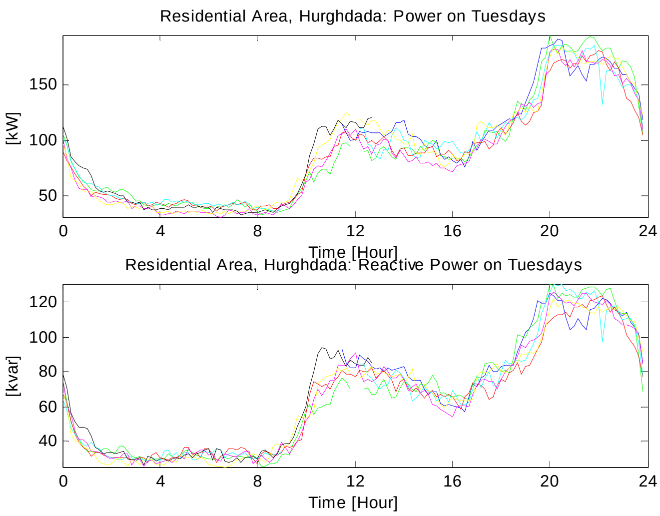


Figure 62 Daily active and reactive power profile for each Tuesday in the data set

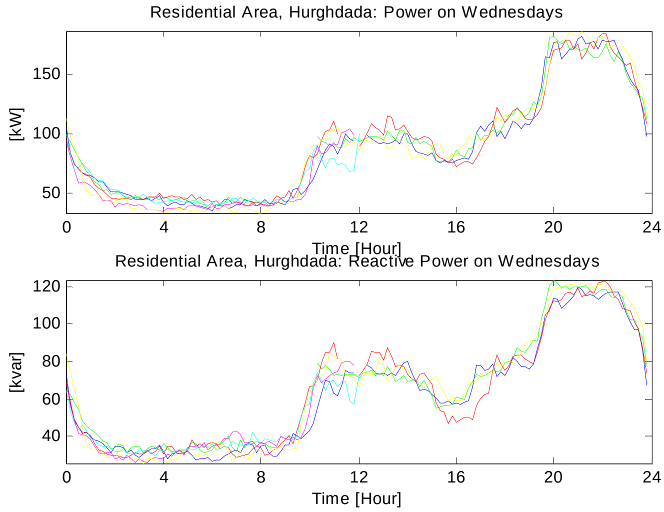


Figure 63 Daily active and reactive power profile for each Wednesday in the data set

Figure 64 Daily active and reactive power profile for each Thursday in the data set

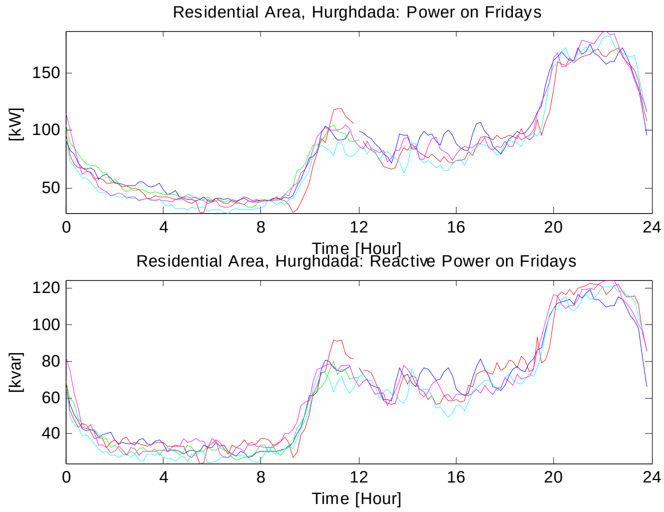


Figure 65 Daily active and reactive power profile for each Friday in the data set

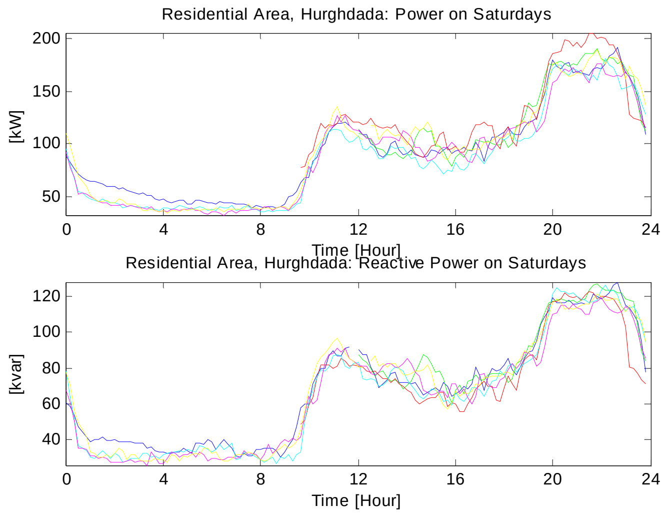


Figure 66 Daily active and reactive power profile for each Saturday in the data set

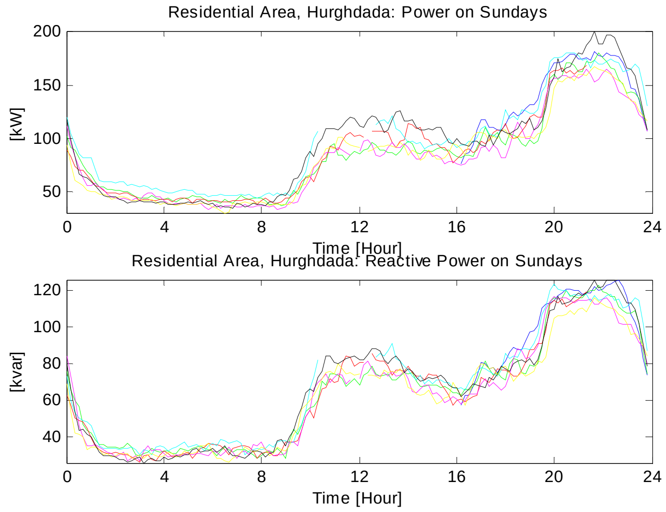


Figure 67 Daily active and reactive power profile for each Sunday in the data set

Ras Sudr

The fourth measurement site is in Ras Sudr, a small town in Sinai.

The measurement system was checked in the morning and in the evening. Data files were changed almost every day. Problems were experienced during the period mainly due to the current measurement using flexible current transformers (CT's). Overloading of the CT's occurred (maybe due to switching in the network, as the current rating was adequate) and this stopped the measurements.

Table 4 Key data for Ras Sudr measurements

Item	Description
Load type	Medium sized town
Grid type	Isolated
Start date	98.11.16
Stop date	98.12.16
Average load	1471 kW
Standard deviation of load	315 kW
Min 10 min load	530 kW
Max 10 min load	2221 kW

Initially graphs are shown indicating the power quality at the point of measurement.

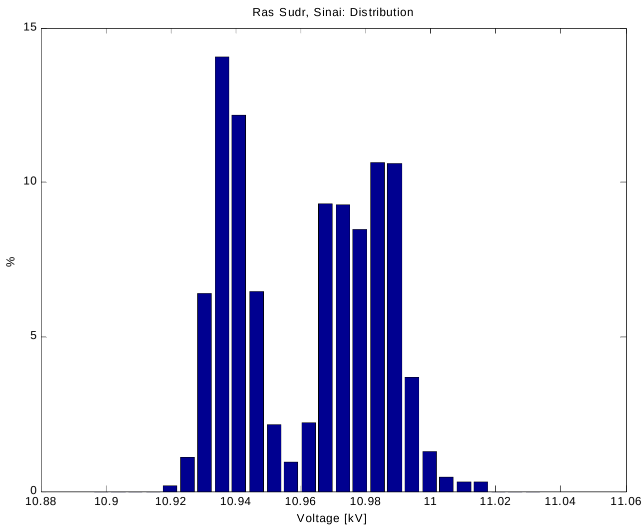


Figure 68 Distribution of 10 min average voltage values

The distribution of the 10 min average grid voltage for the measurement period shows that two different voltage levels dominate, Figure 68. The variation, however, is quite small with a variation of 1% between the minimum value and the maximum value.

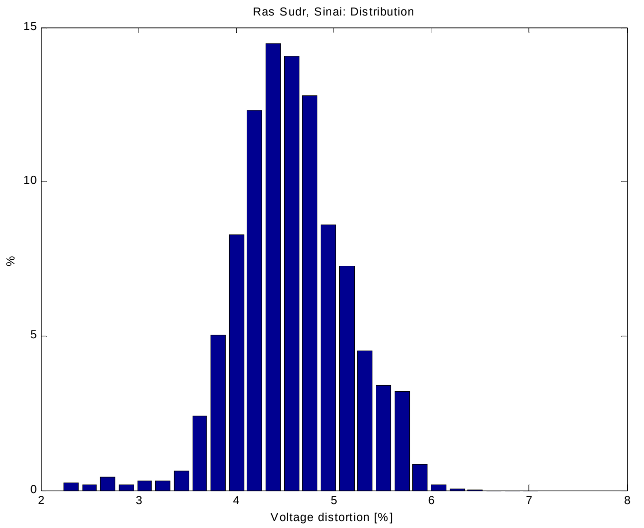


Figure 69 Distribution of 10 min average voltage THD distortion values

The level of the voltage distortion THD, Figure 69, is higher than for the other measurement sites, but it is still within acceptable limits. The distribution is very uniform around the mean value.

The change in voltage is also very limited, Figure 70. The values are less than 15V at the 11kV level. The above figures indicate that close the power station the voltage control is good and the grid is (voltage) strong.

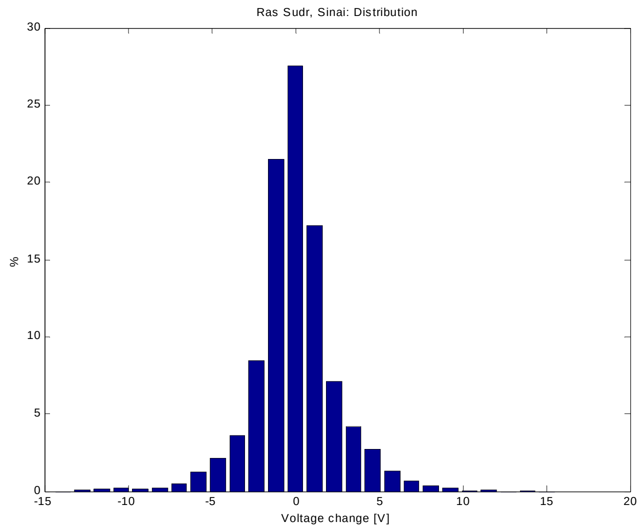


Figure 70 Change of voltage from one 10 min value to the next, absolute as well as relative to the initial voltage

Figure 71 indicates that also the frequency is well controlled with only small deviations from the 50Hz nominal setting. The figure shows that the set point of the frequency controller is slightly above 50Hz. It is noticed on the figure that there is a short period where the system frequency has been higher at 50.3Hz.

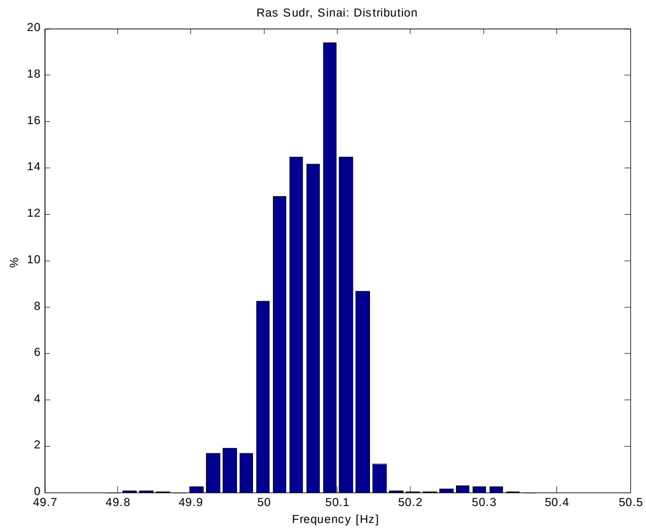


Figure 71 Distribution of 10 min average grid frequency values

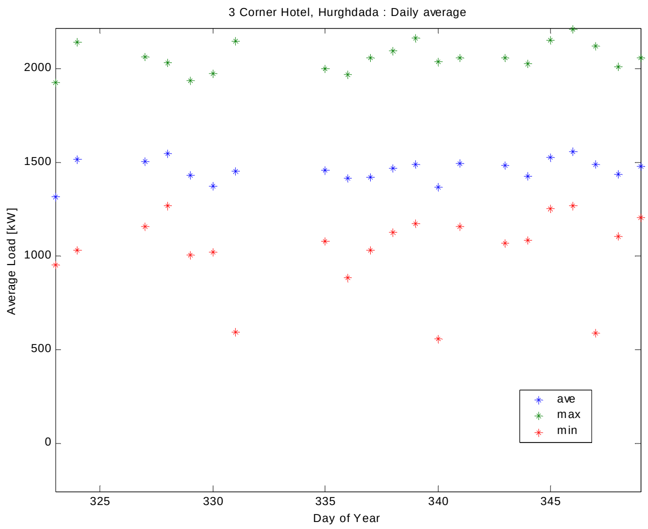


Figure 72 Daily average load and maximum and minimum 10 min average for each day.

