Grid integration of PV systems: could the electric network become the bottleneck?

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***Abstract*-- In late 2008, Spain was forced to slow down on PV promotional incentives, mostly because of speculation on land prices to install PV systems, but also because of potential electric network problems, both at distribution and transmission level: for instance, the Spanish TSO may have, under "favourable weather conditions", to manage a "power noise" of some 3 GW without knowing where the thousands of PV farms are located in the distribution network. In late 2008, Germany changed its regulatory scheme regarding feed-in tariffs that promote PV systems: it was decided to encourage first self-consumption of the produced electricity by the local owners, before re-injecting excess power into the grid. The present paper reviews several issues raised by massive PV integration into electric grids, with insights coming from the recently completed EU-DEEP project: they are described within the expected evolutions of European transmission and distribution networks over the next ten to twenty years. Recommendations for further research and demonstration experiments are presented in order to innovate on grid architecture, grid operations and electricity markets in such a way that PV electricity is integrated seamlessly into electric systems as soon as 2015, while minimizing the costs of this integration.**

***Index Terms* — PV farms, grid integration, market integration, aggregation of PV units**

I. INTRODUCTION

THE present paper addresses the electricity network issues raised by massive network integration of PV units, as encountered in Europe over the past ten years or so. Two European Member States have been deeply involved into grid integration programs of PV systems using feed-in tariffs: Germany and Spain, with a goal to develop a full value chain going from PV cell manufacturing to maintenance of PV farms. Yet, in late 2008, they both changed regulatory rules in order to adjust the previously encouraged "fit and forget" approaches. There were several reasons for such drastic changes.

The cost for society, since attractive feed-in tariffs gave rise to intense speculation from financial players in Spain who took advantage of the long term guaranteed electricity sales to make PV investment a good bargain for their clients. Networks are impacted by the intermittency of renewable energy sources: solar works only at day time whereas wind can blow during night time. Solar electricity is provided during consumption peak hours but also in between with much less needs.

Networks are also impacted by the stochastic nature of meteorological conditions, which or instance means sudden drops of power in-feeds due to clouds passing over a PV farm. Last but not least, voltage transients generated by rapid shut downs of PV panels can lead to voltage overshoots which may damage power systems if not well protected.

First, a summary of the PV growth is presented with examples of issues raised by massive PV generation connections. Next, a summary of network evolutions in Europe is pictured, which must cope not only with PV grid connections but also with other trends including wind generated electricity, electric cars or smart metering. Finally, proposal are presented for future research and demonstration projects which will help PV integration through market mechanisms that value such distributed generation for the involved market players.

II. PV GROWTH IN EUROPE: FACTS AND FIGURES

Germany has been leading a very robust commercial and technical development of PV during the last 10 years, which accounted for 42% of the global installed capacity in 2007 [1] (EPIA / Greenpeace, 2008). PV capacity projections must be examined cautiously since very much dependent upon national regulatory schemes. Spain and Germany have modified the remuneration rules in late 2008 and early 2009 respectively. It is unclear whether the European PV Technology Platform [5] estimates (over 4.5 GW of PV installed power in 2012), or the EPIA's roadmap [2] (cumulative installed on-grid capacity reaching at least 41 GW in 2020) have taken such changes into consideration.

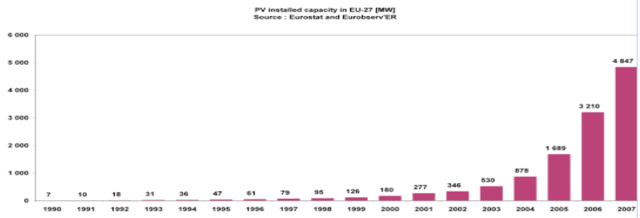

Fig. 1. PV installed capacity in EU27 (MW), Source: EUROSTAT and Eurobserv'er.

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The figure below details the recent evolution in Spain of PV units connected to the network [3].

