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1 Introduction

This document is the EXECUTIVE SUMMARY of the *"Distributed Power Grid Management Based on Space Technologies"* study (ESA contract 20360/06/NL/HE), which has been carried out in year 2007 by :

- **CARLO GAVAZZI SPACE S.p.A.** – Italy – Prime Contractor
- **TERNA S.p.A.** – Italy – Sub Contractor
- **DLR – German Aerospace Center,** with the Instiutes "German Remote Sensing Data Center" and "Institute of Technical Thermodynamics" – Germany – Sub Contractor
- **CRES - Centre for Renewable Energy Sources** – Greece – Sub Contractor
- **RISOE** – National Laboratory – Wind energy Department – Denmark – Sub Contractor

Additional Information on the project can be found at the project website: **www.space4energy.org**

1.1 List of Acronyms

CGS	Carlo Gavazzi Space
CRES	Centre for Renewable Energy Sources
DER	Distributed Energy Resource
DG	Distributed Generation
DLR	German Aerospace Centre
DP	Distributed Power
DPGM	Distributed Power Grid Management
EO	Earth Observation
EMS	Energy Management System
EOMD	Earth Observation Market Development
GIS	Geographical Information system
GNSS	Global Navigation Satellite System
HVDC	High voltage direct current
PV	Photovoltaic
RES	Renewable Energy Sources
RE	Renewable Energy
RISOE	Risø National Laboratory
SCA	Snow Cover Area
SWE	Snow Water Equivalent
SYKE	Finnish Environment Institute
Satcom	Satellite based telecommunications
SoW	Statement of work
TES	Thermal Energy Storage
TLC	Telecommunication
UTC	Universal Time Coordinated

2 Project Overview

The study lasted 1 year (from December 2006 until December 2007) and has been developed along three main axes : WP1 : Review of the state of the art,

WP2 : Simulations and Assessment,

WP3 : Conclusions and Recommendations.

WP4 : Power Grid Manager Review

First of all the state of the art review of the current DPGM with renewable sources (**WP1**) has been analysed.

WP1 started at T0 with six parallel activities :

1. review of current trends of Renewable Energies :
2. review of the Distributed grid architecture and related critical issues;
3. review of forecasting methodologies ;
4. review of NAV-Synchronisation technologies for grid management
5. review of TLC technologies for grid management
6. Available tools for grid management

Considering the focus of the WP 1.3 (Forecasting Methodologies) on the renewable energy electric power generation, this activity has been split according to the team partners related experience on the renewable sources into three parallel sub-activities:

- o Hydro and Wind sources (WP 1.3.1A and WP 1.3.1B)
- o Solar sources (WP 1.3.2)
- o Other sources (WP 1.3.3)

At the end of the WP1 activities , **WP2** (Simulation and Assessment) activities started, focused on simulations experiments aimed to provide a comparative analysis between the results achievable with systems operating with satellite based services (Earth Observation) and systems exclusively ground based; this task has been split into three sequential activities:

WP 2.1: Case study scenarios, datasets & uncertainties. As previously, this activities have been split considering the team partner relevant experiences into three parallel sub-activities where the focus is on Hydro (WP 2.1.1A), Wind (WP 2.1.1B), Solar (WP 2.1.2) and Other sources (WP 2.1.3) renewable sources.

WP 2.2: Simulations experiments, where the two kinds of simulations (WP 2.2.1 for the “large grid” case and WP 2.2.2 for the “small grid” case) have been performed.

WP 2.3: Comparative analysis where the results achieved in the previous activity (WP 2.2) have been analyzed and compared according to the two different system architectures (when possible, with or without satellite services).

The last task (**WP3**), related to the Conclusion and Recommendations, has been performed after the conclusion of WP2.

Considering the strong interaction with the power grid manager TERNA during all the project activities reviews, a dedicated workpackage (**WP4**) has been reserved for this activity that has been carried out during the overall duration of the project.

Roles of the project partners are described in the table below.