The total load of the system is quite constant during the period of measurements, Figure 72. Only small deviations of the average daily power consumption from day to day occur. There are incidents with a very low 10 min average consumption during the period. These incidents are probably due to some of the grid being disconnected. The reason for this is not known.

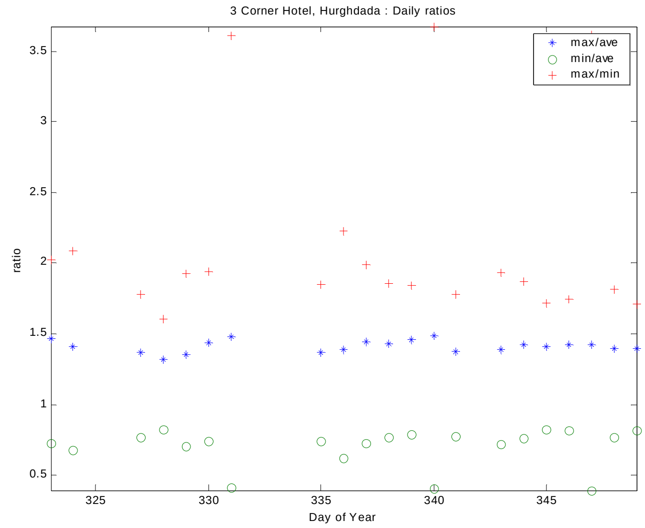


Figure 73 Ratio between maximum and average daily load, minimum and average daily load, and maximum and minimum load for each day. All based on 10 min average values.

It is also worth noting that the ratio between average and maximum load is very constant, and that the variation of the ratio between minimum and average load shows only a slightly higher variation, Figure 73.

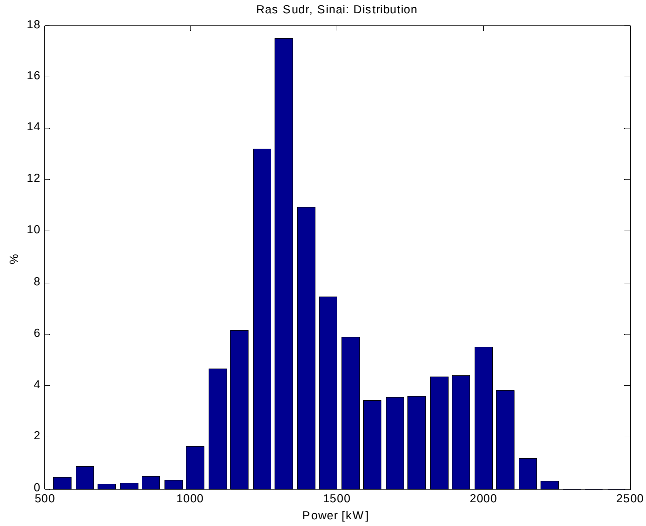


Figure 74 Distribution of 10 min average active power values

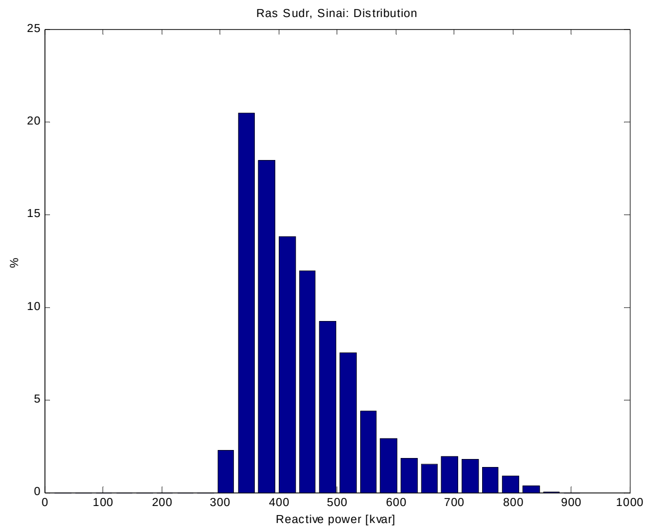


Figure 75 Distribution of 10 min average reactive power consumption values

The distribution of power and reactive power also varies around two levels as it was noticed with the grid voltage, Figure 74 and Figure 75. The distribution of the reactive power is particularly non-symmetric meaning that the correlation between active and reactive power is not so strong on this site as for the other sites.

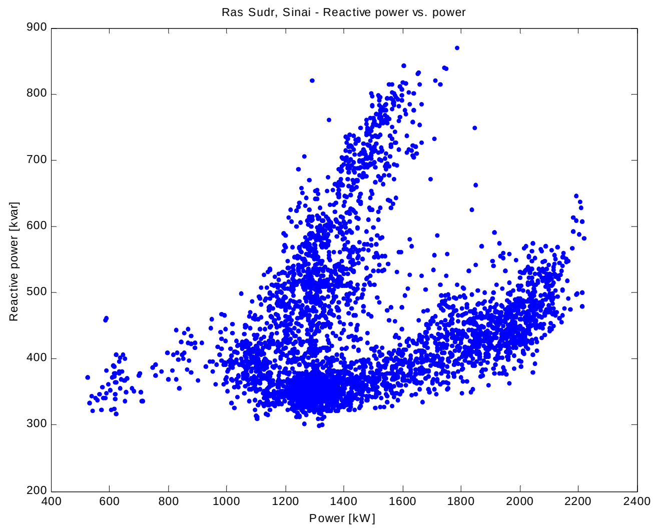


Figure 76 Reactive power consumption as a function of active power production

This is confirmed in Figure 76. In this figure two or three different situations are clearly visible. There is one situation where the reactive power varies proportionally to the active power. Then there is another situation where the reactive power shows less variation with the active power, and finally there is a situation with very low power consumption.

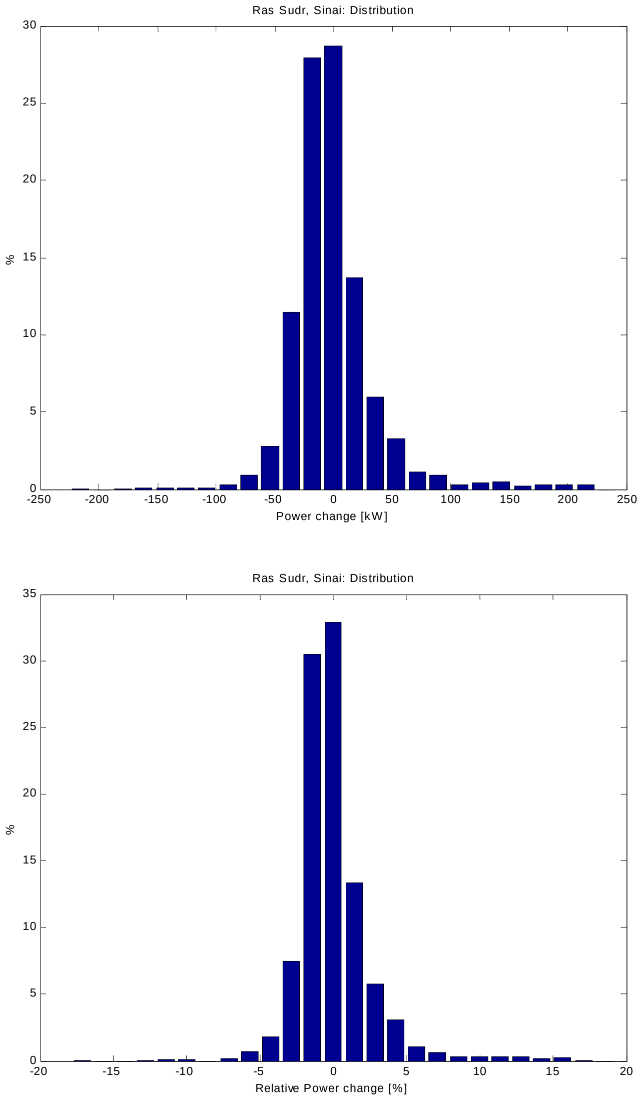


Figure 77 Change of active power from one 10 min value to the next, absolute as well as relative to the initial power

The changes in active power, Figure 77, are small compared to some of the other measurement sites with only few occurrences above 5%. The variation in reactive power is significantly larger and is similar to the other sites. This again illustrates that the correlation between active and reactive power is less at this sites than at the other sites.

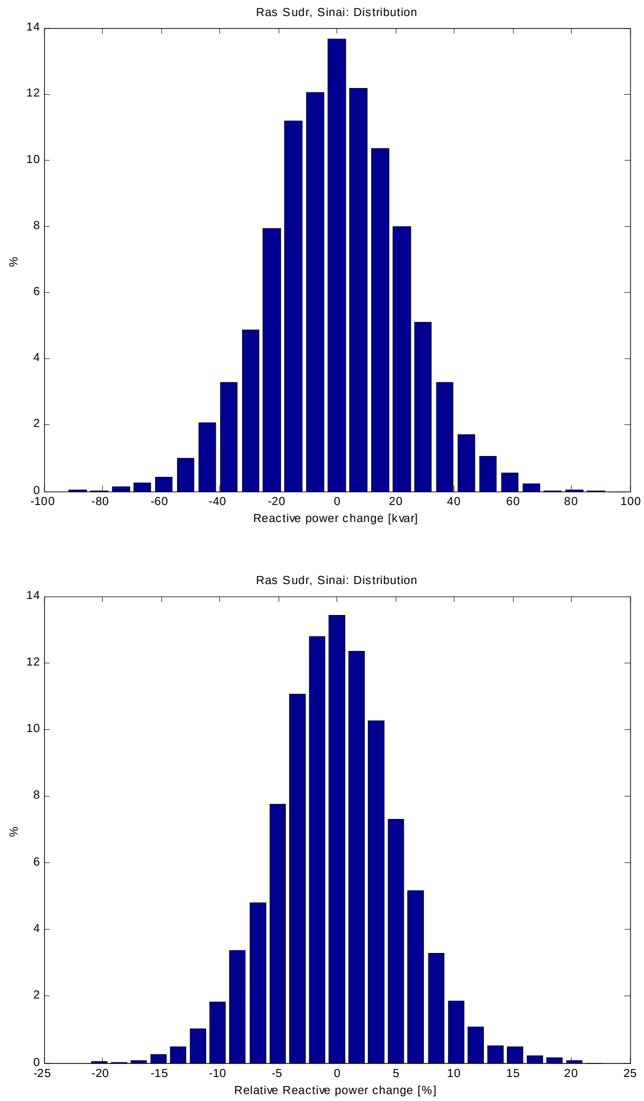


Figure 78 Change of reactive power from one 10 min value to the next, absolute as well as relative to the initial reactive power

The daily average patterns for each day of the week are shown in the next figures.

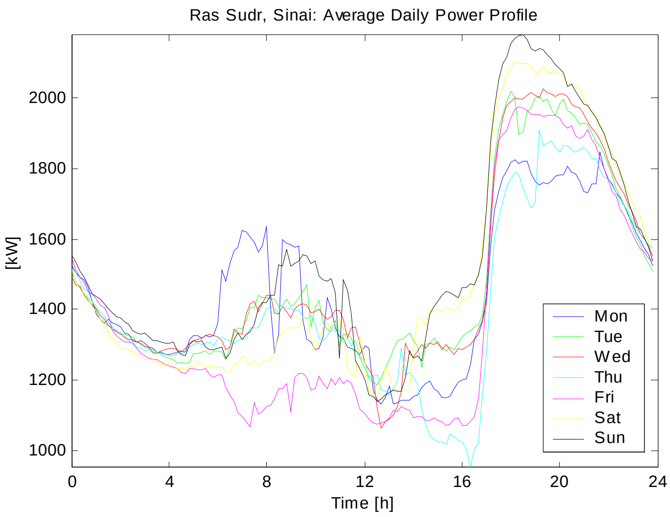


Figure 79 Average daily active power profile for each day of the week

The power consumption has a clear daily pattern for all of the days of the week, Figure 79. From the figure it is noticed the pattern for Fridays are different from the other days in that the consumption during the day does not have a peak but rather has an almost constant low value.