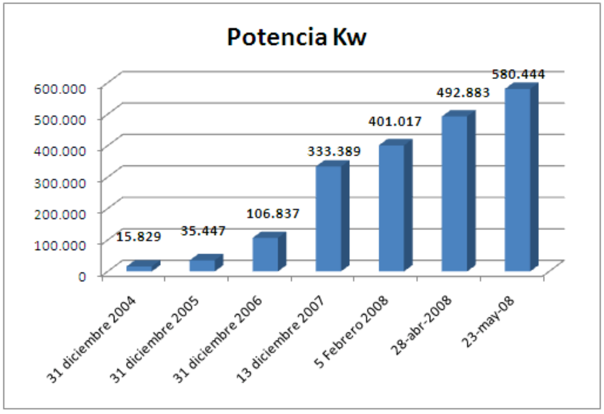

Fig. 2. Evolution of connected PV in Spain (kW), source: Iberdrola Distribucion.

To-day, PV units impact mainly the medium and low voltage distribution networks, with the following issues:

- Voltage regulation at transformer level
- Frequency and voltage perturbations
- Fast voltage changes (flicker)
- Harmonics
- Changes in power flows
- Administrative costs of feed-in tariffs.

This last impact is mainly related to the number of invoices needed to implement the feed in tariffs properly. The Figure below illustrates the growth of this administrative load for a Spanish distribution operator.

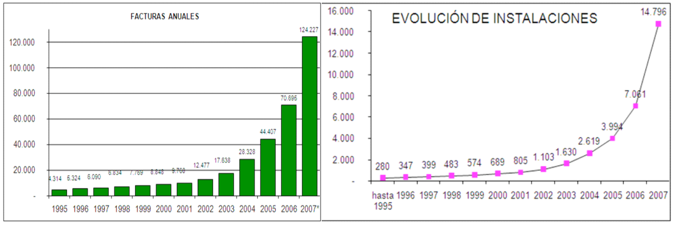

Fig. 3. Evolution of administrative load for a DSO, Source: Iberdrola Distribucion.

The second issue deals with the voltage regulation and voltage/power wave quality of PV units.

The diagram below shows real life measurements of active and reactive power generated by a PV farm located within the Iberdrola Distribucion network in Spain on May 2008, over a sunny day.

Power flow changes can be observed with parent variation in voltages and intensity. Significant changes over short periods of time can be observed with the related impacts at customer's site. Such changes have direct consequences on the ways and means that Distribution Operators must implement to guarantee voltage levels and the related protection schemes dealing with over voltages, independently from power flow directions.

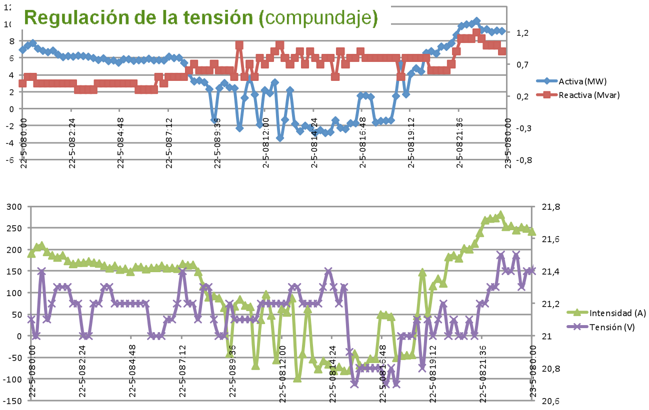

Fig. 4. Real life measurements of active and reactive power generated by a PV farm in Spain, source: Iberdrola Distribucion.

The figure below illustrates the differences obtained from a cloudy and a full sunny day.

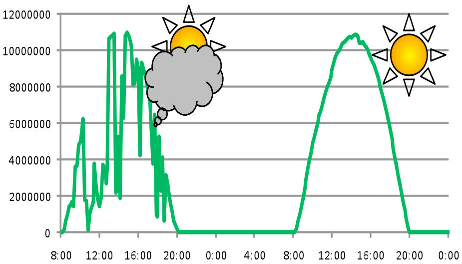

Fig. 5. Typical daily profiles according to solar activity (units) source: Iberdrola Distribucion.

Voltage variations can be handled by voltage regulation schemes at substation level. Yet, when PV farms are located in weak residential and rural grids with high series resistance [4], stochastic solar radiation becomes one of the main drawbacks of the large-scale use of photovoltaic units in distribution networks. Moving clouds produce fast and short irradiance fluctuations, which in turn leads to voltage or power fluctuations in power networks. Voltage flicker is then observed which depends upon the amplitude of the voltage fluctuation, their frequency, and the shape of the waveform.

