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# Review on smart grid control and reliability in presence of renewable energies: Challenges and prospects

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## Abstract

This paper deals with smart grid concept and its reliability in presence of renewable energies. Around the globe an adjustment of electric energy is required to limit CO2 gas emission, preserve the greenhouse, limit pollution, fight climate change and increase energy security. Subsequently renewable energy expansion is the real test for designers and experts of smart grid system. This initiative has made significant progress toward the modernization and growth of the electric utility infrastructure and aims to integrate it into today's advanced communication era, both in function and in architecture. The study is focused on the difference between a conventional grid and a smart grid concept and the integration of renewable energy in a smart grid system where grid control is a must for energy management. Assuring a good grid reliability, taking the right control measures in order to preserve continuous electricity supply for the customers are challenges highlighted in the present paper.

*Keywords:* Smart grid; Grid control; Grid reliability; Renewable energy; Conventional grid

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## 1. Introduction

In order to cope with the energy changes, it is necessary to modernize the electricity system. Worldwide, designers and experts reach to develop electrical networks by the deployment of Smart Grid technologies rather than the replacement and massive reinforcement of the grid.

The integration of new information and communication technologies into the grid will make it communicative and will allow for diverse actors involvement in the electricity system, while ensuring a more efficient, economically viable and safe delivery of electricity.

The electrical system will thus be managed in a more flexible way to manage constraints such as the intermittence of renewable energies and the development of new models such as electric vehicles. These constraints will also have the effect of changing the current system, where the real-time equilibrium is ensured by adapting production to consumption, to a system where adjustment will be made more by demand, thus making the consumer a real actor [28].

The advent of the Smart Grid is the combination of a more demanding business environment and new technological possibilities. Systems that have been unaffordable only a few years ago, could now be built easily.

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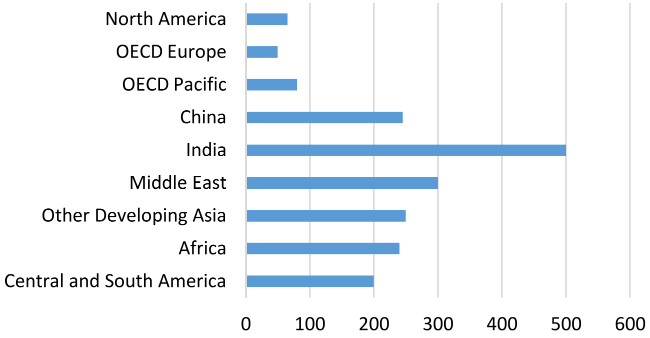

**Fig. 1.** Global energy consumption forecast from 2007 to 2050 [19].

The Smart Grids European Technology Platform has given a definition of Smart grid as “an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supply” [18].

Also, according to the US department of energy, a smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources [6].

The challenge is to prepare for the future, the future of distribution networks, innovate, adopt new technologies, develop tomorrow’s solutions, alongside and serve local and territorial communities.

In other words, it is a matter of accompanying the economic and solidarity development of the Territories and of facilitating the energy transition, in particular:

- Allow the integration of renewable energies on the network.
- Accompany new uses of electricity, including the development of the electric vehicle.
- Encourage the emergence of innovative energy efficiency solutions and the development of cities or smart neighborhoods.

The distribution network must be able to meet these three challenges (Renewable Energy, Electric Vehicles, Control of Energy Demand) while improving the quality of electricity supply and controlling the cost of routing. The energy distributor should have a role of facilitator of the energy but also a role of federator. Indeed, the adventure of the Smart Grids, the digitization of electricity, requires gathering and federating many skills and many partners.

The global energy consumption growth can be forecasted from 2007 to 2050 as shown in Fig. 1:

## 2. Traditional grid versus smart grid

Smart grids are communicative because they integrate information and communication technologies functions. This communication between the various points of the grid makes it possible to take into account the various actors’ actions in the electricity system, and in particular consumers [8]. The objective is to ensure a balance between supply and demand at all times with increased responsiveness and reliability and optimize the network operation. The electrical system passes from a chain that functions linearly to a system in which all actors interact [1]. Fig. 2 highlights the different actors contributing to the diversity of a smart grid system.

In fact, smart grid architecture consists of three levels:

- The first level is used to carry electricity through a conventional infrastructure (lines, transformers, etc.).
- The second level is formed by a communication architecture based on different communication media and technologies (fiber optics, GPRS, PLC, etc.) used to collect data from sensors installed on electrical networks.
- The third level consists on applications and services, such as remote troubleshooting systems or automatic demand response programs using real-time information.