CARLO GAVAZZI SPACE SpA	• Project management and Technical coordination • Technologies State of the Art Review for EO applied to Hydro Power • Technologies State of the Art Review for Satellite Navigation applied to grid synchronisation • Technologies State of the Art Review for Satellite Telecommunication applied to grid data flow • Case study scenarios, dataset and uncertainties model for Hydro Power • Comparative analysis of simulation results • Conclusion, Recommendations and Dissemination.
Terna Rete Elettrica Nazionale	• Review of State of the Art analysis performed in WP1 as power grid industrial representative • Review of the project results and of the Final Report as power grid industrial representative • Simulation Experiments Large Grid • Step-by-step support to other partners in State of the Art Review and in Simulations, giving always the user's point of view, tuning user's requirements and validating the proposed approach.
DLR	• Analysis of renewable energy trends in future decades • Technologies State of the Art Review for EO applied to Solar Power • Case study scenarios, dataset and uncertainties model for Solar Power • Contribution to simulation experiments
KAΠE CRES	• Analysis of distributed grid architecture and critical issues • Technologies State of the Art Review for EO applied to "other" renewable sources • Technologies State of the Art Review for grid management available tools • Case study scenarios, dataset and uncertainties model for "other" renewable sources • Simulation Experiments Small Grid
RISØ	• Technologies State of the Art Review for EO applied to Hydro and Wind Power • Case study scenarios, dataset and uncertainties model for Wind Power

3 Synthesis of Results and Recommendations

3.1 Synthesis of Results

3.1.1 Space Technologies Applied to Distributed Power Grid Management with RES

The study has evidenced that the impact of renewable energy sources on the electric grid management is steadily increasing and will continue such trend in the future.

The increase of RES distributed generation will impact, besides on the transmission and distribution grids themselves, also on current technologies for:

- ★ Grid security and protection
- ★ Grid frequency and voltage regulation
- ★ Power fluxes programming

In a few European regions of Europe, like Denmark, the grid management has already been modified to cope with RES (wind energy) introduction, but still it is experiencing instabilities (Nov 2006 black out episode) .

The Future RES scenario in Europe is expressed by the targets established by the European Community:

Targets of Overall energy demand :

- 2010: 12 % RE to overall energy demand in EU-25
  - Current status is 6.3% and the target is likely to be missed
- 2020: Recent EU Council: 20% RE in EU-27.
  - Country and sector targets are to be suggested by the Commission

Targets on Electricity:

- 2010: 22% RE of the electricity demand in EU-25

The main technical problems related to RES (Wind, Sun, Mini Hydro) impact on the grid are the following*:*

- Uncertainty of energy production forecasting
- No control on active power injected in the grid
- Possible inversions of the active power fluxes in the areas with high impact of RES
- No control of Reconnection of wind farms after disconnection at minimum voltage threshold.
- High absorption of reactive power
- Others, like instability in small grids with high RES penetration.
- Remote locations of RES

In such context, use of Satellite technologies is summarised as follows:

- **EARTH OBSERVATION** from space will assist DPGM systems by quantifying available RES in a timely and accurate manner, thus providing geophysical parameters needed for models used in short and medium term forecasting systems.
- **Navigation Systems (**GPS, GALILEO) will allow grid time synchronisation, both for the management of distributed data and for improving the performances of the grid control processes.

- **Satellite Telecommunication** services will provide the suitable communication infrastructures for a global and robust transmission of large amounts of data in the grid, in particular for plants located in remote locations .

The study has remarked that the current status of integration of Satellite technologies in the European grid management can be summarised as follows:

- **Earth Observation Data**
  - ★ Standard Meteorological Forecasting Systems are used as inputs to Wind and Solar Energy Prediction systems and Load forecasting both by electrical energy producers and dispatchers.
  - ★ EO snow cover maps /Wind maps/Solar irradiation maps already used for planning of new installations;
- **Navigation Systems**
  - ★ Already widely used for time synchronisation in the grid.
- **Satellite Telecommunication**
  - ★ standard satcom services provided by commercial telecom operators are used as back-up link in the grid, but not for nominal operations, due to low performances and high cost.

The major drawback of the introduction of RES in the power grid system is their intermittent nature; in order to assess the benefit of space technologies application to the power grid, the project has decided, within the two selected realistic study cases of the Large Grid in Italy (TERNA grid) and the Small Grid in the Greek island of Kythnos, to simulate and quantify, on one side, the effects of the fluctuations of the RES on the power grid stability; and to evaluate the usefulness of EO based forecasting data of RES production, on the other side, in order to provide the grid manager with a tool to plan in advance recovery procedures in case of sudden RES falls.

In the TERNA grid case study, impact of **Hydro** , **Wind** and **Solar** power forecasting had been evaluated.