The last issue deals with recently observed voltage overshoots when PV panels are suddenly disconnected from the network. The Figure below illustrates measurements made in the field and the corresponding over voltages which can be damaging for the connected loads.

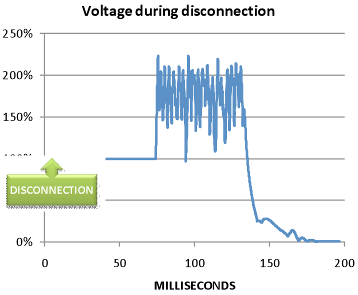

Fig. 6. Measured overvoltage due to disconnection, source: Iberdrola Distribucion.

Such over voltages are due to the response of inverters, the piece of equipment which transforms DC power into AC power for use by customers of electricity networks. It will require further optimization of inverters to avoid such damaging situations.

III. FUTURE EUROPEAN NETWORK FEATURES: WHAT WILL CHANGE?

In the next twenty years, grid operators will have to invest both in RD&D and innovative assets to be ready for the simultaneous integration of Distributed Energy Resources and active demand into the pan-European electricity system. At the same time, DER manufacturers and DER-based power producers and retailers will have to meet technological and market constraints to comply with network security.

As seen above, the massive connection of Distributed Energy Resources[4] based on solar energy sources to the existing electric system will impact this electric system as a whole, including the performances of transmission and distribution networks. Yet, the basics of power system design and operations remain valid to account for more and more network-integrated DER units. The cornerstones of the resulting network re-engineering will be similar to the ones which prevailed in designing to-day's electric system: preventive security margins and voltage/frequency controls in order to ensure robustness against a predefined list of contingencies[5]. The structure of existing control systems will be further extended, taking into account the benefits of smart metering.

A. Reminder

First and foremost, one must recall that transmission[6] and distribution networks are not organized in a similar fashion in the EU 27. Two types of organizations prevail. In the first one, TSO activities are limited to the upper layer of the system, which is made of one layer, like in England and Wales with 380 kV or 275 kV or two layers, like in Germany with the 380 kV and the 220 kV networks; the rest of the network is considered as distribution. In such systems, distribution is made of at least 3 layers ("thick" distribution): high, medium and low voltages. In the second type of organization, distribution is only made of medium and low voltage networks ("thin" distribution), all other networks from high voltage up to ultra-high voltages being operated by the TSO. Such facts do make life easier when designing demonstration experiments since scalability and replicability is not right away guaranteed because of such a grid disparity.

B. Future network evolutions in Europe

Distribution networks are typically radial, passive networks. These networks will evolve toward more active networks (i.e. allowing for more and more distributed energy resources and controllable loads): thus, distribution networks will be managed in a way similar to the one used by transmission networks today.

By 2030, with the help of new generation and ITC technologies, innovative planning approaches, advanced architectures and power control units, distribution networks should be able to manage load balancing (with the help of DER units), to control voltage and power flows, to provide ancillary services to the global system and islanding capabilities, and to control the loads to circumvent the danger of peak conditions.

Thus, the current activities and businesses of the TSO will be progressively impacted since the difference between distribution and transmission networks could progressively vanish. This evolution is pictured in the diagram below [6], where it is implicitly assumed that smart metering has been rolled out in Europe by 2020, which sets the beginning of the "SmartGrid Era". Services will develop from "aggregated DER" to "integrated DER" as the SmartGrid environment develops. Services for TSO and DSO deal with control "C", emergency control "E.C.", congestion management "C.M" like implicit services such as those implemedted via PowerMatcher, or dealing with "N-1" conditions, DR during restoration phase

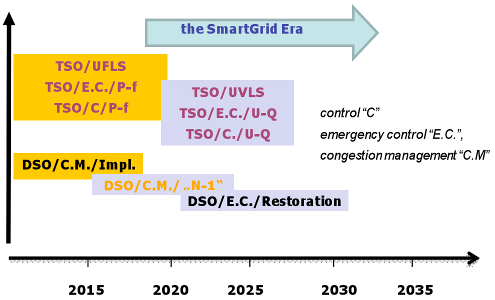

Fig. 6. Roadmap towards a SmartGrid Era, source: EU-DEEP

IV. INTEGRATING PV: THE TSO POINT OF VIEW

Transmission System Operators (TSOs) are required to maintain a continuous balance between generation and consumption. Thus, they need sufficient control capacities, which need to be adapted from conventional generators to PV units as an increased PV network penetration is observed. Beyond penetration levels covering a substantial amount of the demand, PV units will have to be fully integrated into system security management, participating in system control and in provision of reserves in a way similar to large conventional power stations.

