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A new energetic scenario with renewable energy

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Abstract

The article presents a summary of the new energy scenario, based on distributed generation and on the integration into the electricity networks of the generators of small and medium power. They are based on clean technologies and renewable energy, including cogeneration, micro-generation with renewables (non-fossil energy sources, such as wind, solar, geothermal, tidal, hydroelectric, biomass), energy storage systems, energy efficiency techniques, and flexibility and demand responsibility techniques.

The perspective shows a new system, where thousands or millions of users are their own generators, becoming producers and consumers of electricity. All these generators will be interconnected through an electricity network totally interactive and intelligent. For this new environment a sophisticated control and communications technologies are required to ensure the correct operation of the electricity networks, the creation of new models of power distribution, and advanced technology development of energy storage, power electronics and superconductor devices.

The main technology that can lead to this new revolution, equivalent to the technology of silicon, which is revolutionizing the conventional limits of electricity and electronics, is nanotechnology, as well as its applications in the development of new nanostructured materials. The new energy systems will present smaller scale, will be easier to build and dismantle, decentralized, renewable, with localized and decentralized energy production.

Key words

Renewable energy, Distributed Energy Resources, Energy Storage Systems, Smart grid

1. Introduction

All around the world, there is increasing use of renewable energy sources and more efficient use of energy. This is motivated by the goal of reducing the Green-House Gases (GHG) emissions and the increase of fuel prices that drives up the prices of energy. Behind the will to reduce GHG, a large number of countries have ratified the Kyoto protocol, which has been transposed into national laws and energy policies. At the same time the role of electricity as an energy carrier is increasing and the process of authorizing, locating and constructing new transmission lines and large central power plants has become extremely difficult, expensive an time consuming.

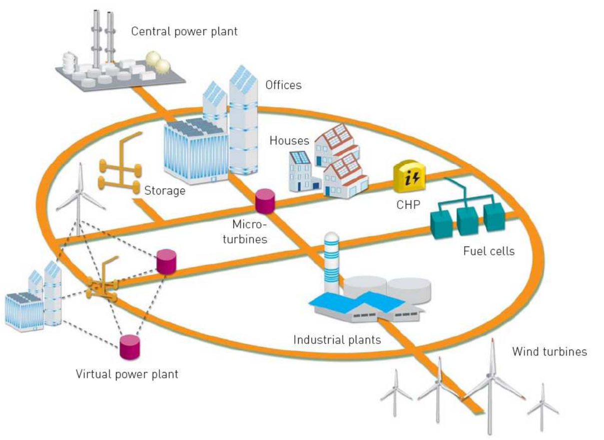

Figure 1. Future Operation of system will be shared between central and distributed generators

In view of this background the tendency of energy policies goes in the direction of increasing energy efficiency, distributed generation (DG) and renewable energy resources (RES), such as: microturbines, fuel cells, wind power systems, small hydroelectric power stations, gas or diesel combined heat and power plants (CHP), solar photovoltaics, hybrid-minigrids systems, and energy storage systems.

The new energetic scenario with renewable energy faces up the challenge of how to achieve a better integration of flexible demand (demand response and demand side management) with distributed generation, energy storages and smart grids, in order to reduce significantly the costs of integrating renewable sources into the networks.

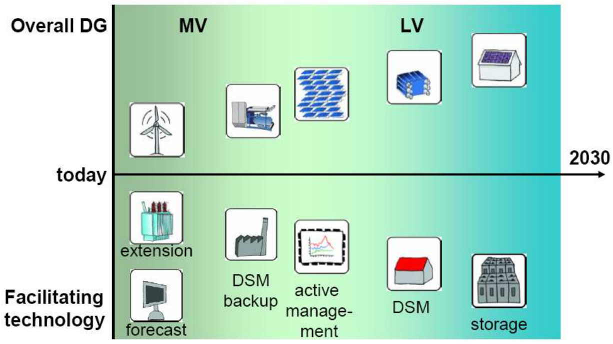

Figure 2. Timeline of DG and its technical impact

In the future system a proportion of the electricity generated by large conventional plants will be displaced by distributed generation, renewable energy sources, demand response, demand side management and energy storage. Several models for the future electricity system recognise the fundamental fact that with increased levels of distributed generation and active demand-side penetration, the distribution network can no longer act as a passive appendage to the transmission network.