3.1.1.1 EARTH OBSERVATION APPLIED TO HYDRO POWER FORECASTING

In the case of **Hydro power**, **EO** data have been used as input to a hydrological model in order to provide examples of seasonal forecasting of water availability on a test basin in the Italian Alpine Area. It has been demonstrated that use of EO data instead than only ground data does improve the accuracy of the forecasting. As hydro power can be easily regulated, such hydro power forecasting data are mainly used by the grid manager for seasonal planning, not for daily management of the grid. Examples of already existing EO based services for hydro power forecasting can be found under www.eohydro.com.

3.1.1.2 EARTH OBSERVATION APPLIED TO WIND ENERGY FORECASTING

In the case of **wind energy**, techniques for establishing the actual wind field from space currently exist only for the offshore case. Here, data from Synthetic Aperture Radar (SAR) or scatterometers can be used.

The SAR images have a quite reasonable resolution and accuracy, in the order of 1 km or better spatial resolution, and accurate to about 1.1 m/s wind speed. SAR has the advantage of covering the coastal area at a resolution around 100 m. Examples of near-real-time wind maps are available at http://www.risoe.dk/business_relations/Products_Services/Software/VEA_windmaps.aspx. However, the low frequency of visits of a particular site (e.g., the SAR instrument on Envisat has a return period of 35 days) make them unusable for the day-to-day running of the power system. The disadvantage of SAR is the not so frequent mapping.

Scatterometer has the advantage of rather frequent mapping from both QuikSCAT and ASCAT presently in operation. The disadvantage is the spatial resolution that is relatively low, around 25 km, thus nearshore areas cannot be seen as this area will also be influenced from land features. For ASCAT there is a plan to produce scatterometer wind products near-shore in the future. It is however not yet available. For QuikSCAT a special 12.5 km product is available which has advantages for hurricane mapping and also may approach the coastline further. Yet not up to the coastline as for SAR.

If a constellation of satellite SARs were in operation, e.g. in global mode or wide-swath (wide-scan) mode, it would be highly interesting for wind farm operation. At present however there does not seem to be a plan to increase the number of satellite SAR, only to replace Envisat ASAR within the Sentinel series.

Usually, wind power forecasts for the day ahead are based on Numerical Weather Prediction (NWP).A NWP intrinsically assimilates EO data. This meant for the wind part of the space4energy project was that it was beyond our means to assess the effect of satellite data using NWP test runs without satellite data as a baseline. The effect on the accuracy of the NWP is however high.

Wind Power Production Forecasting systems (WPPS) based on Numerical Weather Prediction models are already working routinely for major wind farms in Europe. In TERNA, a WPPS model is under test in the Sardinia area. NWP models, providing inputs to WPPS systems , are using already a lot of EO data as input, so that the comparison with versus without space technologies is not feasible. The TERNA WPPS system under experimentation in Sardinia use as input data from ECMWF services, already making a lot of use of EO data in input.

The project has provided the grid manager with a description of performances of major WPPS systems in Europe. The study has put in evidence that Wind Energy Prediction Models today can reach a quite good forecast quality with ***60% of all errors being smaller than 5% of installed wind power capacity***. However, in a ***very few selected*** cases the error could reach up to over 40%, and that is due both to a time shift error and a value error of the forecast. Of course , as currently WPPS uses standard meteo forecasts, margin of improvement by improvement of EO data input to NWP or directly to WPPS do exist.

The TERNA grid manager on his turn has performed a set of three simulations to quantify the effects of wind power fluctuations on the grid stability in three cases, located in the south of Italy where there is a major concentration of wind farms:

1. Sardinia Island
2. Sicily Island
3. Isofrequential Italy

The study had the objective to verify, in the case of a sudden loss of wind farms power generation, in some particularly critical cases, the contribution of the primary frequency regulation and the impact on the frequency of the portions of large net analyzed.

Therefore calculations have been executed in conditions of steady state before and after the loss of generated power, without proceeding to the analysis of transitory.

The results of simulations on the TERNA grid show that fluctuations of wind energy production can become critical for the grid operations in the first and second simulation case (very critical hypothesis). In the third case, considering the wind power installed today, the situation isn't critical. In the future, at the increasing of wind power production in south of Italy the fluctuations of wind power can give problems of congestion on power lines.

3.1.1.3 EARTH OBSERVATION APPLIED TO SOLAR ENERGY FORECASTING

Also in the case of **Solar power,** forecasting of global solar irradiance is already routinely done by metereological services (ECMWF) using as input meteorological EO data while direct irradiance forecasting is still missing. Also in this case the comparison with-without space services cannot be done.