Moreover, TSOs are responsible for system security: they need to consider the impact of PV units onto the system, especially during possible critical events. In addition to information about demand and its evolution, TSO will have to collect information about the amount of "on-line" DER units, including PV and other distributed generation units: this requires in turn estimating power injections at the boundaries between the TSO and DSO grids, since indeed, DSO will move from a distribution grid that is passive (i.e. only consuming) to a distribution grid that is active (i.e. injecting power into the DSO grid). The actual monitoring of the net injection will not be sufficient to ensure system security: TSOs will need to get information about real time power generation. Another critical point for system security

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[4] DER in this paper means Distributed Generation (DG), the possible storage of electricity and/or thermal energy, and/or flexible loads: DER units are usually connected to the transmission network (large wind or PV farms, CSP units, large biomass firing plants) or to the distribution network (PV panels, small wind turbines, micro CHP, …).

[5] Created initially for rotating generators, design and operational practices remain compatible with both generation using power electronic interfaces and demand response.

[6] With full observability of the connected units and real time control.

is the resilience of DER to contingencies. Above a certain penetration level, DER should be able to withstand contingencies similarly to centralized production units.

A. PV farms connected at TSO level

Recent experimental work performed at distribution level[7] has shown that flexible loads and intermittent generation can be aggregated to provide system services, thus increasing the energy market value of renewables within the electricity system. The approach must be validated when extended to transmission connected generation assets. Two complementary routes can be followed like in DSO connected DER units:

- Aggregation of PV farms to provide system services
- Aggregation of PV and controlable loads to reduce imbalance costs

For the first route, development and demonstrations must address the capability of aggregated solar farms to provide system operation services.

- How to set the operating point of a single PV farm in order to be able to control the reactive power provided/consumed for an aggregation of PV farms, according to the voltage control algorithms of the TSO at EMS level?
- How to set the operating point of a single PV farm in order to be able to increase or to decrease the total active power output of an aggregation of PV farms, while providing secondary frequency control, and considering the technical and economical performance of the PV farms too?
- What is the dynamic response of the aggregated PV farms, including their ability to fulfill the UCTE response requirements (described in the *"UCTE Operation Handbook"*)?

For the second route, TSO and end users are challenged by solar resources from a system security and from an economical perspective. With increasing PV (and wind!) gradients, the necessary reserves to maintain system stability will increase. This causes a need for high system margins on power reserves and standby production. With higher margins on reserves, the PV (and wind!) integration has increased costs for balancing services which ultimately means increased costs for security and also for the end-users. Increasing PV gradients causes unexpected imbalances in production which may lead to loss of earnings for the PV farm operator.

Large scale PV integration can be performed through an optimization across the value chain - from the power generation at the off- and on-shore wind farms, to regulating the central power production and the mobilization and management of distributed generators and consumptions units (hereafter referred to as 'local assets') including the transmission system operator network and operation. PV power can be balanced effectively and cost efficiently using a co-optimized management of central production, distributed energy resources integrated into existing markets, and contributing to the demand side management.

B. PV units connected at Distribution level

Small size single DER units such as PV panels cannot directly interact with electricity markets and the TSO. PV aggregation is a provisional interface between dispersed resources and the TSO, which somehow prefigure future, more integrated SmartGrid solutions. Aggregators are service providers that can provide balancing power and power-frequency control as an alternative to large centralized power plants, thus increasing the competitiveness of reserve markets. Yet, a proper integration of PV units in the system can only be ensured when information necessary for guaranteeing system security is made available. Aggregation will thus make PV more visible to TSOs (hopefully at acceptable costs), helping TSOs in managing system balancing and improving the coordination of defense schemes in the DSO and TSO grids.