The entire system has to be designed and operated as an integrated unit. In addition, this more complex operation must be undertaken by a system where ownership, decision-making and operation are also dispersed. In this model, Distributed Energy Resources (DER) provide a significant proportion of power generation. Power can even flow from DER into the distribution network and from distribution to transmission networks. The intelligent FACTS at the nodes between producers and consumers would 'route' power between the nodes in the same way as e-mail is routed from node to node in the Internet.

In the area of equipment enabling the integration of small-scale energy systems, progress in emerging technologies should facilitate a remote control of the flows of electricity, ensuring the quality of the system in all its aspects (quality of supply and waveform quality), and giving security and independence to the systems. Under this premise, the implementation of Custom Power devices in distribution networks of medium and low voltage is considered, adapted to the most demanding requirements of network sensitive to disturbances, which ensure high quality provision and coordination among devices, and integrate without many problems this new energy system

This new approach of the energy systems is opening new opportunities for consumers, energy suppliers, and energy generators. The possible combinations allow a wide range of consumers (including homes) to install plants that satisfy their needs of heating, cooling, and electricity in most cases (if not all of them).

2. New axes of development for the greater penetration of DER

The key to the integration of these higher levels of variability and uncertainty are to increase the system operational flexibility and diversity, fuel and technology diversity, with more sophisticated analytics, faster response times and reaction capabilities. Improving grid flexibility requires more dispatchable power plants with wide operating ranges and fast-ramping generation for balancing variations in load, intermittent resources and contingencies such as the loss of transmission or generation assets, but also much greater use of power electronics, energy storage, automation, and managing customer loads and demand-side resources to balance supply side resources.

In order to reduce the problems that began to emerge due to the massive integration of distributed generation in the electrical system, it is necessary to develop and implement the following areas of knowledge.

- Demand response (DR): To use flexibility in electricity consumption.
- Information and communication technologies (ICT).
- Add energy storages into the systems (centralised or distributed energy storages DS)
- Power Electronics controllers

A. Demand response (DR)

Demand response (DR) or Demand Side Response (DSR) is programs and activities designed to encourage consumers to change their electricity usage patterns, including timing and level of electricity demand, covering all load shape and customer objectives. DR includes time-off use and dynamic rates or pricing, reliability programs such as direct load control of devices and instantaneous interruptible load, and other market options for demand changes (like demand side bidding). This means that given both the ability to easily manage their electricity use and information about its value, they can be willing to change that usage. Some part of their consumption can be shifted in time or simply suppressed.

The most common DR scheme is the time of use tariff (ToU) or the real-time pricing. These are schemes where consumers see different electricity price according to the time of the day. In ToU tariffs, the price vary only between a few values (typically day or night for example) while in real-time pricing, the price is linked to the spot market trade

B. *Information and communication technologies (ICT)*

In today's electricity networks, information and communication technologies (ICT, include communication, monitoring, metering, automation and intelligence questions related to the DER integration) is, and will be to an even greater extent, a key tool for the operation of the electricity networks, for both technical and administrative purposes. New features added by ICT and ICT-based applications as universal connectivity, services over internet and web, distributed intelligence, advanced fault handling, intelligent load shedding etc will transform the existing electrical grid into a smart one.

The integration of ICT into the centralised grid transforms it into a fully interactive intelligent network. Sensors and intelligent agents embedded in the grid provide instantaneous information on energy conditions throughout the system, allowing current to flow exactly where and when it is needed and at the cheapest cost. An agreed protocol for exchange of information about power demand and supply could make it possible to distribute control of the electricity distribution system to a much smaller scale. Each node would 'listen' to the rest of the network, adjusting its power production or consumption in relation to the global state of the electricity network. This information and control layer would extend into the home, where systems already exist that can adjust domestic consumption to 'shed load' at times of network 'stress'.