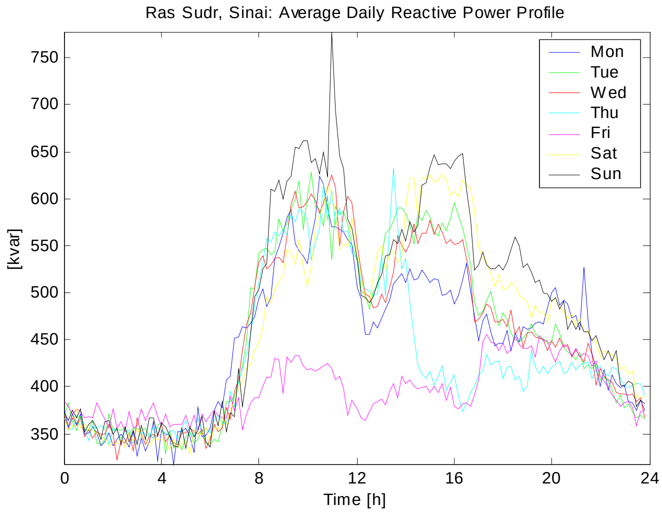


Figure 80 Average daily reactive power profile for each day of the week

The pattern for the reactive power confirms that the Fridays are significantly different from the other weekdays, with a lower activity level.

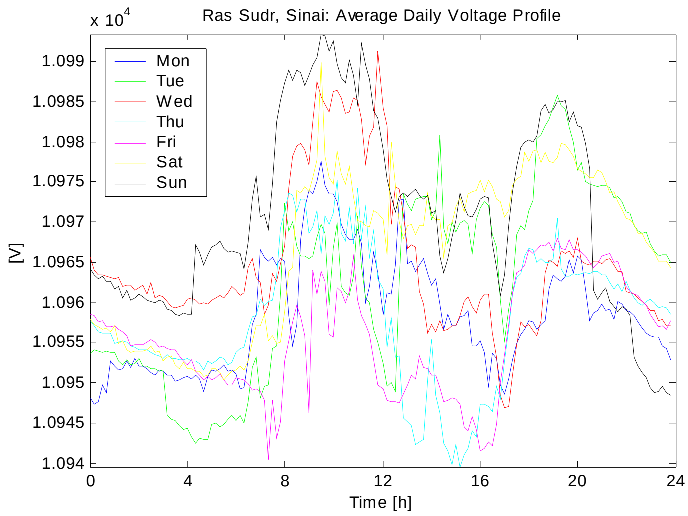


Figure 81 Average daily voltage profile for each day of the week

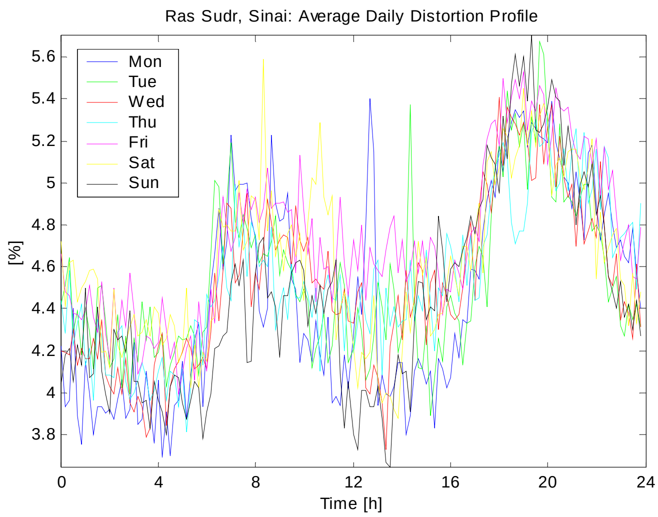


Figure 82 Average daily voltage THD profile for each day of the week

The differences between Fridays and the other weekdays do not show up in the voltage and distortion patterns, Figure 81 and Figure 82.

The next figures, Figure 83-Figure 89, show the time series for a weekday. It is clearly seen that for most of the days the variation from one day to the next a week later is limited. There are a few exemptions e.g. Mondays and also there are particular events with either very high or very low values. It is noticed that the variations between Fridays are small. The difference in pattern is therefore significant.

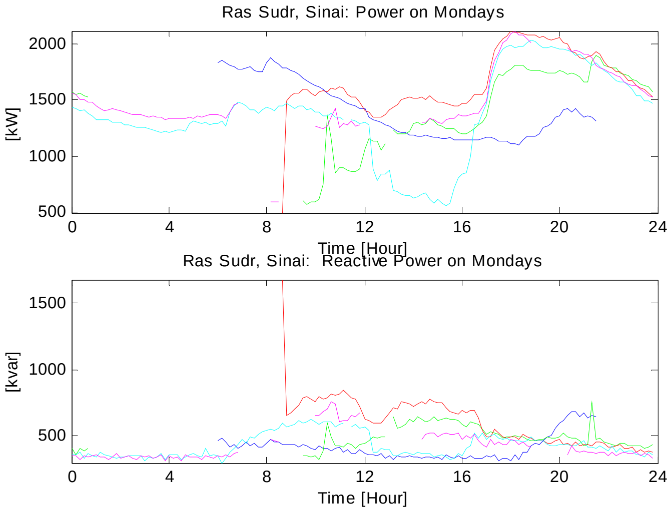


Figure 83 Daily active and reactive power profile for each Monday in the data set

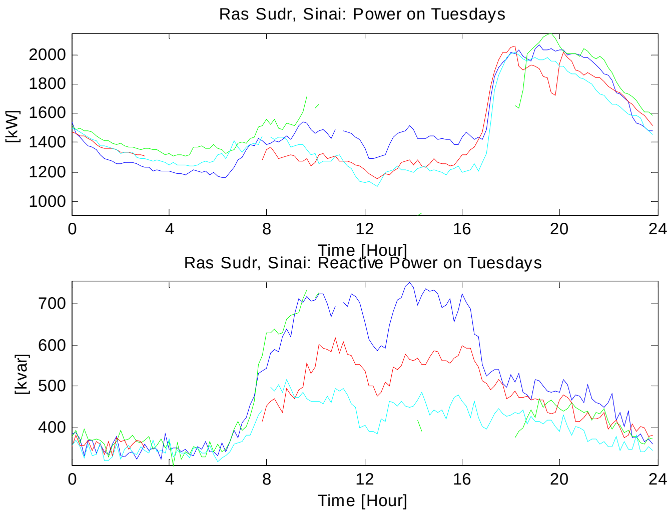


Figure 84 Daily active and reactive power profile for each Tuesday in the data set

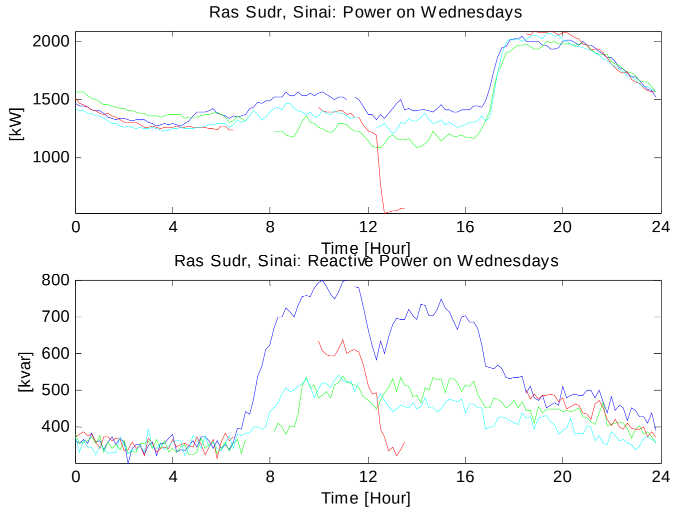


Figure 85 Daily active and reactive power profile for each Wednesday in the data set

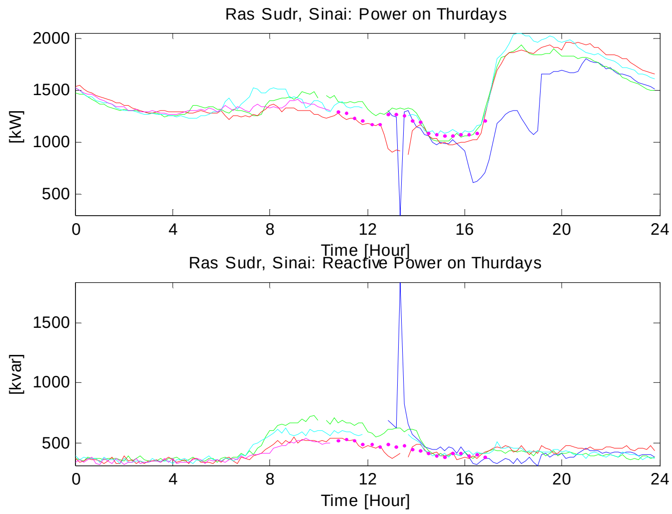


Figure 86 Daily active and reactive power profile for each Thursday in the data set

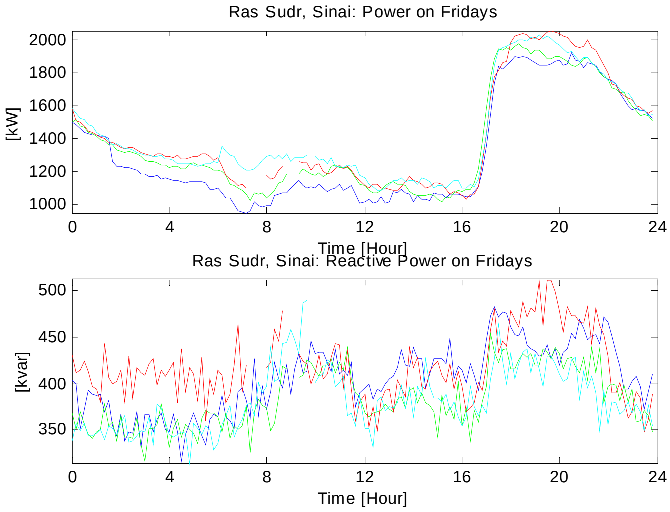


Figure 87 Daily active and reactive power profile for each Friday in the data set

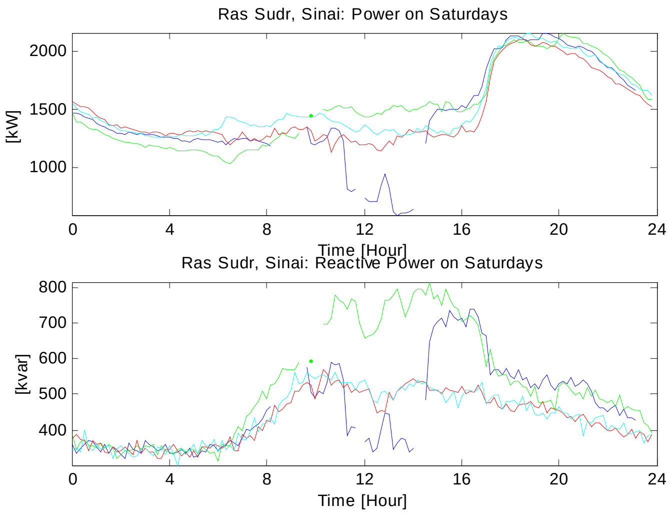


Figure 88 Daily active and reactive power profile for each Saturday in the data set

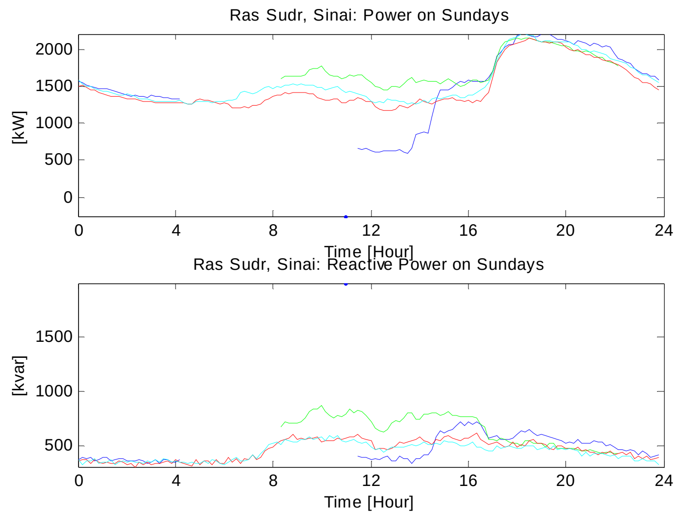


Figure 89 Daily active and reactive power profile for each Sunday in the data set

Wadi Tal

The fifth measurement site is in Wadi Tal, which is a small village in Sinai.

The measurement system was checked once a week and data files were changed. Very few problems were experienced during the period.

Table 5 Key data for Wadi Tal, Sinai measurements

Item	Description
Load type	Small village
Grid type	Isolated
Start date	98.11.18
Stop date	98.12.18
Average load	20 kW
Standard deviation of load	1 kW
Min 10 min load	16 kW
Max 10 min load	23 kW

In Wadi Tal power is only available for a few hours every day from approx. 17.00 until 21.30.