1) Low voltage ride-through performance of small PV units

The September 2003 and November 2006 incidents in Europe demonstrated empirically that, in case of contingencies beyond the "secured event" (standard assumed loss of 3000 MW, which is the total amount of PV connected to the Spanish distribution network), it is mandatory that generation of whichever type remains connected to the system to avoid further deterioration of the system's state. For normal operations, system frequency remains near its nominal setting (within a range of about ± 200 mHz around 50 Hz for the UCTE system). During a "secured event", the frequency can transiently decrease down to 49.25 Hz, and even to 47.5 Hz, within a sub-network. In addition, a high proportion of DER means a reduced number of large generators on-line, which reduces short-circuit power leading to higher system voltage sensitivity during transient conditions. Faults in the transmission network will lead to deeper and geographically more wide-spread dips in voltage. DER must therefore present sufficient robustness and low voltage ride-through capability, thus at least facing normally cleared faults in the transmission network.

2) Towards local load shedding?

Load shedding schemes are generally implemented in HV – MV substations by tripping MV feeders. When a high penetration of small PV units is observed, this practice is no longer optimal, since feeder tripping leads also to the disconnection of PV units. In the future, more adequate selection schemes of feeders will be implemented leading to new load shedding schemes, together with emergency demand response embedded within the smart system–customer interface (i.e. the future smart meter).

3) Further high priority areas of improvements before 2020

Two areas of further work must be addressed at a European level:

(i) The new services induced by aggregation operators will interact with increasing shared resources between control zones: studies on cross-border balancing must be undertaken through research and development projects staring by 2013-1014.

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[7] Through EU funded Project such as EU-DEEP, FENIX, ADDRESS,

(ii) The reconciliation between commercial and security demand response must be addressed, based on the new services brought by aggregation: attention is to be paid with decision making by the main stakeholders under unsecure event conditions, under the coordination of regulatory bodies.

V. INTEGRATING PV: THE DSO POINT OF VIEW

Design and operation of existing transmission and distribution networks, together with the associated regulatory and market rules, were decided on the basis of a centralized system, thus leading to unidirectional power flows in the distribution network. Given the fast developments of PV, the assumptions made when designing the system do not hold true as shown above. Due to the technical and economic changes induced by PV and its location in the electricity supply chain, PV integration sets new challenges to network players. DSOs are on the frontline of the small power DER integration process: moreover, the advent of smart metering will allow changing network management rules in favor of DER integration since allowing a more adequate monitoring of power flows.

A. Managing voltage profiles

Voltage issues are the main technical concern for network operators when increasing PV penetration. Loads cause the voltage to drop along feeders: thus the voltage set point is traditionally adjusted near its upper limit, since this reduces system losses. In the presence of local generation, the voltage profiles can increase and decrease along the various feeders depending on load and generation.

1) The "fit and forget" principle

Distribution networks have margins which are sufficient to operate satisfactorily in the presence of a significant amount of PV. Sometimes this requires downwards adjustment of the voltage set point but without the need for abandoning the traditional "fit and forget" approach. Pushing the "fit & forget" principle assumes sufficient homogeneity between feeders and regularity in terms of behavior of the load and generation.

2) Active network management

Sufficient voltage margin are sometimes lacking allowing for a fixed voltage set point that gives acceptable voltage at all points and at any time in the low voltage branches of the network. This is where dynamically changing the voltage control settings in the HV-MV substation becomes an appropriate solution, where it is assumed that load shapes of the different feeders exhibit similar voltage features. This is active network management where occasional generation curtailment can further increase the acceptable PV penetration ratio: future system-customer interface integrated into smart metering will facilitate such curtailment.

3) New design criteria for distribution network

New working margins are needed for distribution networks, which will avoid curtailment decisions in the future. Thus, new design criteria are needed involving exogenous clear objectives and constraints for PV penetration and allowing to adjust the design of the system for making active management possible. Voltage control issues that cannot be solved using active management most often result from the existence of non-homogeneous feeders (different proportion of load and PV - and other DER generation units) along the different feeders' see www.eudeep.com), the non-coincidence of load and generation, as well as a lack of physical space for implementing additional voltage control device on feeders. "Flexible - symmetrical" design that equally shares the voltage ranges between generation and consumption have been proposed for testing by the EU-DEEP project.