Different solar energy forecast services are currently under development. They are mainly based on the ECMWF service, but other complementary and in some cases more efficient EO based method exist. They will be based also on the "real time" assimilation of EO data, like the HELIOSAT method.

In the framework of the project, ECMWF forecasts and "actual" productions retrieved by means of the satellite-based HELIOSAT method have been compared and provided for being used into the power grid simulations, both in case of the TERNA grid (Large Grid) and the Kythnos grid (Small Grid) .

The idea was to select a case, where there's a significant phase shift between the ECMWF forecast of solar radiation and the actual solar irradiance of that day. The 29th of October 2003 has been selected. The forecasted data has been directly taken from the ECMWF model output, the data for the actual day has been calculated with the HELIOSAT method from Meteosat images for a number of sites in Italy: Etna , Oristano , Venice , Ispra, Lampedusa and Lecce.

It has been assumed that a 300 MW PV power plant has been installed close to each of these sites.

The TERNA grid manager's opinion is that solar energy impact is too low (and will remain such in the future) that the benefit of such solar energy forecasting data for the grid management is negligible.
As far as the "Small Grid" of the Greek Island of Kythnos is concerned, the static as well as the dynamic behaviour of the Kythnos' power system under weather disturbances were examined. More analytically, it was assumed that a substantial portion of the produced power comes from PV generators. The tests were divided into two groups. In the first one, the grid operation was examined for 1 hour period as the PV power varied, at constant power consumption. These tests were performed with a relatively small simulation step (<0.1sec) for the investigation of the dynamic phenomena that take place during the disturbance. Especially, the same tests were carried out with three different maximum simulation steps (0.001, 0.01 and 0.1 sec) proving that there was no difference in the monitored quantities. For this reason and in order to reduce the simulation time, the maximum step was finally chosen 0.1 sec. The second group included a simulation period of 24 hours where the consumption, the power contributed by the diesel generators and the photovoltaic systems varied considerably according to realistic data profiles. In this case the maximum simulation step was chosen 1 sec for the same reasons as above. The basic purpose of this group of tests was the introduction of satellite data for the irradiance and the investigation of quantities which vary in larger time scales. For each group of tests some very interesting conclusions have been derived.
In the study it has been evidenced that the implementation of **Earth Observation** is a very attractive solution especially when the stability and the power quality of a power system is considered. However, this implementation has also some additional benefits. In order to become clearer how and why the satellite based observation is advantageous, some further analysis and a comparison with other possible solutions have been quoted.

Alternatively to E.O. some other techniques could be used. Anyone of them has important disadvantages and limitations. Some of them are outlined in the following paragraphs:

- One solution for weather observation would be the use of sensors on the earth's surface but their basic disadvantage is the limited area coverage compared with that of a satellite as well as the complexity and cost.
- Monitoring of the PV produced power is an indirect means of measuring the insolation. Thus, when a rapid reduction in the power of successive units takes place emergency signals can be generated in order to start up a generator. However, this method does not provide information about the possible duration or the extent of the disturbance. In addition, this method does not provide a prior knowledge of the fluctuation but only when it happens.
- Other possible solutions would be the use of larger battery storage units in order to provide the system with a backup source for longer intervals or the continuous operation of backup generators which will operate at low

power levels. It is obvious that though both methods can prevent instability are generally expensive and of low interest.

Summarizing the results and comparing the Earth Observation technique with the alternative ones, we distinct the following advantages:

- The satellite E.O. provides direct information of the kind as well as the possible duration of a forthcoming weather disturbance. Thus, the operator has a clear image of the situation which can affect the final decisions. For example we could cope with a short-term disturbance simply by using a battery system without starting up an additional generator, thus reducing unnecessary startups and associated costs, while in the case of a long-term disturbance the penetration of additional generators is necessary.
- Another advantage of E.O. has to do with the statistical study of data which means that based on meteorological measurements a database could be created. The latter could provide the operator with predictions of the PV production during specific seasons and periods of the year.
- In addition to the operation, the aforementioned statistical analysis can also be implemented for the optimum design of a power system with PV units. In other words the data provide information of irradiance levels from area to area, indicating so what are the most or least appropriate geographical places for exploitation of the solar energy.