Initially graphs are shown indicating the power quality at the point of measurement.

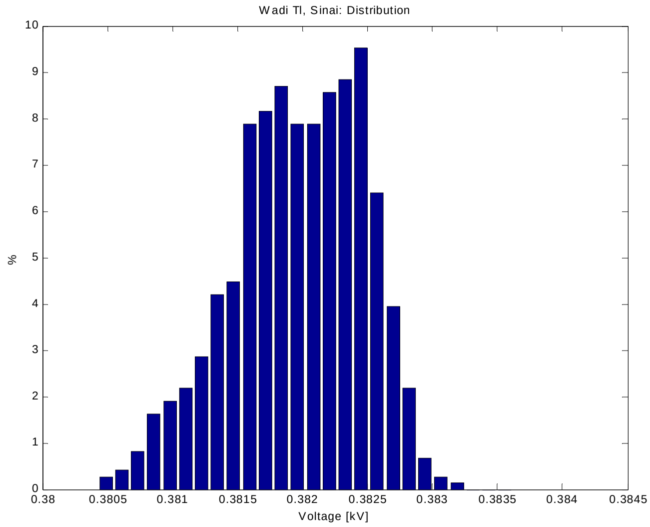


Figure 90 Distribution of 10 min average voltage values

The grid voltage shows very little variation, Figure 90. The variation is less than 1%. The distortion is also very low at only 1.5-2%, Figure 91. As can then be expected the changes in voltage are also very low. The voltage quality is therefore quite good.

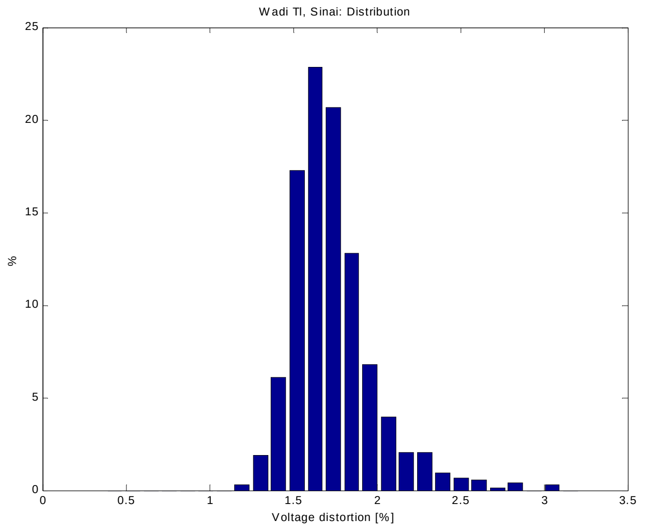


Figure 91 Distribution of 10 min average voltage THD distortion values

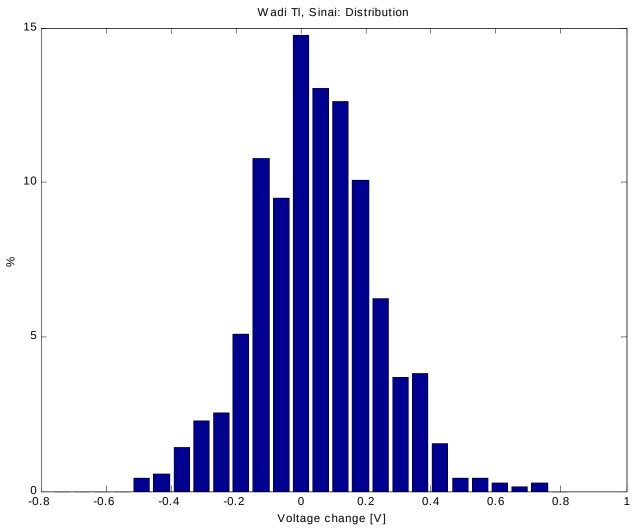


Figure 92 Change of voltage from one 10 min value to the next, absolute as well as relative to the initial voltage

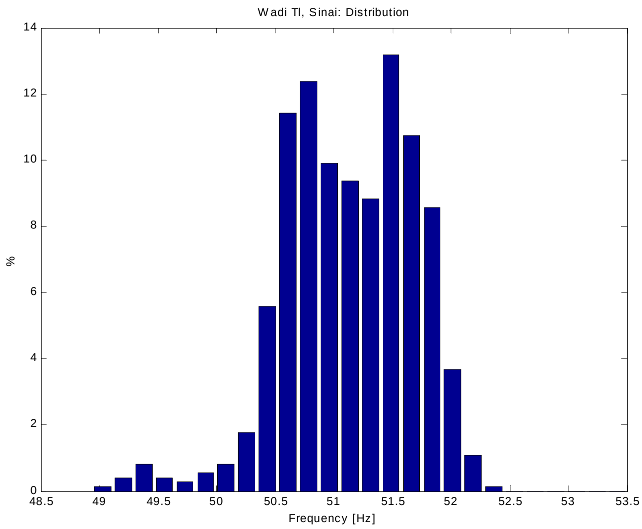


Figure 93 Distribution of 10 min average grid frequency values

The frequency shows some variation with values ranging from 49-52.5Hz. However, the majority of the values are in the range from 50.5-52Hz. The rather high value for the grid frequency is a result of the low load of the system. The average load is approx. 20kW and the diesel engine rating is 80kW.

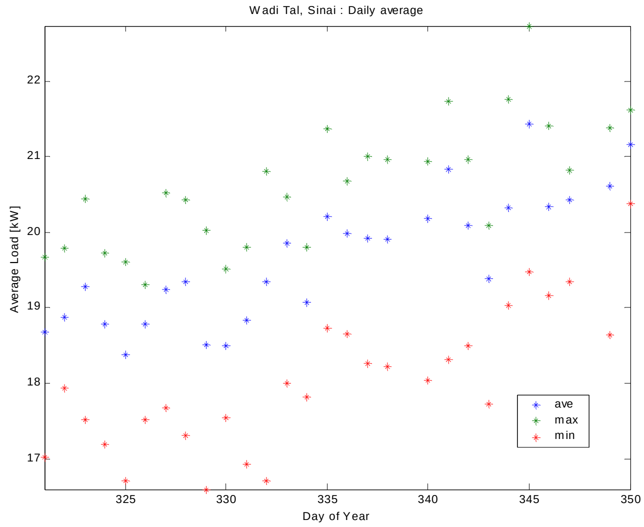


Figure 94 Daily average load and maximum and minimum 10 min average for each day.

It is seen that the load is quite constant during the period of measurements, Figure 94. Both the average and the minimum and maximum values vary only a little and are close together. This is confirmed in the next figure showing again that the variation is very limited.

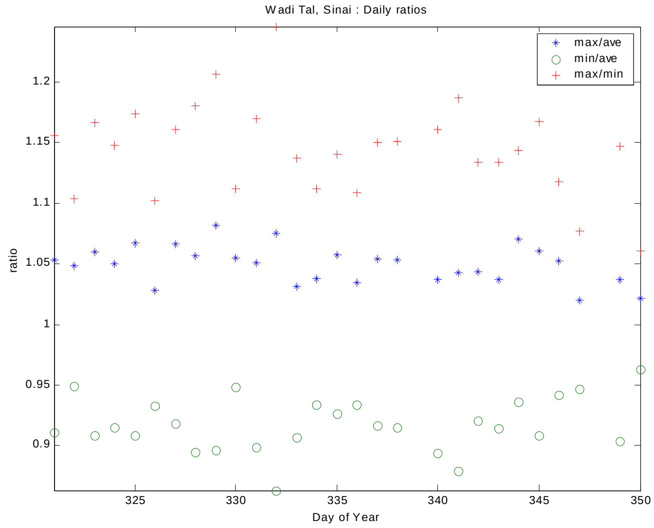


Figure 95 Ratio between maximum and average daily load, minimum and average daily load and maximum and minimum load for each day. All based on 10 min average values.

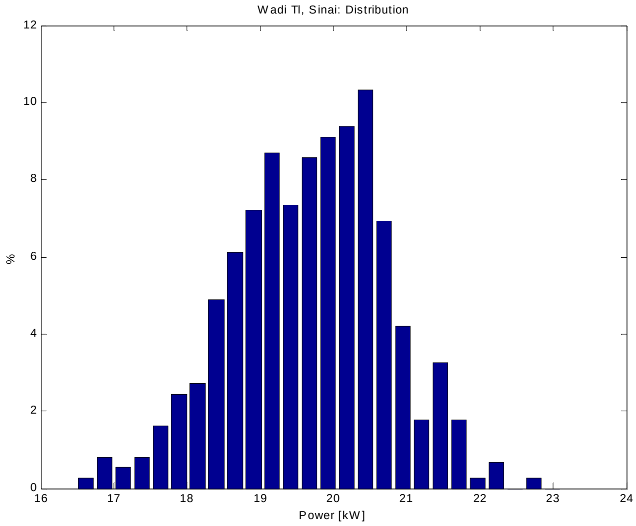


Figure 96 Distribution of 10 min average active power values

The distribution of the active power consumption is shown in Figure 96. The limited variation of the power is confirmed with almost all values in a band of average ± 10%.

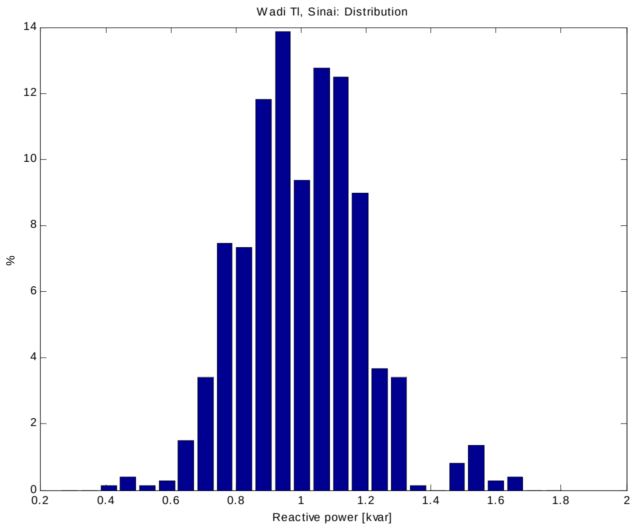


Figure 97 Distribution of 10 min average reactive power consumption values

The reactive power consumption is distinctively different from all the previous measuring sites, Figure 97. The reactive power consumption is very low and the result is an almost resistive load.

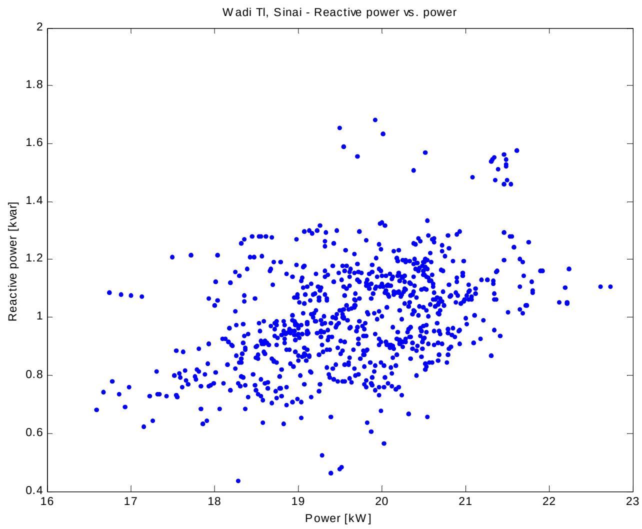


Figure 98 Reactive power consumption as a function of active power production

There is only a vague correlation between active power P and reactive power Q. The small variations in both active and reactive power results in cloud on the Q vs. P figure, Figure 98.