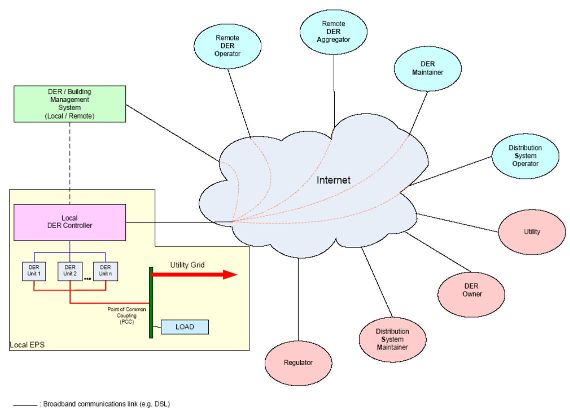

Figure 3. Example on the Communications System Architecture for DER

Public communication networks exist and are operational. Most of the pilots conducted nowadays utilize public TCP/IP networks, such as the public or private Internet in order to transmit information. Some other technologies, such as radio or cell phone communications are also possible in areas where the Internet access is not possible or too expensive to install, although a convergence of Internet technology currently is taking place in which the communication medium is transparent.

Internet is the undisputable choice for a public TCP/IP network, as it is the biggest virtual network in the world and is accessible to everybody independently of its platform. The main advantages of the Internet are:

- Interoperability, as it is based on the standard TCP/IP protocol suite.
- Availability of cheap hardware and software devices with TCP/IP functionality incorporated.

C. *Energy Storages Systems*

Energy storage technologies are valuable for reducing pricing volatility, protecting against power quality problems, and supporting intermittent RES on the grid. The storage systems are capable of smoothing out load fluctuations as well as to react to fast transient power quality (Fig. 4). This way they can contribute to efficient energy management policies and faster economic investments in new projects

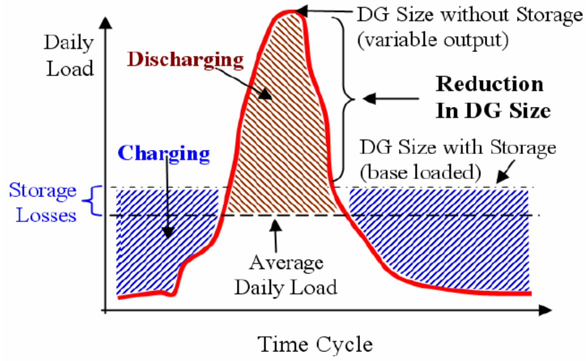

Figure 4. Impact of energy storage on DG rating.

The energy storage technologies can enhance DG in different ways:

- ✓ Stabilizes and permits DG to run at a constant and stable output
- ✓ Provides energy to ride-through instantaneous lacks of primary energy
- ✓ Permits DG to operate as a dispatchable unit
- ✓ Enhancement of DG penetration by reducing its required size
- ✓ Improving asset management and extending useful equipment life by reducing the peak loads at all system levels,
- ✓ Reducing equipment cost by lowering required power ratings (lowered peaks)
- ✓ An opportunity to offer energy arbitrage in deregulated environments
- ✓ Provide voltage and frequency regulation benefits.
- ✓ In the short-term,
  - Deferring upgrade capital by reduction of load peaks,
  - Improving service reliability where conventional solutions might not be readily available or would take several years to implement,
  - Allowing more time for service restoration during scheduled or accidental power interruptions due to the ability to provide interim power to customers.

A wide variety of technologies are being studied for various applications of different storage capacity and duration (Fig. 5). The technologies include batteries of various types (conventional lead acid, Gel and AGM lead, NiMH and lithium-ion and lithium polymer), super capacitors, reversible fuel cells and redox batteries, super conducting magnetic energy systems (SMES), flywheels, thermal storage and compressed air storage.

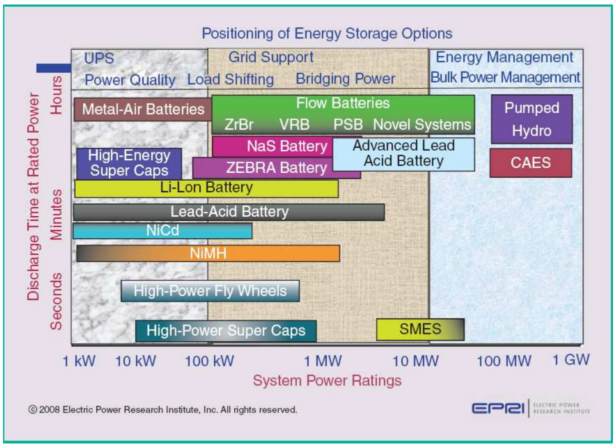

Figure 5. Types and applications of energy storages

The applications of electricity storages can be defined on the basis of different parameters like storing or discharging time and capacity of storages.