3.1.2 SPACE TECHNOLOGIES APPLIED TO POWER GRID MANAGEMENT

Despite the project was focused on the management and on impacts of RES, the discussion and the interest of the power grid manager partner of the project team, TERNA, have gone beyond those specific topics and have encompassed a much more wide view of potential applications, also on account of the list of priorities in the current daily management of the Italian Grid. This change of the project objectives has been accepted and supported by ESA.
While impact of RES to the Italian power grid (with exception of conventional hydro power which anyway can be easily regulated) is still too low, for the time being, for representing an urgent problem in the management, other topics such as grid maintenance, communication links, need of innovative technical solutions in proposals for new grids in remote developing countries, in order to improve competitiveness, have been proposed by TERNA for a further analysis on potential applications of space technologies.
Moreover the discussion with TERNA has lead to the identification of a number of already ongoing internal activities of the company were space technologies are already tentatively used, although with scarce efficiency, awareness and satisfaction of the user, due to the lack of customization and adaptation of the technology or the service to the application. Differently, a correct and efficient exploitation of space by the power grid managers will need a direct link between the space service/technology provider and the user to be established in the future.

Although TERNA management deems important to prepare for facing the impact of RES, which indeed will steadily increase in the future , currently there are more urgent needs.
Moreover TERNA strong interest in the application of satellite technology to the grid is linked to the potential competitive advantage that the use of such technology could bring to the company in the frame of international bids for installations of new grid in remote and developing countries.
In table 4.1.2-1 a summary of the preliminary analysis of overall potential applications of Space Technologies to the management and planning of the GRID is reported.

APPLICATION TO THE GRID	SATELLITE USE		
	EO	**SATCOM**	**NAV**
SHORT TERM PROGRAMMING **(FREQ.: 10 MIN – 1 DAY)**	• 30 MIN FORECASTING OF SOLAR ENERGY • 1 DAY FORECASTING OF WIND ENERGY • SPECIALIZED METEO FORECASTING FOR DAILY LOAD PREDICTION		
MEDIUM-LONG TERM PROGRAMMING **FREQ.: WEEKLY, SEASONAL**	WEEKLY / SEASONAL FORECASTING OF WATER AVAILABILITY IN MOUNTAIN BASINS		
SECURITY **RELIABILITY** **AVAILABILITY** **MAINTENANCE**	MONITORING OF NATURAL HAZARDS (FIRES, FLOODS, LANDSLIDES) SENSIBLE SITES IMAGING FOR SURVEILLANCE	SENSIBLE SITES MONITORING DATA TRANSMISSION	
REAL-TIME CONTROL AND MONITORING	REAL TIME METEO FORECASTING	COMMAND AND MONITORING DATA TRANSMISSION	TIME SYNCRONIZATION OF GRID CONTROL & MONITORING SYSTEMS
PLANNING OF NEW GRID INFRASTRUCTURES	GEOGRAPHICAL INFORMATION SNOW MAPS SOLAR IRRADIATION MAPS WIND MAPS		

Table 4.1.2-1: overview of potential applications of space technologies to the Italian grid, elaborated in collaboration with TERNA SpA.

3.2 RECOMMENDATIONS FOR FOLLOW-ON ACTIVITIES

3.2.1 NAV AND SATCOM

As far as Satellite Navigation for Synchronization Services are concerned, the study has highlighted that GPS systems are already well exploited and integrated in the power grid management systems; this conclusion is agreed by TERNA as well, so that no additional or particular effort to be done in this field is recommended.

On the other hand, the study has evidenced that the integration of Satellite communications technologies to the European grid is generally very low, although there are significant potential advantages with respect to ground based links and TERNA has demonstrated a clear interest for them.
Such interest is based on the following main needs, which are common to grid managers at European level:

- need of connecting distributed grid nodes in ***remote locations***,
- need of ***back up*** solutions to terrestrial networks,
- ***rapid deployment*** for new grid installations (in developing countries without efficient telecom infrastructures) ,
- improve ***availability*** and ***reliability*** of the connections .

The current status on the use of SATCOM in the TERNA power grid is the following:

- Satcom links are used as back up in a few cases, mainly in southern Italy : Sardinia and Puglia.
- Satcom Links are provided by telecom providers such as WIND and VODAFONE.

TERNA current opinion is that SATCOM services are not adequate both in term of performance (due to too long latency periods) and cost.
The main requirements described by TERNA for the SATCOM link are the following.