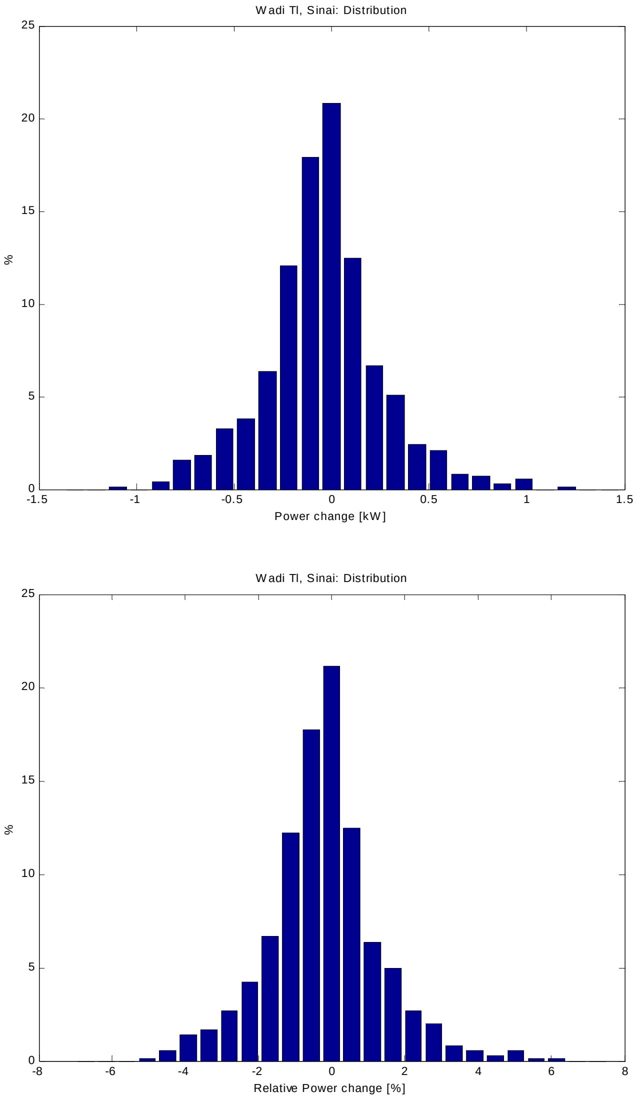


Figure 99 Change of active power from one 10 min value to the next, absolute as well as relative to the initial power

The very small changes in active power are confirmed in the next figure, Figure 99. The figure shows that the power does not change more than 6% from one 10 min average to the next. This is a very low value.

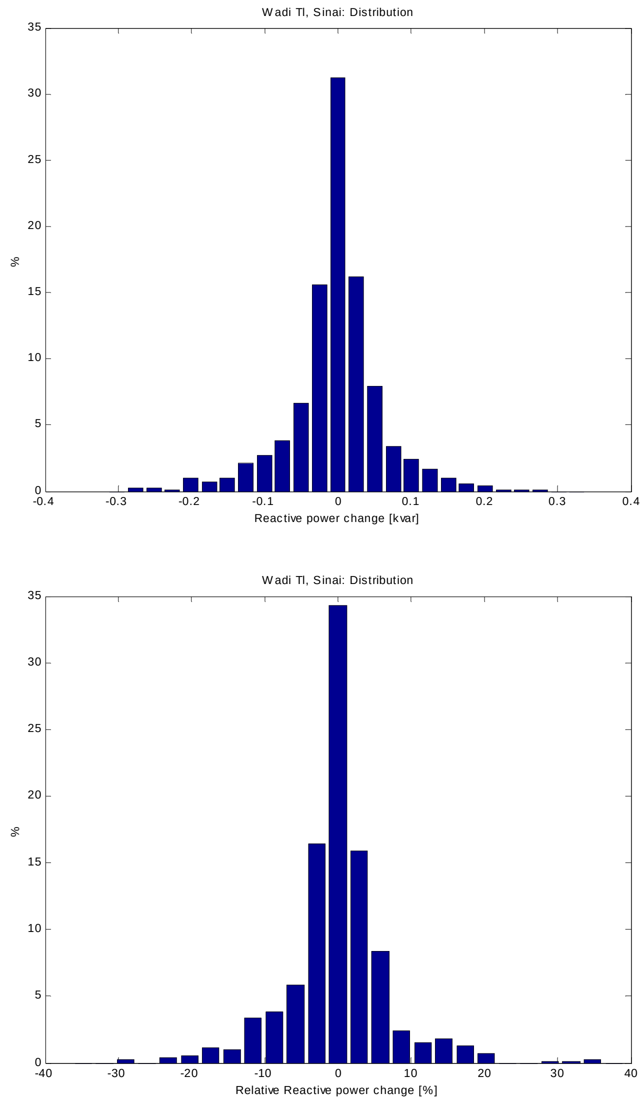


Figure 100 Change of reactive power from one 10 min value to the next, absolute as well as relative to the initial reactive power

The relative variation of the reactive power is larger than for the active power, Figure 100. This is mainly due to the very low level of reactive power consumption.

As then expected the variations from day to day is very small. The active and reactive load pattern is almost flat during the period where there is power, Figure 101 and Figure 102.

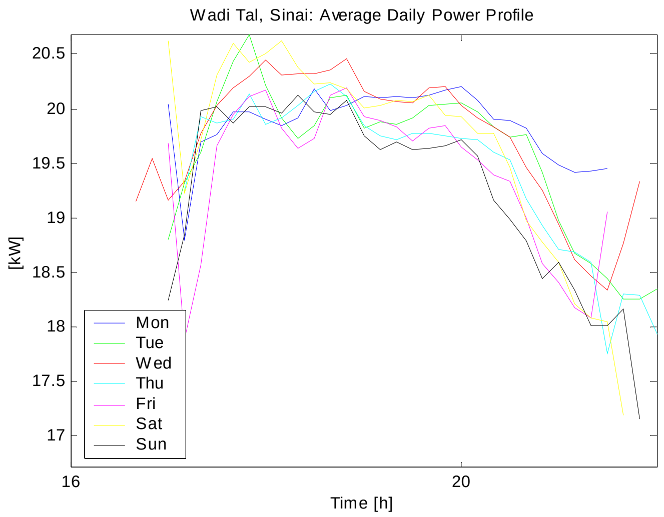


Figure 101 Average daily active power profile for each day of the week

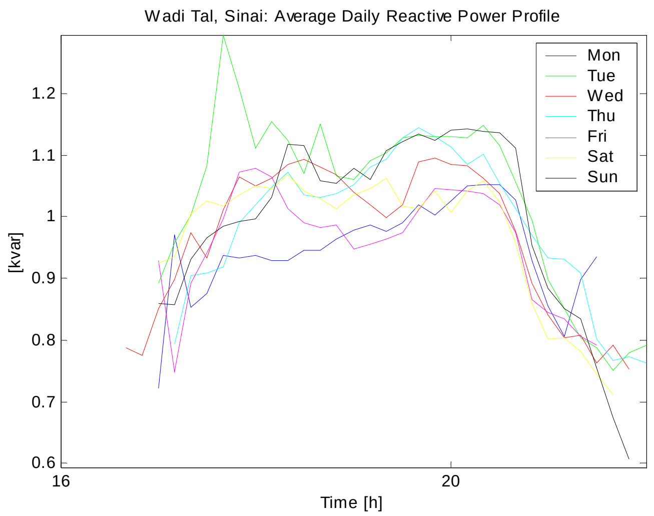


Figure 102 Average daily reactive power profile for each day of the week

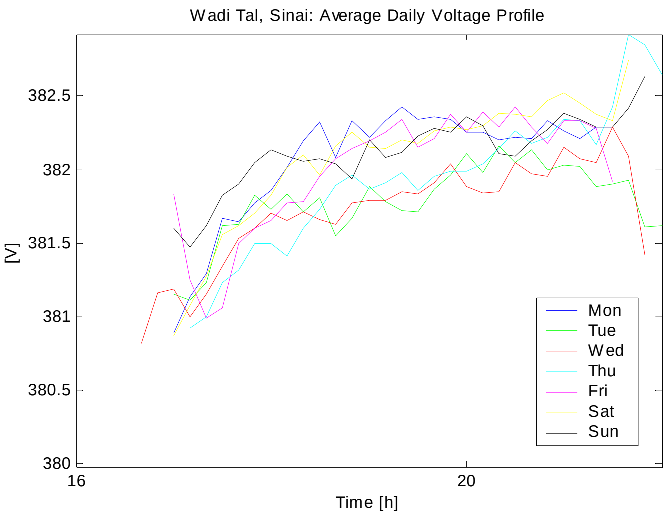


Figure 103 Average daily voltage profile for each day of the week

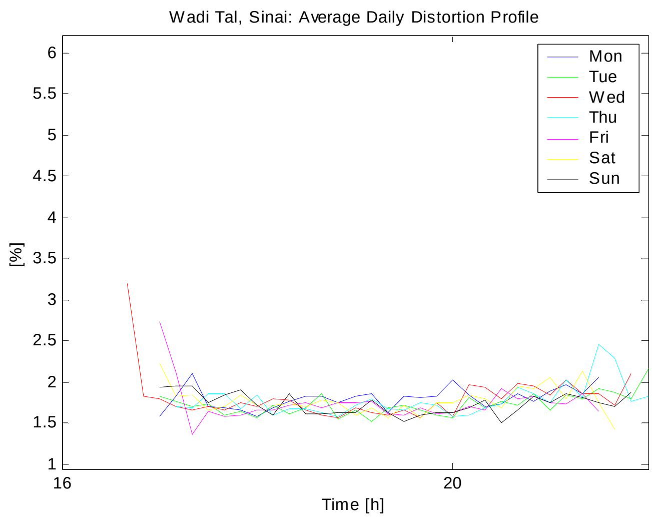


Figure 104 Average daily voltage THD profile for each day of the week

The grid voltage and the voltage distortion are also very flat for all days of the week, Figure 103 and Figure 104.

The variation between e.g. Mondays is as large as between e.g. Mondays and Tuesdays so there is no pronounced particular pattern for each day of the week.

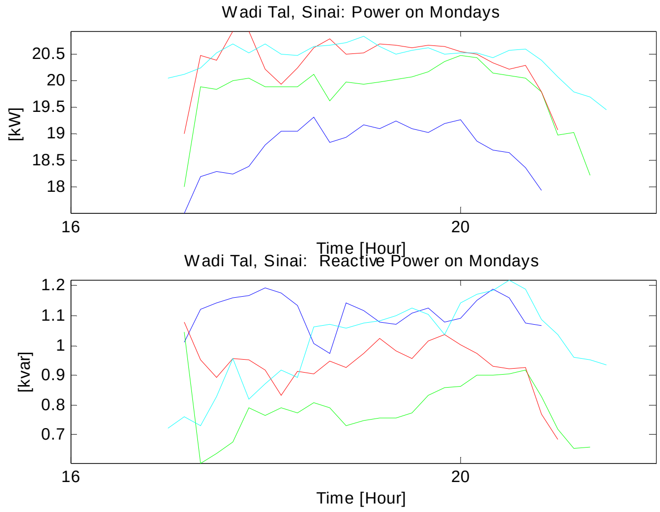


Figure 105 Daily active and reactive power profile for each Monday in the data set

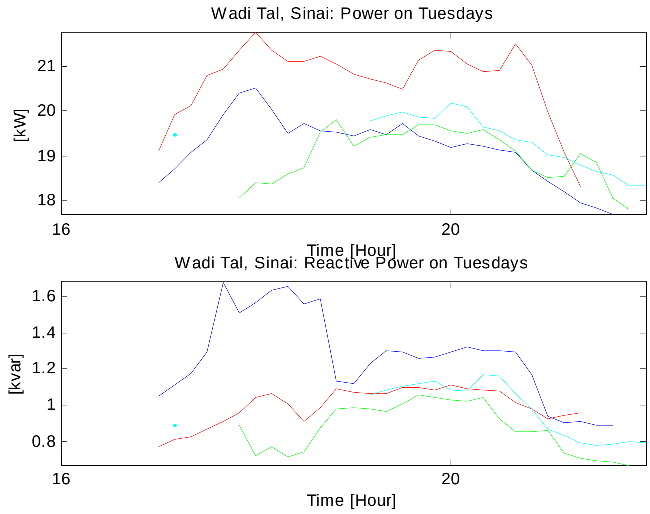


Figure 106 Daily active and reactive power profile for each Tuesday in the data set

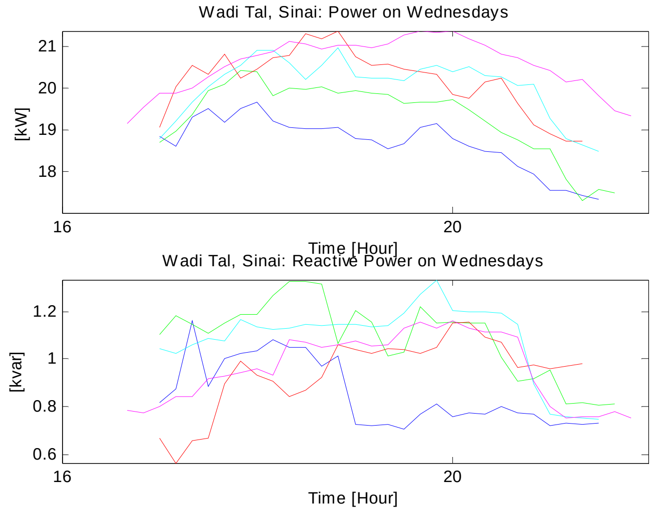


Figure 107 Daily active and reactive power profile for each Wednesday in the data set