B. Implementing more efficient "Use of System" tariffs

Present "Use of System" tariffs for distribution networks are not cost reflective: they are unable to value PV and/or flexible loads based on their footprint on the network infrastructure. Today, incentives are given to investors for installing distributed generation, when connected behind the meter and using a net tariff. This does not necessarily reflect the benefits that these PV units bring to the DSO, e.g. reduced losses, since this reveals correct if the consumption and production coincide at exactly the same time. Consumption and production should be considered separately in order to value the impacts that load and generation have on the distribution network. Such implementation requires large-scale deployment of smart interval metering with automatic meter reading and ex-post data processing.

C. System services at DSO level delivered by PV units?

In the future, MV and LV distribution networks will probably lose their present unconditional adequacy. Future services could be delivered by DER in MV and LV distribution networks. They deal with contribution to voltage control, reactive power compensation, and possibly power flow management.

For critical conditions, like for instance voltage control in "N-1" situations of a reconfigured radial operated network, the "service" will often correspond to generation curtailment. More generally, the implementation of protection schemes is dominated by the short circuit current supplied by the HV network. Small size DER units installed at the low voltage level generally do not supply short-circuit current. Hence, they cannot disturb protection operations as long as the network area is connected to HV network. Detailed attention must be paid with the protection of distribution network against islanded operations.

D. DER connection requirements

Connection standards[8] as covered by EN 50438, or similar solutions in the U.S.A. with IEEE 1547, show commonalities. Yet, connection procedures are still too heterogeneous across Europe. For instance, the 'inform and fit' procedure is only allowed in half of the EU member states. IEC TC 8 has to find quick and common choices to show the way to DSO for easier PV integration, according to the PV capacity, with simpler procedures for small power. The new European power quality standard EN 50160 should take into account a wider penetration of DER units.

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[8] Standardization processes need to be performed in a coordinated way at international level. It is recommended that work be concentrated at international level via IEC and at European level via CENELEC (and where appropriate CEN). IEC TC 57 takes a central role in providing standards for a Smart Grid environment. Furthermore, IEC decided to establish a Strategic Group on Smart Grid, which is supposed to coordinate the standardization work between the committees and parties involved, such as TC 8, TC 13, TC 57, and TC 88.

E. Regulatory harmonization at EU level

DER can be both a complement and a substitute to network services. Future regulatory frameworks will have to account for such a feature in Europe:

- DER investments that lead to deferred network investments may be promoted adequately by DSOs provided that their regulatory regime is based on total expenditure for a gross load output, not on mark-ups on grid investments. As the substitution is highly location and time dependent, DSO participation is vital for full welfare effects.
- A similar approach should be envisaged for wind farms at TSO level
- DER investments may provide value-added services to the network. Optimal regulation should introduce incentives for joint investments from DER investors and network operators to maximize the DER impacts. Traditional models for DSOs using delegation or contingent investments perform poorly, whereas coordinated direct mechanisms give better results in terms of investment level and benefits. New models involving both TSO and DSO must be studied.

Yet, so far, regulators have implemented a wide scope of different rules covering their interactions with TSOs and DSOs, The resulting impact is higher regulatory risk that lowers investment incentives, impedes economies of scale in DER deployment, and increases operating costs for TSOs and DSOs. DER penetration can be further promoted at lower social costs and higher efficiency, provided that the DER-TSO-DSO regulations converge on a common set of rules and clarify what are the drivers for future network investments.

VI. INTEGRATING PV INTO EUROPEAN NETWORKS: FUTURE RESEARCH AND DEMONSTRATION NEEDS

Whatever the DER at stake, integration studies must be performed in the years to come to answer the following questions:

- What can the network bring to facilitate the use of such novel technologies (Solar, Wind, Efficient Buildings and Green Cars)?
- What can novel generation technologies bring to the network?
- What are the planning/operation/architecture features of the future networks that will secure further integration of such novel technologies?
- What are the interoperability and common standards for communication and information exchanges needed to ensure a proper network control?

There are several issues which will deserve studies at EU level, either because of standards needs or because of reduced development costs and regulatory approaches needed to favor market integration of PV technologies, in line with other competing renewable solutions.