- Data traffic based on IEC 60870-5-104 Telecontrol protocol
- Data rate : 64Kbyte/sec
- Command Data packet maximum transfer time from Control Center to Plant : **0,5 – 0,8 sec.**

The recommended activity is aimed at a detailed analysis of TERNA user requirements and at the identification of current and medium-term technical solutions based on SATCOM technologies.
The Satellite communication systems, available on the market, need to be better investigated in order to select the more suitable in conjunction with the terminals-pole distribution, traffic data costs (volume and frequency of transmission) and Tx-Rx module costs.
A cost and performance comparison of SATCOM solutions versus conventional solutions used by TERNA must be carried out as well.

Possible combined use of wireless links (ZIGBEE – IEEE 802.15.4 , others) with the SATCOM for the remote monitoring of the lines needs investigations as well.

3.2.2 EO FOR HYDRO ENERGY FORECASTING

Within the study, EO data have been used as input to a hydrological model in order to provide examples of seasonal forecasting of water availability on a test basin in the Italian Alpine Area. It has been shown how use of EO data instead than only ground data does improve the accuracy of the forecasting. As hydro power can be easily regulated, such hydro power forecasting data are mainly used by the grid manager for seasonal planning, not for daily management of the grid. In recent years, snow falls in mountains regions of Europe had been very variable, making hydro power productions to change significantly from one year to another. For this reason, together with the liberalization of the energy market and the advent of energy trading, it seems reasonable that seasonal forecasting of hydro power production will become a valuable information in the future.

The ESA –EOMD EOHYDRO project (www.eohydro.com) has well demonstrated the usefulness of snow cover maps as input for hydrological models in order to forecast hydro power productions in the Alpine Area and in Scandinavia. Several hydro power companies are already experimenting this information in Europe (e.g : Statkraft , BKK and GLB in Norway, ENEL in Italy, Verbund in Austria). Lack of timely and suitable EO data prevent those services from being fully self-sustainable .

Nevertheless further recommended activities are the following:

- Refine and make snow cover maps retrieval from SAR data operational: this is important to cope with frequent cloudiness in mountain areas, in order to have all-weather services.
- Refine and make assimilation of snow cover maps in hydrological models for SWE forecasting operational at least at seasonal time frequency, over almost all productive hydro power basins in Europe.
- Extend current pre-operational snow cover mapping services in remote areas, like South America or Central Asia .

It has to be remarked that currently MODIS sensor is the only suitable source of EO data for this kind of application (and in the wind case there is a very similar case) , so it is highly desirable that:

1) a backup solution (MODIS is going to finish nominal operations in a few years) is found;

2) a sensor best fitting application requirements (e.g. MODIS-like multispectral sensor with higher spatial resolution) is provided

3.2.3 EO for Wind Energy Forecasting

Wind power forecasting is an indispensable tool for a Transmission System Operator (TSO) once the penetration of wind power gets above a quite small level. The wind power forecasts being delivered nowadays are all dependent on NWP input. The NWP input is also widely recognized as being the main source of error for the wind power forecast, therefore improved NWP systems would bring improved wind power forecasts.

There are conceptually two sources of error: the so-called local error or background error, which is essentially stable over the forecasting horizon, and a component rising with rising horizon called the modeling error. The latter is mainly due to non-perfect assumptions on physics and numerics within the model.

The local error can be remedied to some extent by the use of Earth Observation (EO) data. TERNA already has a wind power forecasting system installed, which is based on data from ECMWF, the European Centre for Medium-range Weather Forecasts in Reading, one of the most advanced centres world-wide.

Some additional avenues to improve the NWP predictions could be:

- Actual roughness from TERRA-SAR-X

- Wind fields from cloud motion vectors - MODIS

- Scatterometer data acquisition

- High-frequency, high- resolution SAR data

In the following, we will develop the proposals one by one.

Actual roughness fields

Currently, the state-of-the-art in the calculation of wind fields over terrain often uses the orography (height contours) derived from SRTM data, but the roughness often just comes from a global land use dataset with fixed or season-dependent mappings to actual roughnesses. However, fully polarimetric SAR images allow a fairly direct assessment of the roughness of a particular point of the surface. With the launch of Terra SAR-X this is now possible from space. With the high spatial resolution and the relatively frequent updates of the SAR images, a more up-to-date roughness parameterization (in combination with more accurate topography) can be done. This should improve the wind fields and thereby bring down the local error for particular wind farms.