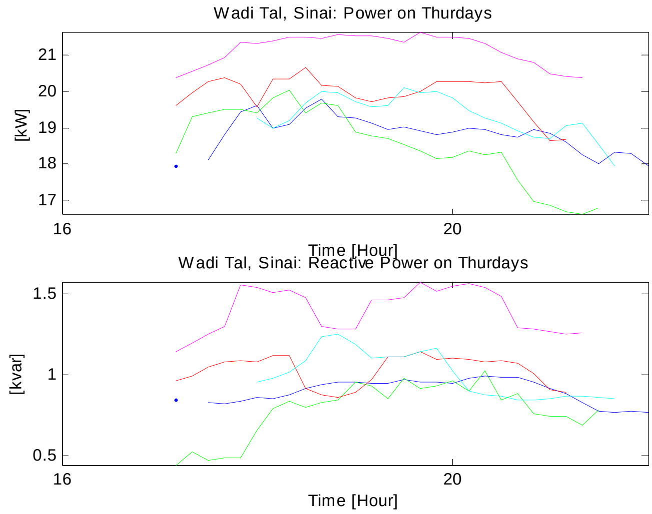


Figure 108 Daily active and reactive power profile for each Thursday in the data set

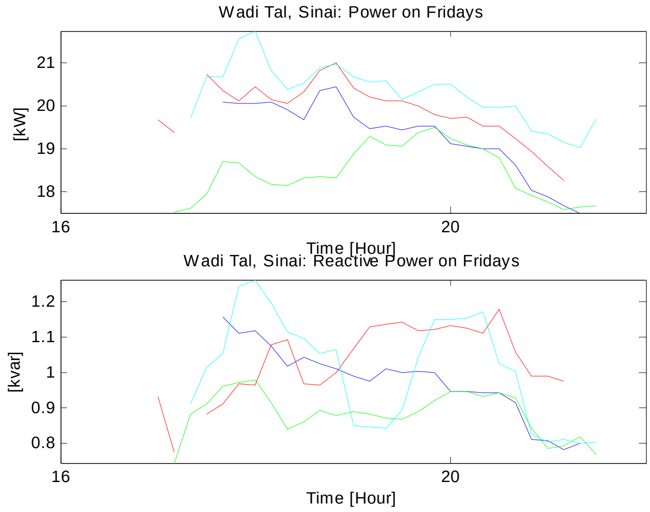


Figure 109 Daily active and reactive power profile for each Friday in the data set

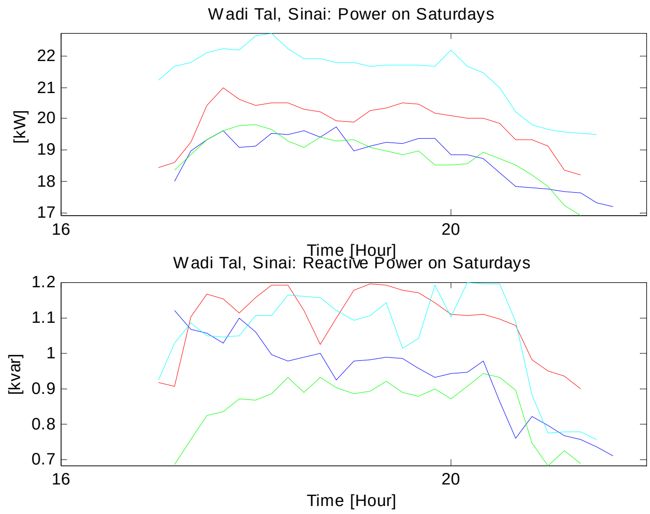


Figure 110 Daily active and reactive power profile for each Saturday in the data set

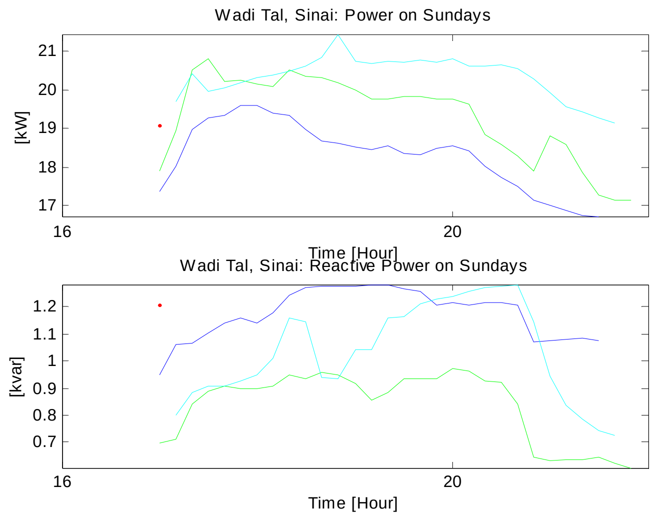


Figure 111 Daily active and reactive power profile for each Sunday in the data set

3 Analysis of data

After the initial analysis of the data for each of the sites where measurements have been conducted, a comparison between the different sites is done on order to highlight similarities and differences.

The comparison is done for key characteristics of both load and power quality.

In Table 6 key figures for the five sites are listed. The first three (Hotel, Residential Area, Shopping Mall) measured on the large grid of Hurghada are characterised by the very small variation of the frequency. This variation is an order magnitude smaller than the variation of the frequency in Ras Sudr with its medium sized diesel grid which again is an order of magnitude smaller than the variation at Wadi Tal, the small system.

The variation of the voltage is influenced by other factors than just the size of the grid. Here the distance to the power station is very important as well as the range of load changes. It is therefore seen that the tightest voltage variation range is measured in Wadi Tal. This is the case since the voltage is measured at the bus bar at the power station and the variation of the load is very small. The voltage is also measured at the bus bar in Ras Sudr, and even if the system is rather small compared to Hurghada the voltage range is smaller here than for the three sites in Hurghada.

It is also seen that the load characteristics for the five sites are very different. The load range in Wadi Tal is extremely small compared with the other sites. For Ras Sudr the maximum load is only 1.5 times the average load, which is a small value although the minimum load is 0.36 times the average load. This value, on the other hand, is quite small.

The load range for the hotel site is very wide. This is due to the nature of the load since the load will change with the number of guests staying at the hotel.

Quite interestingly the site with the largest standard deviation of the load is the residential site. For an explanation of this it is necessary to look at the load in more detail (see load profiles below).

Table 6 Measured key figures (based on 10 min average values)

	Hotel	Residential	Shopping	Ras Sudr	Wadi Tal
Pave [W]	88981	82385	161362	1470882	19678
Pmax/Pave	2.65	2.49	1.78	1.51	1.16
Pmin/Pave	0.31	0.34	0.47	0.36	0.84
Pstd/Pave	0.3811	0.5465	0.2373	0.2143	0.054
Umin/Un	0.9516	0.9998	0.9207	0.9928	1.0009
Umax/Un	1.0437	1.0992	1.0598	1.0016	1.0083
Uave/Un	1.0151	1.0625	0.9929	0.9966	1.0052
Ustd/Un	0.0151	0.0188	0.0253	0.002	0.0013
fmin/fn	0.9986	0.9988	0.9958	0.995	0.982
fmax/fn	1.0004	1.0004	1.0048	1.017	1.049
fave/fn	0.9994	0.9995	1.0004	1.0013	1.0227
fstd/fn	0.0002	0.0002	0.0009	0.0011	0.011

3.1 Loads

To compare the load characteristics of the different sites, figures showing the load distribution, the load, the duration curve, the daily load profile with standard deviation and the reactive vs. active power have been prepared.

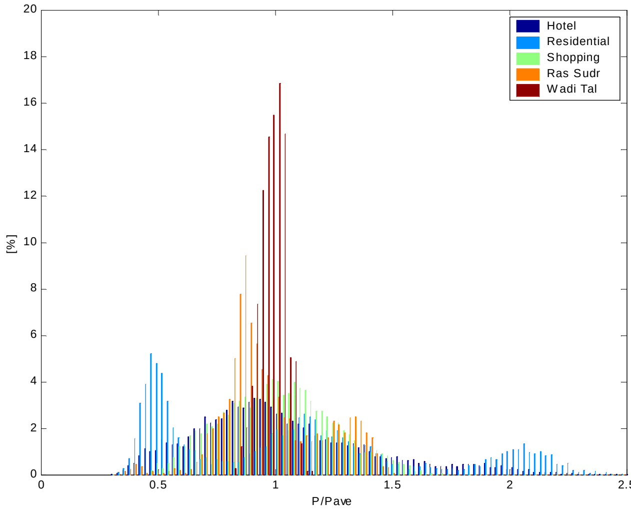


Figure 112 distribution of loads

The distribution of the loads is shown in Figure 112. It is very clearly seen in the figure that the shape of the distribution is very different for the different sites. The load at Wadi Tal is concentrated in a close band around the average value (as indicated also by the key figures in Table 6). The load at Ras Sudr has two peaks but also a tail at low loads. This tail is the reason for the low value of the ratio P_{min}/P_{ave}. The number of data points in this tail is quite low.

The distribution of the load at the shopping mall is quite symmetrical without extra peaks. The hotel load is more distributed covering a wider range. The residential load is very different from the others. It covers a wide range but the load is concentrated around three values. The same data is presented as duration curves of the loads in Figure 113. The same features are therefore seen in this figure.

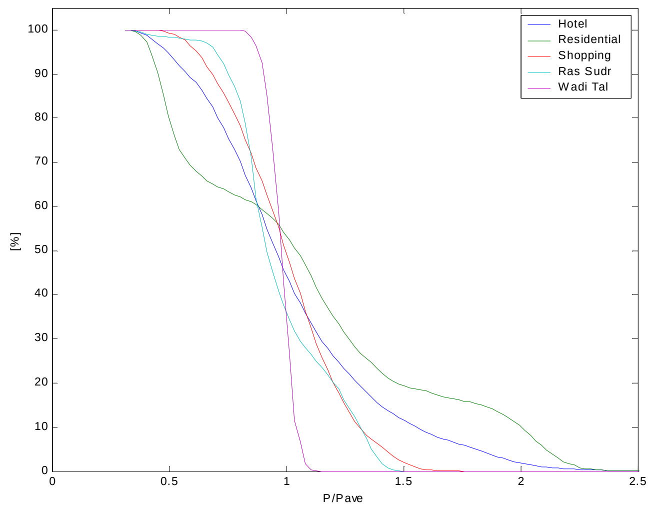


Figure 113 Load duration curves

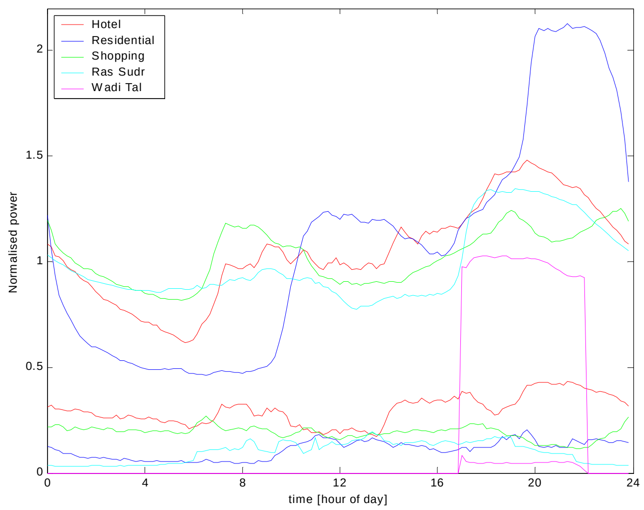


Figure 114 Load profiles for the five sites. Also included are the standard deviations for each 10 min bin

The load profiles for each of the five sites are shown in Figure 114. It is clearly seen that the profiles are very different. The hotel load is characterised by a rather high standard deviation for each of the 10 min bins. This means that the mean load profiles is not very well determined. This is of course due to the changing number of hotel guests staying at the hotel. Another very particular feature to notice is that for the residential load the night time load is very low and the evening peak is very high, and this is quite well determined since the standard deviation is low. This is also the case for the Wadi Tal load with an extremely low standard deviation confirming the almost constant load there.

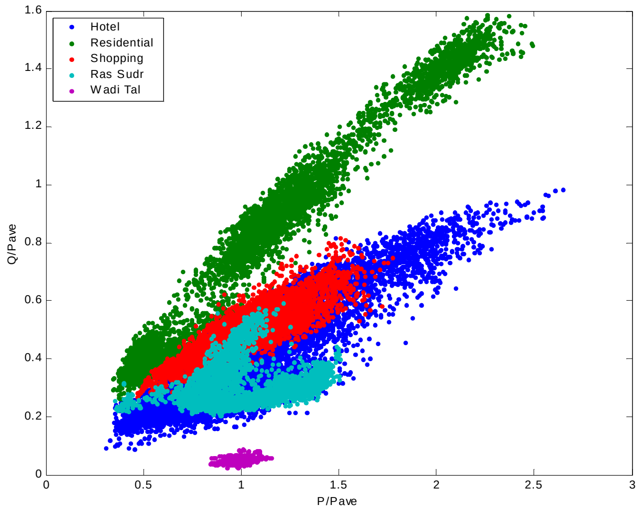


Figure 115 Normalised relationship between active and reactive power

Another important characteristics for the load is summarised in Figure 115. Here the amount of reactive power consumption vs. active power consumption (both of them normalised with the average power) is shown. The two extreme cases are Wadi Tal with an almost resistive load and the residential load with the largest Q/P ratio. The shopping mall and the hotel have almost identical characteristics in this respect, and for the Ras Sudr load two quite different load cases are visible. The exact source of this is not known.