High-power applications. Very short-term applications (less than one second) are related to power quality, reliability and security of power systems. Capacitors, flywheels, superconducting magnetic energy storage (SMES) etc.

High-energy needs. The applications from minutes to hours can relate to the support of distributed energy generation or load variations but also to needs for uninterruptible power supply or energy management needs of consumers or power suppliers. Depending on applications in power systems, the capacities of storages can vary from less than 1 kW to 1 GW. Pumped hydro, CAES and SMES are large with capacities from tens of MWs up to hundreds MWs compared to capacitors, different types of batteries and fly wheels, which range from 10 MW down to several kWs.

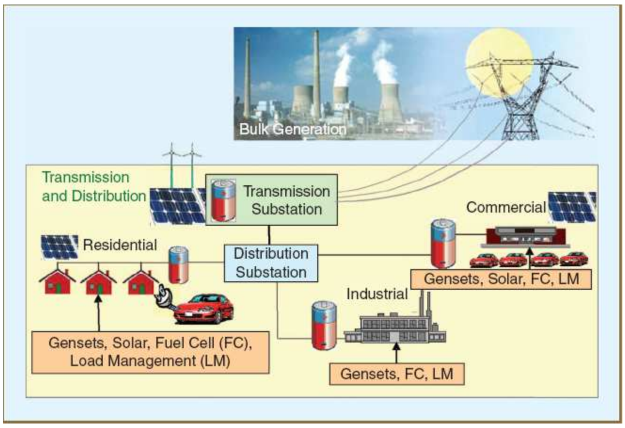

Figure 6. Power system with integrated central & distributed energy resources.

In general terms, power applications would be storage systems rated for one hour or less, and energy applications would be for longer periods. The applicability of different types of storage also depends on the efficiency, lifetime (in operating cycles) and investment costs. Especially in the applications of DR these characteristics are important.

In 2008, AEP (American Electric Power) installed three 2-MW, 14.4-MWh NaS energy storage systems at three different locations on its system, and they has started a new project with Beacon Power to install a 1-MW, 250-kWh flywheel system at one of its substations in the Columbus, Ohio, area.

Every year more attention has been given to storage in the grid at all levels, from large-scale bulk-storage systems to small units at or near the point of load (Fig. 6). The future of electric grids will be impacted by a growing penetration of plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs). A growth of EVs to 50 million units (15-kW capacity average) is expected by 2030, which would dwarf the installed capacity of major renewable energy sources, which will represent a new dimension for grid management; vast amounts of energy storage will be present in the grid in the form of millions of electric cars. Gigawatts to kilowatts, electricity storage devices will change the grid dramatically. The real technology challenge will be making all of the new electric power resources function in a fully integrated "smart grid."

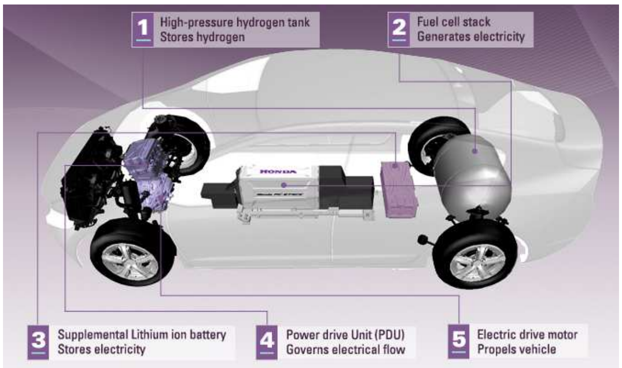

Fig.7. Fuel Cell Electric Vehicle (FCEV)

D. Power Electronics controllers

Power Electronics is to play a major role as 100% of electricity produced by renewable energy sources has to be converted by power electronic equipments. Additionally, power flow control using power electronic converters will be needed to ensure proper and secure work of the grid when submitted to the economical laws of the liberalized market. Without increased intelligence in power flow management, it will be impossible to secure a stable network with large numbers of small to medium sized dispersed generators. This is recognised by European Commission under "The challenges", where it is stated "Power electronics: Devices such as FACTS are critical components of a future grid control infrastructure".