Wind fields from MODIS cloud motion vectors

MODIS data (MODerate-resolution Imaging Spectroradiometer) has only started to appear in the data acquisition. The high rate of data acquisition and the 3-D view of the atmosphere allows to estimate wind velocities in certain heights by the use of cloud motion vectors.

MODIS wind data acquisition is already implemented at ECMWF and other centres in their operational models, but it could be interesting to see whether the derived winds would improve the prediction when used directly in the wind power prediction model. So far, it has not been used operationally or even tested sufficiently for accuracy.

Scatterometer data acquisition

Scatterometers allow to detect surface winds offshore, and thereby to establish the wind patterns offshore. Especially due to the high frequency of observations, scatterometer data would be a good candidate to be used in the data acquisition process preceding the run of the numerical model. It is the ASCAT and QuikSCAT scatterometers that are used. ASCAT is onboard a European Eumetsat satellite (http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi), QuikSCAT is operated in the US (http://manati.orbit.nesdis.noaa.gov/quikscat/).

Since the wind fields especially for the case of Italy are often advected from the surrounding sea, the scatterometer data acquisition has the potential of improving especially the wind field for the half-a-day ahead forecast. It is already implemented in the ECMWF model providing the meteorological input at TERNA, but, as with the MODIS winds, it has not been used directly as separate input in the short-term forecasting model.

High-frequency, high-resolution SAR data

For the day-to-day management of a power system with a reasonable amount of offshore wind power, having the high-resolution SAR data available twice daily or so would probably be beneficial. The direct assessment of wind speeds in the area of the wind farm could be used for the very short-term prediction of wind power (1-6 hours ahead) using a direct wind field advection algorithm. Additionally, the data would improve the short-term NWP prediction if assimilated correctly. However, one would have to assess whether this could also be achieved with a few measurement towers strategically spaced around the wind farm.

3.2.4 EO for Solar Energy Forecasting

In general solar energy is one of the most promising application fields for the use of EO data in the management of electricity grids, because:

- Solar energy is highly variable in space and in time.
- Solar energy can only be stored for a very short time. This means solar energy has to be harvested where and when it is available.
- Solar energy has very high growth rates. The wind energy example tells us that the demand for management tools grew with increasing installed capacity and wind forecasting is now a standard tool - the same will happen with solar. Additionally, project development for concentrating solar power is highly active e.g. in Spain and the targeted 500 MW may be reached and surpassed within a very short time frame.
- Solar energy is mainly influenced by clouds and aerosols, which can be monitored in real time by meteorological earth observation systems.

Earth observation based on meteorological satellites is ideally suited to monitor the major parameters influencing available solar resources in a very high spatial and temporal resolution. Additionally, there are **upcoming necessities** in solar energy management:

- As shares of solar energy are increasing in countries with feed-in tariffs (e.g. Germany, Spain, Greece), their influence is, as wind energy, appearing as "negative load" in the grid management and has impact on necessary regulatory power. A precise forecast reduces the amount of backup power in network management.
- Systems with storage can be operated more efficient if a solar forecast is known, it can be avoided to run the system at inefficient part load, e.g. by first feeding the storage and running the power system at full load out of the storage.
- Prices at the energy trade systems are already sometimes higher than the feed in tariffs or systems like the Spanish feed-in law offer additional revenues, if the power systems participate in regular scheduling and trading. A solar energy forecast is a necessity to participate in such systems.

Different types of forecast will be needed:

- **Day-ahead forecast**: A forecast for the following day. This will be needed for operations planning of the solar power systems and networks, e.g. to estimate production schedules and amounts.
- **Short term forecast**: A forecast of 0.5 to 2 hours. This will be needed to assess differences to the day-ahead forecast and to optimize operations.

Forecasts will be needed with different outputs.

- For network management the cumulated power output connected to a node or a network area is the most interesting factor.
- Power plant management needs precise information for the power plant's location.

The proposed forecasting system will consist of modules to

- receive the incoming EO-data
- process relevant meteorological parameters, e.g clouds, aerosol optical thickness, water vapour content, and direct and global solar irradiance in real time or as forecasts
- convert the meteorological parameters into energy yields by a system model
- aggregation of several systems to a electricity network node or a sub grid.