The load data collected as part of the project can be used to illustrate different load profiles. However, since the measurement periods for all the cases are limited to approx. one month the results should be used with care when applying the profiles for system studies. The load profiles are believed to be reasonably well determined for the measurement period, but seasonal variations as well as variations between weekdays are not well determined.

3.2 Power quality

Power quality is an issue of increasing importance. The main reason for this is the increasing demands from the customers with respect to security and quality of supply in order for them to rely on the public power supply in such as way that they do not have to take special measures to ensure that they can conduct their business without concern about the availability of computers, machines, appliances etc.

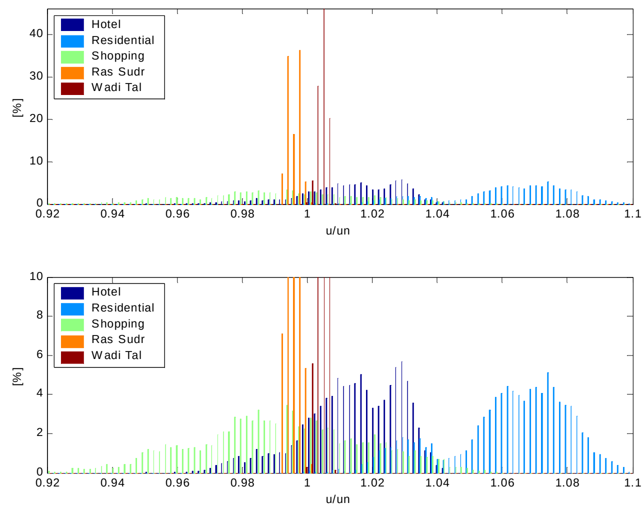


Figure 116 distribution of voltage

Figure 116 summarises the distributions of the grid voltage as measured at the measurements points shown for the five sites. It is clearly seen that the voltage range at the main bus bar at Ras Sudr is not varying very much, and this is mainly due to (a) the low impedance between the bus bar and the generators and (b) the modern voltage controller of the generators. The voltage for Wadi Tal is also quite constant, and the reason for that is that the load is almost constant.

For the three cases in Hurghada the voltage variations are larger. All these measurements are carried out on the secondary side of a distribution transformer, and the impedances for these sites are therefore significantly higher. This will results in voltage changes when the load changes, but even if the voltage changes are higher at the three sites in Hurghada they are still within acceptable ranges.

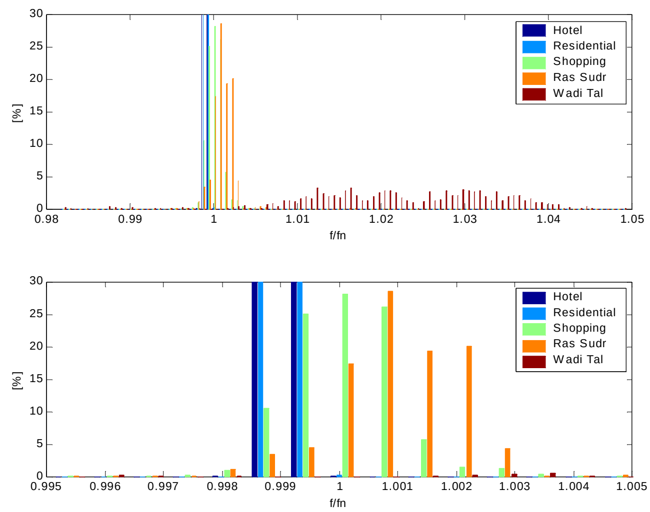


Figure 117 Distribution of frequency

The ranges for the frequency variations are mainly determined by the size of the generating capacity. This is clearly seen in Figure 117. For the cases in Hurghada the frequency range is very narrow. For the Ras Sudr case the variations are larger although they are still small, since the generating capacity is quite large compared to the load and especially to the load changes. For Wadi Tal it is clear that the system is small. Even the small changes in the load is causing changes in the frequency that almost exceed the standards for frequency limits.

In general it is noticed that the power quality as measured is quite acceptable also for the smaller systems. They all exhibit good voltage control with a narrow variation range. The end user voltage range has not been measured at Ras Sudr and Wadi Tal. The voltage variations seen by the user will be higher that that of the main bus bar. The frequency control is also good, although it is seen that the quality experienced at Wadi Tal will degrade if more changes in the load were introduced e.g. if more appliances were installed.

4 Application of Results for System Performance Analysis

The purpose of this Section is to investigate the impact of different load profiles as measured at the five different sites and compare the impact with other important parameters in a System Performance Analysis.

When assessing system performance during the feasibility stage of a project the amount of data of the future system is often not complete and the forecasts are often not based on detailed analysis. There is therefore uncertainty on the data on which the feasibility analysis is performed.

Part of the uncertainty also includes the load profile. In order to conduct the feasibility analysis it is important to have a good impression on the impact of some of the uncertainties. The impact of the load profile is compared to the impact of the load development.

4.1 The System Performance Analysis Method

The systems performance is here taken as the fuel saving, the utilised and dissipated wind energy, and the economic profit based on a Life Cycle Cost Analysis (LCA). In order to investigate these things a range of scenarios is defined and the performance parameters as are calculated based on a life cycle simulation of each scenario using a dedicated simulation model.

The simulation model is a technical/economic model that simulates the total behaviour of the system throughout its operational life with respect to energy flow, and based on the results of the technical simulation the model calculates the economic performance. The simulation model is able to represent the development in consumer load from year to year throughout the 20 year operational life.

The important issues are the scenario definitions and specification of the base system. This is described in the next section.

4.2 Assumptions and Tools

Table 7 Key parameters common to all scenarios

Parameter	**Value**
Full load fuel consumption	385..8kg/h
No load full consumption	23.8kg/h
Technical minimum load of Diesel	25%
1st year energy consumption	12900MWh/y
Weibull scale parameter	8.0
Weibull shape parameter	2.0
Fuel cost	2500 DKK
Wind turbine	Nordtank 300kW
Systems technical lifetime	20 years
Discount Rate	8%

The system that is simulated is based on the situation in Ras Sudr. The power system is assumed to consist of two 2.5MW MAN B&W diesel generator sets feeding a load which in all the scenarios' first year is the average load as measured during the measuring campaign. The diesel gensets are characterised by the fuel consumption curve and their allowed minimum load. In all the scenarios no energy storage is included and the genset capacity on line is therefore always large enough to cover the demand including some spinning reserve.

The wind speed is specified by its Weibull scale and shape parameters. They are assumed to be the same throughout the year. The wind turbines are assumed to be 300kW stall controlled wind turbines. For all the scenarios the simulation of the system performance is repeated for 1 to 10 installed wind turbines i.e. installed capacity in the range 300-3000kW.

The scenarios are defined by three different energy consumption forecasts and by five load profiles. The system is simulated for a 20-year period. The energy consumption forecasts are:
1. constant load throughout the analysis period,
2. 3% load increase each year throughout the analysis period and
3. 10% load increase the first five years followed by a five year period with 3% load increase per year and a constant load thereafter.

The load profiles are the four load profiles measured (Wadi Tal is not used since 24h power supply is assumed) and a constant load.

The tool used for the analysis is WINSYS, [1]. WINSYS is a power system analysis model designed for technical and economic analysis of primarily power systems with diesel power combined with wind power. One unique feature of WINSYS is its ability to include the development from year to year in consumer load throughout the operational life of the system in the analysis of the technical performance of the system. The analysis of the economic performance of the system is done as a life cycle cost analysis.

4.3 Results

For all the scenarios the system is simulated for 20 years and for 1 to 10 300kW wind turbines installed. The main output from the simulations are the net profit, the fuel consumption and the dissipated wind energy. The net profit is of course the key parameter in the evaluation of different system solution options and the fuel saving and dissipated wind energy are very good indicators for explaining the behaviour of the system.

For the 3 different energy development profiles and the 5 different load profiles the profit as calculated by the simulation model are shown in the Figure 118-Figure 120, in dependence of the number of wind turbines installed. It is clearly seen that in all the cases the maximum profit is in the case of a constant load and the minimum profit is in the case of the residential load profile. It is also noticed that the other three load profiles are rather close to the maximum profit curve while the minimum profit curve is at a much lower level. This is explained by low value of the minimum load of the residential load profile. This leaves very little room for the wind energy between the technical minimum load of the diesel genset and the consumer load. Even when the installed wind turbine capacity is low the system constrains forces the system to dissipate wind energy.

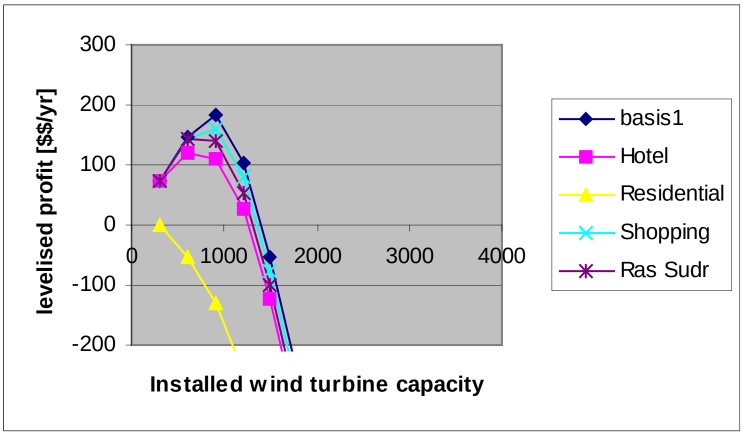


Figure 118 Profit of systems with constant annual energy consumption

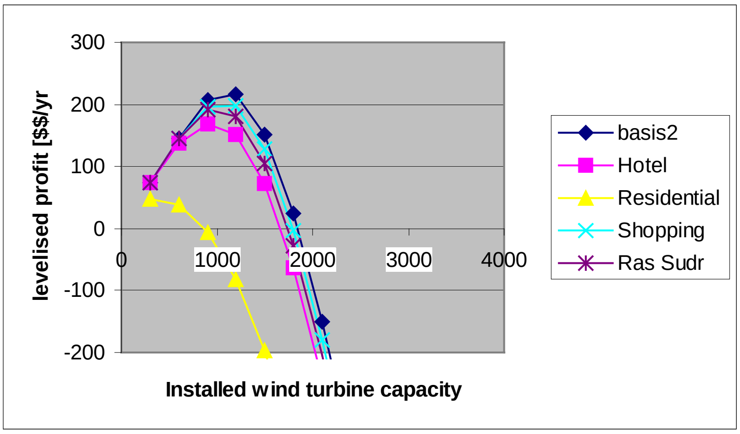


Figure 119 Profit of systems with 3% annual load increase

The scenarios with a 3% annual increase are at a higher level than the case with a constant annual energy consumption. This is mainly due to the increase in the minimum load giving more room for the wind energy. It is also seen that the curves except the one for the residential load profile are closer to each other.

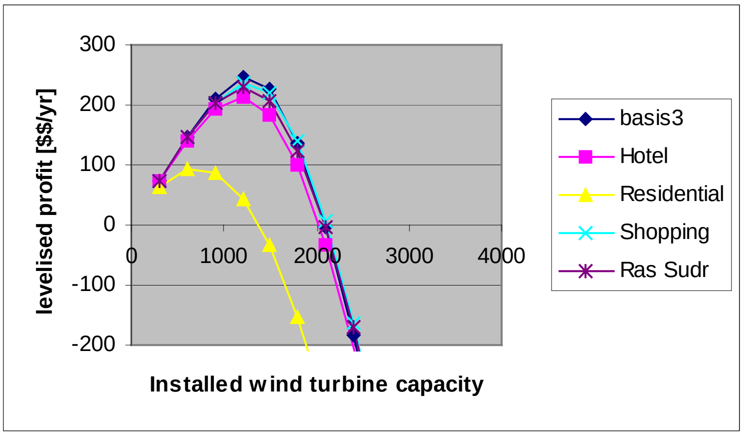


Figure 120 Profit of systems with 10% initial annual load increase followed by a 3% annual load increase followed by constant load in 5, 5 and 10 years

This trend is even more pronounced in the case with high load increase in the initial years. It is clearly seen here that the impact of the different load profiles is much lower than in the case with constant energy consumption.