A. Grid connection and power supply

1) Development of power electronics and grid control strategies to improve the quality of grid electricity at high PV penetrations:

- New load management and dispatching systems,
- distributed energy resource management systems,
- PV support for ancillary services,
- Improved power electronic equipment to improve the impact on the grid,
- Optimized grid operation in areas with high PV penetration.

2) New concepts for stability and control of electrical grids at high PV penetrations:

- Solutions for observability and control of PV generation, including the impact of large PV farms, and the associated large scale experiments which allow studying the behaviour of a mix of renewable sources
- control system requirements and applications developments,
- design control mechanisms to improve the network safety aspects.

3) Management of islanded micro grids with high share of PV capacity

- Virtual power plants
- Aggregation of PV units and farms
- Micro grids.

B. Power conditioning

1) *PV supplying energy not as a « current source »* (thus feeding only perfectly balance loads] but also as a « voltage source », helping harmonics and unbalanced loads

2) Smart inverters with improved transient behavior.

C. Large scale PV integration

- Grid control and ICT infrastructure for the high penetration of PV systems
- Assessment of the value of PV systems integrated in power markets, including peak demand and ancillary services
- Grid planning and simulations of European-wide future power generation systems involving large-scale renewable energy sources
- Cost/ benefits analysis at network level of large amounts of PV
- Market-based approaches for PV integration such as time-of-use and real-time pricing
- Load shifting, distributed energy storage, electrical or plug-in hybrid vehicles

D. Codes, standards and regulatory issues

- Harmonized solution for grid connections in Europe
- Upgraded grid codes to account for large amounts of PV, wind, etc…
- Recommendations for regulatory harmonization at EU level.

VII. CONCLUSIONS

The present paper reviews several issues raised by massive PV integration into electric grids, with insights coming from the recently completed EU-DEEP project and measurements performed in Spain: they are positioned within the perspective of the expected evolutions of European transmission and distribution networks over the next ten to twenty years. Recommendations for further research and demonstration experiments are presented: they aim at innovating on grid architecture, grid operations and electricity markets in such a way that PV electricity is integrated seamlessly into electric systems as soon as 2015, while minimizing the costs of this integration. Overall, the "fit and forget" principle will progressively vanish away and be replaced by more "active grid management". Several integration options are then available based for instance on PV aggregation services which will require regulatory frameworks to make them optimal for the European electricity consumer.

VIII. ABBREVIATIONS AND ACRONYMS

DER	Distributed Energy Resource
DG	Distributed Generation
DR	Demand Response
CHP	Combined Heat and Power
DSO	Distribution System Operator
TSO	Transmission System Operator
HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
ITC	Information and Communication Technologies
kV	kilo Volts
E.C.	Emergency Control
C	Control
PV:	photovoltaic

IX. REFERENCES

Technical Reports:

[1] European PV Industry Association – Greenpeace, Solar Generation PV, 2008.

[2] European PV Industry Association, EPIA Roadmap, 2004. Available:http://www2.epia.org/documents/Roadmap_EPIA.pdf

[3] Juan Antonio Sánchez Ceballos, Iberdrola Distribucion, "Generacion Distribuida: Impacto en la Distribucion", 2008

[4] Ricardo Albarracín, Hortensia Amarís, Universidad Carlos III de Madrid "Power Quality in distribution power networks with photovoltaic energy sources". Madrid. Spain, 2009.

Papers Presented at Conferences

[5] Perezagua, E. (2008). Welcome Presentation at the 3rd General Assembly Ljubljana, 2008: www.eupvplatform.org/fileadmin/Documents/GA2008/PPT/AG_2008_1_1_Perezagua.pdf

Books:

[6] EU-DEEP results, page 58, 2009. See www.eudeep.com

X. BIOGRAPHIES

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Serge Galant, CEO of Technofi, Aeronautical Engineer from ENSMA (1971) and Ph. D. in Mechanical Engineering from the Massachusetts Institute of Technology, USA (1975), joined Bertin (France) in 1976. From 1992 to 1998, he was Director of new business development at Bertin. In 1998, he joined Technofi as a Vice President for Business Development in the private sector. Since 2001, he is CEO and main shareholder of Technofi.