The inclusion in the electrical system of the distributed generation, associated to the diversification of the energy sources, modify the topology of the power system. This new generation system, either because of its nature, or because of the frequent incorporation of power electronic converters as element of connection to the net, make necessary an extra survey of the quality of the nets where they are connected. There is a double reason for it: on the one hand they are very sensitive, and in the other they generate perturbations, which can occasion stability problems in the system, not individually but as a whole.

Within the envisaged networks of the future, power electronic converters will be needed to perform many different conversion functions (AC-AC conversion, AC-DC conversion, unidirectional power flow, bi-directional power flow, reactive power injection, FACTS, etc) connected at various points in the network. Such converters will provide, for example: interface for connection of renewables, integration of energy storage, optimised utilisation of transmission/distribution infrastructure, enhanced network stability, power quality (active filtering), power flow control, voltage support and unbalance compensation (Fig. 8).

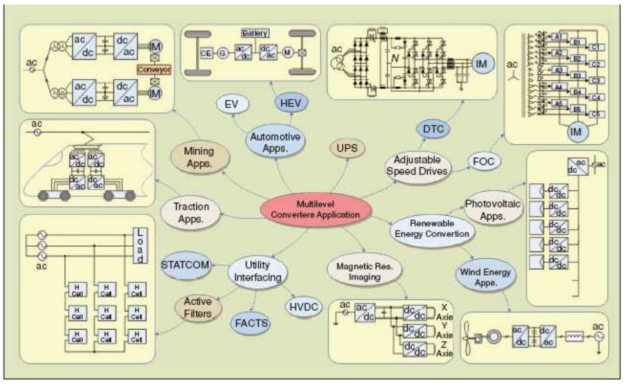

Figure 8 . Power electronics controllers applications

3. New Energetic Scenario

The global primary energy consumption totalled 227 million barrels of oil equivalent (MMBDPE) in 2008, a 1.8 percent increase from 2007 (Fig. 9). From the environmental point of view, CO2 emissions continue increasing, which in 2008 was estimated at a total of 8565 metric tons (20.7 by gas, 34.8 by oil and 44.5 by coal).

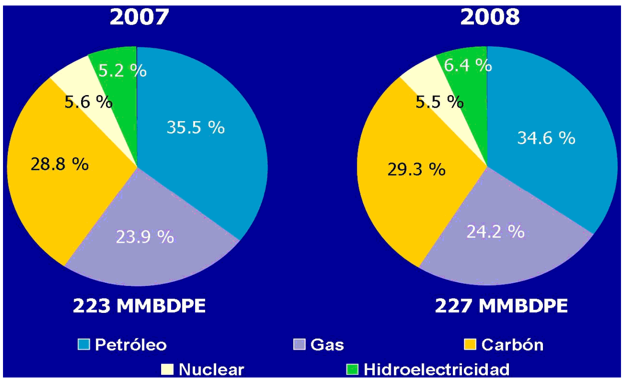

Figure 9. World primary energy consumption

The primary energy in the current energy system is used in general in:

- 40% in power generation
- 40% in transport, (15% cars)
- 20% in non electrical residential and commercial uses

The energy conversion systems using thermal processes, to convert primary energy into mechanical, electrical, electrochemical, or heat energy, etc. are very inefficient. The overall efficiency is about 20%, and in the case of transport is 10%, without taking into account the ecological damage caused. Today there are 800 million cars in the world and in 2030 could be over 1500 million, which is unsustainable for the planet and intolerable for the system.

Faced with this dilemma, the choices that lie ahead to meet the new requirements of the system is the distributed renewable alternative, which electrical energy can be obtained from inexhaustible renewable resources by "cold" systems, with efficiencies that can reach 90%, without thermal or electrochemical processes, based mainly on the capture of incident solar energy, by photovoltaic, wind and hydroelectric transformations. It would be required 25% of primary energy that we are currently using for our development, with minimal problems for the environment and health, vastly lower than the current.

To carry out this alternative the electrical energy systems should be generalized at all levels, starting with the generation, transport and energy distribution, and ending in final consumption, in cases where the benefits of their use is evident such as the electric car, lighting, inductive kitchen, etc..

While in the short term it is difficult to compete with technologies based on oil and gas, in the medium term it is likely that decentralized renewable energy find their own complementary market. This is a first step to an economy based on a combination of electricity and hydrogen energy system capable of providing globally abundant, clean and low cost energy. In the longer term a sustainable energy system where clean hydrogen and electricity act as the two main energy forms with fuel cell technology providing the bridge between them.