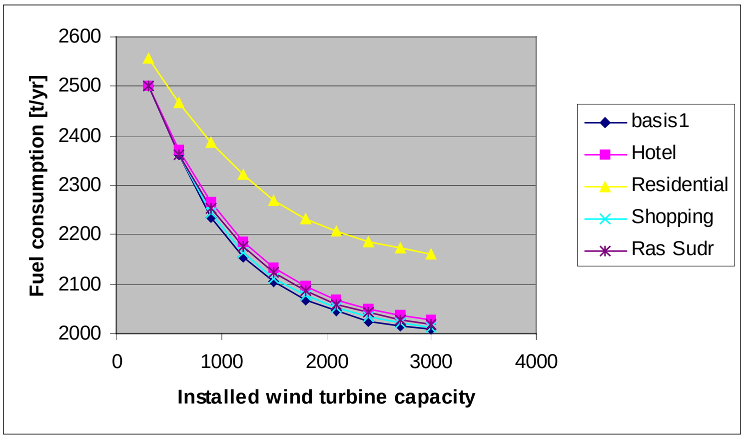


Figure 121 Profit of systems with constant annual energy consumption

The fuel consumptions of the different scenarios are shown in the next three figures. It is again noticed that the cases with the residential load profiles are significantly different from the other cases. As is the case for the profit the differences are reduced as the energy consumption is increased.

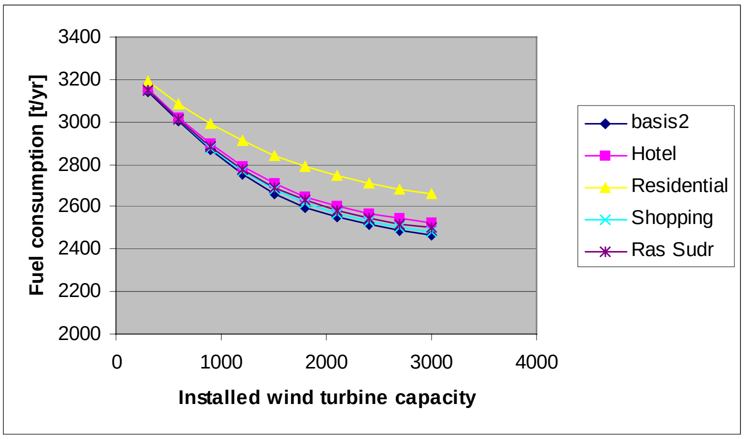


Figure 122 Profit of systems with 3% annual load increase

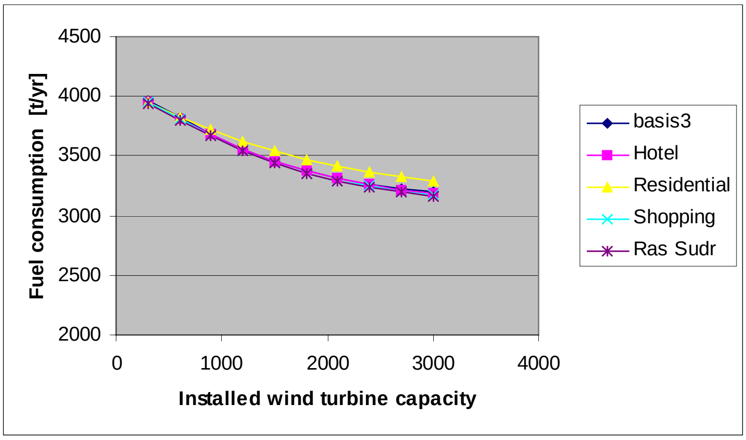


Figure 123 Profit of systems with 10% initial annual load increase followed by a 3% annual load increase followed by constant load in 5, 5 and 10 years

It is noticed that the reduction in fuel consumption is decreasing as the amount of installed wind turbine capacity is increased, and the next three figures indicate the reason for this.

As the installed wind turbine capacity is increased the fraction of the potential wind energy that is actually utilised decreases because the amount of wind energy that has to be dissipated in order to maintain the operating limits of the system given a particular load profile increases.

At the very high penetration level most of the potentially available wind energy of the last added wind turbine has to be dissipated. It does therefore not contribute significantly to the reduction of the fuel consumption. It is therefore very expensive to add this wind turbine to the system as very little fuel is saved at the same specific investment. The marginal cost of utilised wind energy at high wind power penetration is therefore high.

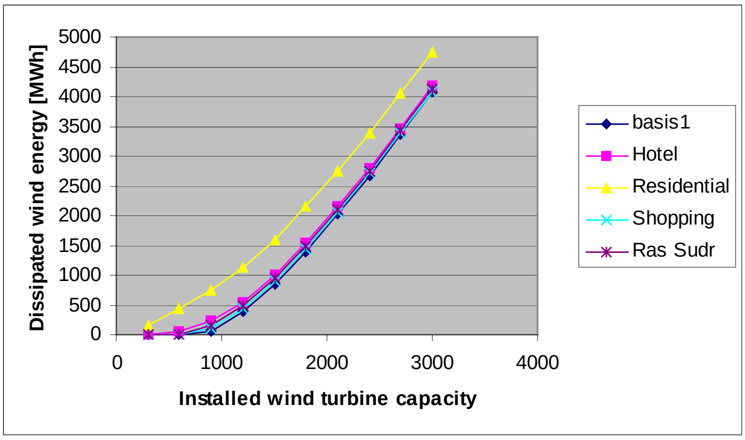


Figure 124 Profit of systems with constant annual energy consumption

The comments above are confirmed by the figures with the dissipated wind energy, Figure 124-Figure 126. It is noticed that in the case of residential load profile and constant energy consumption some of the potential wind energy is dissipated even at only 300kW installed wind turbine capacity.

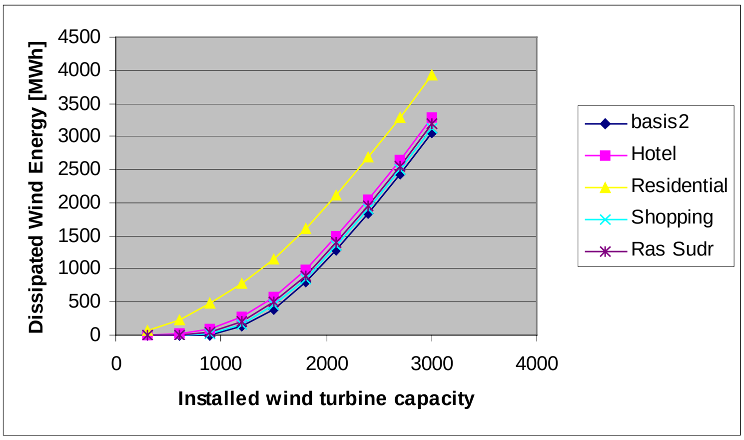


Figure 125 Profit of systems with 3% annual load increase

The point of maximum profit in the Figure 118-Figure 120 corresponds to the point in the figures with dissipated wind energy where only a small amount of wind energy is dissipated. The maximum profit is actually when some of the wind energy is dissipated and not at the limit where it is necessary to start dissipating wind energy.

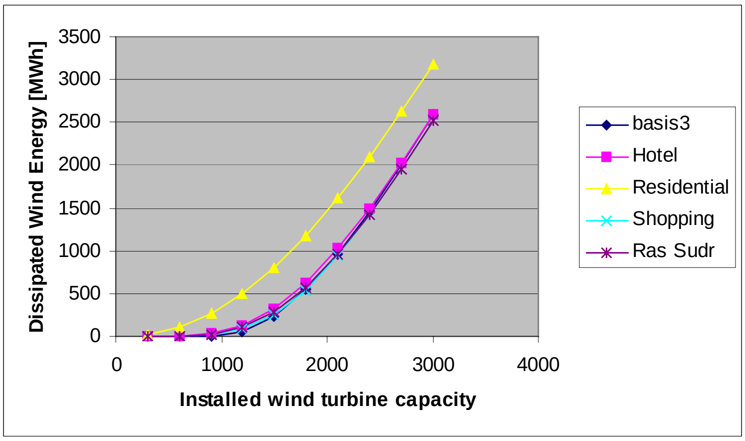


Figure 126 Profit of systems with 10% initial annual load increase followed by a 3% annual load increase followed by constant load in 5, 5 and 10 years

It is also seen that the point where the dissipation starts, moves to the right as the energy consumption increases. This means that an increasing amount of wind energy can be integrated profitable in the system at increasing energy consumption. It is also noticed that the differences between the various load profiles decrease.

From the above it is seen how the shape of the load profile that is used to analyse a given system does have an impact on the predicted technical and economic performance. The load profiles are significantly different with two limiting cases: a constant load and a load profile with very salient minimum and maximum values.

However, this impact has to be considered together with the impact of other parameters that are important in the assessment of wind diesel systems. Two of the particularly important parameters in these cases are

1. the minimum load of the diesel gensets and
2. the development of the energy consumption during the life time of the system.

In the system studied here the size of the diesel gensets and the average load of the system do not match particularly well in the initial years of operation since the load is too low for the diesel sets. This quite naturally leaves only little room to include wind energy especially if the load profile has a low minimum value.

When assessing such systems it is therefore important to determine if the system load profile will have a very low minimum value, and if this is the case then to be very careful in the determination of the load profile. If the initial investigation indicates that the minimum value of the load is not particularly low, then other issues such as especially the energy consumption development are more important.

After the feasibility analysis is completed there is a phase of actual system design. During this phase the actual operating strategy is developed, and in this phase the load profile can have an important impact. This has to be investigated by models suitable for simulation and development of operating strategies.

5 Conclusions

Measurements have been carried out at five different location in Egypt. The main objective of the measurements was to establish knowledge of the behaviour of different types of load in order to use that information in the feasibility analysis phase of a project.

The measurements have been carried out at a hotel, a shopping mall, a residential area, a large village and a small village. The measurement period have been approximately one month for each of the sites. From a load perspective it is clear that the load profiles are very different at the different sites.

The residential load profile has some very pronounced extremes, whereas the other load profiles have a more narrow range of variation. The variability of the load in terms of rate of change is also different from the different sites. The variability from day to day at the small village and at the residential load is quite small. For the other loads the day to day variation is rather large.

It can also be concluded that a one month measuring period is too short for a good statistical description of the load. Loads should be measured for longer periods in order to include seasonal variations and other long-term variations. The actual load profile is however reasonably well determined for the different sites.

The power quality is quite satisfactory at the measurement sites. Voltage and frequency fall within the ranges required by international standards as far as slow variations are concerned. The total harmonic distortion THD of the voltage is also within standards. In the case of Ras Sudr (large village) and Wadi Tal (small village) it is clearly seen that the variations are larger, especially variations of the frequency.

The voltage fluctuations are smaller when the voltage is measured at the power station bus bar, but this is mainly due to the small impedance between the generator and measurement point and not necessarily a result of better voltage control. The voltage fluctuations at the customers can very well be equal or even worse although the measurements at the power station in the two villages indicate a small range as compared to the measurements done at the secondary side of the transformers in Hurghada.

The measured load profiles have been used to investigate the impact of different load profiles when executing a feasibility study. The results indicate that load profiles can indeed have a significant impact on the technical and economic performance of a system. However, this will only be the case when the load profile has a low value for a rather long time each day and little or no increase in the load from year to year. For load profiles with less salient extreme values the impact of the load profile on the system performance is not so strong and other parameters are just as much or even more important.

The energy consumption and minimum load of the diesel gensets are also very important parameters in the assessment of systems with a large amount of wind energy, and in most cases they are more important than the load profiles.

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Results of Measurements in Egypt

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Abstract (max. 2000 characters)

The objective of the measurements were to characterise different types of consumer loads in order to be able to construct load patterns to be used in feasibility studies where the available data often will be incomplete, not available or not existing.

Measurements have been carried out at five different sites. Three of the sites were in Hurghada, where the power system is rather large. The last two measurement sites were at village systems: one large system and one with only power ca. five hours per day. The measured load profiles were quite different at the different sites. The power quality at the different sites was adequate even at the small village sites where the load is almost constant.

The impact of different load profiles on the technical and economic performance of a wind diesel system in the feasibility phase was investigated. The results indicate that when the profile has low values for a long time each day the impact on fuel consumption and profit is significant. However, if the load profile is not so extreme the annual development of the energy consumption is more important. Since development of the load is often very rapid at relevant sites, emphasis should be put at determining this feature rather than the load profile.

Descriptors INIS/EDB

DIESEL ENGINES; DISPERSED STORAGE AND GENERATION; EGYPTIAN ARAB REPUBLIC; LOAD ANALYSIS; ON-SITE POWER GENERATION; POWER DEMAND; REMOTE AREAS; RURAL AREAS; WIND POWER

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