3.2.5 EO for Load Forecasting

Another emerging market for the use of Earth Observation is forecasting of the electricity load for electric utilities. Both, scheduling of power plants and the overall grid management need a precise knowledge of the load. Because of liberalised markets a highly accurate load forecast is necessary to achieve good prices in energy spot markets. Besides temperature, irradiance has a major environmental influence on electricity demand.

As load is to be forecasted, also solar irradiance needs to be forecasted. Currently, this is done e.g. using model output statistics on the basis of a numerical weather prediction. Satellite-based irradiance values from the previous day are used as input for this model output statistics besides other parameters.

A service example is the Weather Portal (http://www.meteocontrol.de) operated by Meteocontrol and used by approx. 110 German and international utilities. It includes historical, current and forecasted weather information including solar irradiance.

Further investigations for improvement of EO data as input for Load Forecasting is recommended in the future.

3.2.6 EO for GRID Maintenance & Security

Maintenance of the grid is one of the major concern of TERNA, and more in general for any grid operator. An efficient maintenance of the grid allow to guarantee the security of the electric system, to lower fault probability and lack of the service. TERNA utilizes an operational structure 24 hours active, ready to intervene on the field in less than two hours on the overall Italian territory .

In case of natural hazards, TERNA collaborates with the Civil Protection authorities; hazards such forest fires, floods and landslides can be monitored by Earth Observation form space, and with this respect there are several projects already on-going having the Civil Protection as user.

Maintenance consists mainly in grid fault prevention by a continuous monitoring of the grid infrastructure main elements : pylons, lines, substations and cables. Such monitoring activity is very expensive, requiring on field surveys and lot of man-made inspections.

In principle, Earth Observation from space could offer a powerful automatic tool for the inspection of the grid minimising expensive human intervention.

The personnel of TERNA involved in the project has strongly recommended further investigation and trials in order to verify the usefulness of Earth Observation from satellite-borne instruments for grid maintenance, in the following main areas:

1. Monitoring of the vegetation growing close to the power lines
2. Monitoring of buildings close to the power lines
3. Monitoring of pylon stability
4. Monitoring of thermal anomalies of the grid infrastructure.

4 TERNA main comments on the results of the study

FORECASTING METHODOLOGIES

Considering the increasing of installed wind and photovoltaic solar power, one of the main problem in the management of HV electrical transmission system is the impact on power/frequency regulation. In fact the nature itself of the two sources above named, imply that it can't give a contribution on regulation of energy put in the network in relation to the requested energy. Therefore it is very important to have a very reliable forecasts of the productivity of such plants in terms of power. The study has put in evidence that satellite technologies (Earth Observation) are already used in the field of the weather forecasts but however today the probable errors are less or equal then 50%, also i.e. for wind power forecasts in the short term. This shows that we have wide margins of improvement in terms of errors on wind forecast.

In reference to solar radiation the EO techniques give very good forecast ,today, in the short term; however the study has shown that the trend of installed power of such sources gives a very low impact on grid management today.

In terms of trend of installed wind power, the study has put in evidence that today there is in some areas of the examined network (island) a low criticality in terms of power/frequency regulation.

In the case of the hydroelectric source the study has put in evidence that we have a real margin of improvement in the forecast of snowmelt runoff acting opportunely on the supplied data of forecast from the EO techniques. Moreover the study has demonstrated that, concerning long term forecasts (annual, three-monthly, monthly), the application of EO technology to the estimation of water storage in mountain basins allows wide margins for improvements of accuracy.

SYNCHRONISATION AND TELECOMMUNICATION SATELLITE-BASED SERVICES

The use of satellite communication infrastructures instead of ground based connections (optical fibers, copper or radio bridges) for substations remote control and data flow management, is essentially related to technical and economic convenience, in the sense that at the same service quality, is opted for one or the other connection in function of total costs: investment, operation and maintenance. In some particular cases, where are not available ground based connections is necessary to resort at satellite communications and this happens in particular for substations situates in remote zones not still caught up from ground based connections.

The study has highlighted that GPS systems are already well exploited and integrated in the power grid management system. so that no additional or particular effort to be done in this field is recommended.

CONCLUSION

The very important result of the study is that a series of possible improvement margins on errors of productivity forecast of wind power plants do exist.

The other 'result' is the direct exchange of knowledge among the experts of Earth Observation and the world of utilities. In relation to this result it has been put in evidence that there are other fields in the utilities tasks where the EO technologies can be applied with profitability.

The above considerations are valid in general for typical EHV transmission grids in particular for European transmission grid.