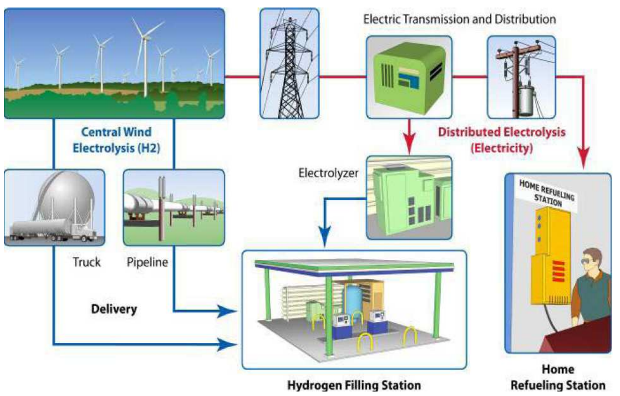

Figure 10. Energy system based on electricity and hydrogen

4. Smart Electrical Energy Network (SEEN)

La continua y necesaria incorporación de las DERs into the power system obliga a plantear una transformación the current Electric Power system (EPS) into a future Smart Electrical Energy Network (SEEN). The new model is based on the integration into electricity networks of large number of small and medium size generators based on new and renewable energy technologies. It may create a new era, where thousands or millions of users will own their generators, becoming both producers and consumers of electricity. All these generators will be interconnected through a fully interactive intelligent electricity network. The large-scale use of real-time sensors and data communication technologies, concepts like plug-and-play and self-healing will transform today's electricity grid into a future smart electricity web.

The new SEEN will involve a huge increase in data and information traffic to meet the requirements for the functioning of future networks, for which the most obvious communication link would be the Internet. The flow of information around the World Wide Web uses the concept of distributed control where each node, web host computer, e-mail server or router, acts autonomously under a global protocol.

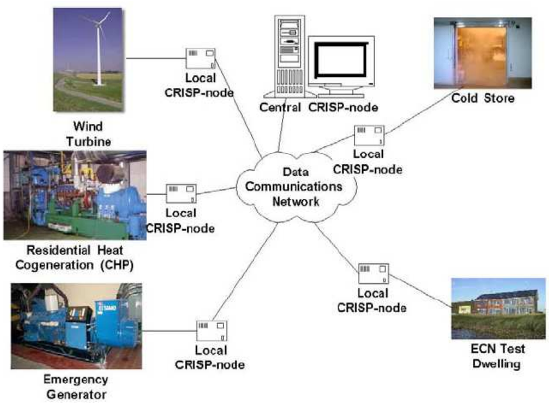

Figure 11. CRISP (Distributed Intelligence in Critical Infrastructures for sustainable power) Project

In the analogous electricity system every supply point, consumer and switching facility, corresponds to a node. With increased distribution of power input nodes due to DERs, bi-directional energy flow is possible and new technologies are emerging that can enable the direct routing of electricity. New power electronics systems offer ways of controlling the routing of electricity and also provide flexible interfaces to the network. FACTS and Custom Power Devices at lower voltages offer the potential to manage routing of power supply in an active manner.

The new grids are being transformed into millions of interconnected bilateral nodes at all levels of transmission and distribution integrated grid. Bulk transmission and distributed generation will coexist on interconnected grids where the distinct difference between traditional transmission and distribution becomes increasingly blurred. This unified electricity grid will provide a highly secure electricity supply on a most cost-effective basis with minimum damage to the environment.

5. Conclusion

The infeasibility of the current system based on the conversion of energy by inefficient and polluting thermal methods speeds up the process of implementing an energy system based on electricity as an energy vector, from its generation from renewable energy by cold methods, through transport, storage and distribution, to its final consumption.

The new scenario require a structure similar to the internet model. These interconnection technologies are a precursor to the "Energy Web," a shift to a power grid with a multitude of localized power units like a virtual power plant. Electronic intelligence connects Smaller DER to the grid, making possible net metering through which surplus renewable generation is fed to the grid and generator owners receive credit.

Plug-in Hybrid Electric Vehicles (PHEV) may constitute the engine of development of intelligent networks by allowing full bidirectional control between the automobile batteries and the grid, for load levelling or regulation and for spinning reserve (cashback hybrid, vehicle-to-grid -V2G- power).

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