**Service providers:** It includes providers of commercial services such as billing and charging and technical services such as stability, security services, energy use management and home energy generation. It is the interface between the

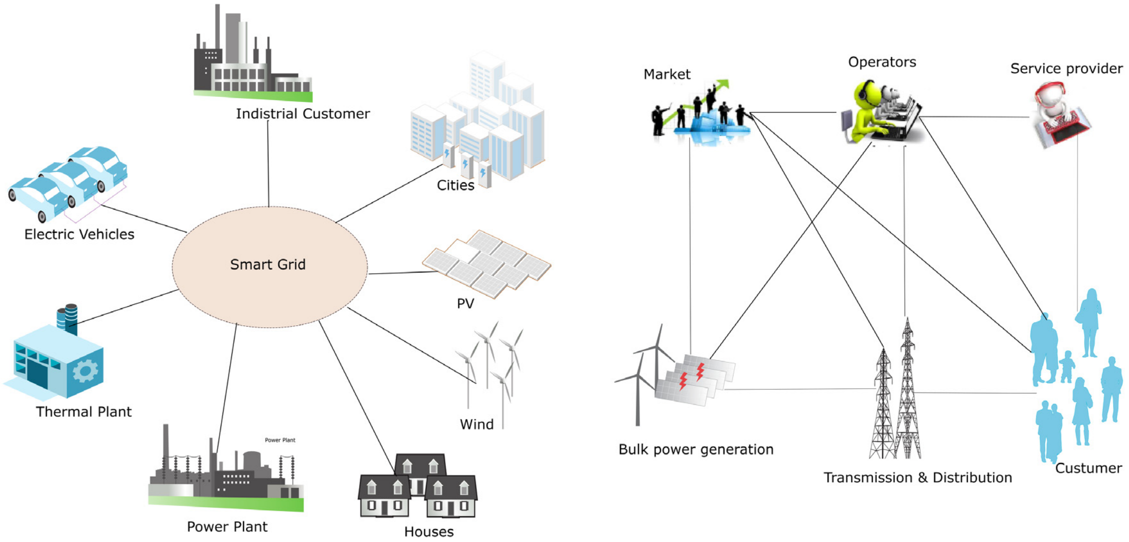

**Fig. 2.** Smart grid architecture [9].

market, the customer and the operators. Service providers perform all the services related to support the grid process business.

**Operators:** They are two types of operators, transmission and distribution operators. They both are responsible for the reliable, efficient and smooth operations of transmission and distribution grid. They need to analyze and operate in real time a large quantity of informations from different sources and offer several services such as demand/response management, smart metering services, energy storage, plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs).

**Market:** A new market is developing with the venue of smart grids. There are new services to support and new products to sell which is affecting the energy flow. A new market is then rising based on energy trading and supply of ancillary services. Producers and consumers can enter hourly electricity purchase and sale contracts.

**Customer:** On a smart grid system, the customer will have an interactive role in participating to energy trading by using or producing energy. A new management profile is put in place in order to assure a demand and response balance, to deal with supply conditions and to promote customers using energy during off-peak hours such as weekends and night-time.

**Transmission and distribution:** On one hand, the challenge for a distribution network is to deal with the bidirectional power flows on a grid that was designed only for unidirectional need. Moreover, it has to integrate all the micro-grids and the small-dispersed generation sources into an advanced grid that implements smart metering. On the other hand, the transmission grid has to ensure a reliable connection between bulk power generation and distribution grid taking into account the economic and technical factors.

**Bulk power generation:** It includes the variable sources of renewable power plants and the fully controlled traditional plants. Energy storage plays an important role in order to preserve the grid stability and absorb the unpredictable intermittent renewable energy sources.

The main aim of smart grids is mainly to equip the electrical network with the right instruments in order to make it intelligent. Currently, the transport network is already notably instrumented, for security of supply reasons. On the other hand, distribution networks are weakly equipped with communication technologies, because of the large number of structures (stations, lines, etc.) and consumers connected to these networks. Smart grids therefore have a major stake in distribution networks [13].

Table 1 highlights traditional and smart grid main characteristics.

In order for an electrical network to become intelligent, six main requirements should be fulfilled as shown in Fig. 3.

**Table 1**
Traditional versus smart grid characteristics.

| Traditional grid characteristics | Smart grid characteristics |
|---|---|
| Analog | Digital |
| Unidirectional | Bidirectional |
| Centralized production | Decentralized production |
| Communicating on some parts of the grid | Communicating on the hole grid |
| Management of the equilibrium of the electrical system by supply versus production rule | Management of the equilibrium of the electrical system by demand versus consumption rule |
| Consumer | Consum'actor |

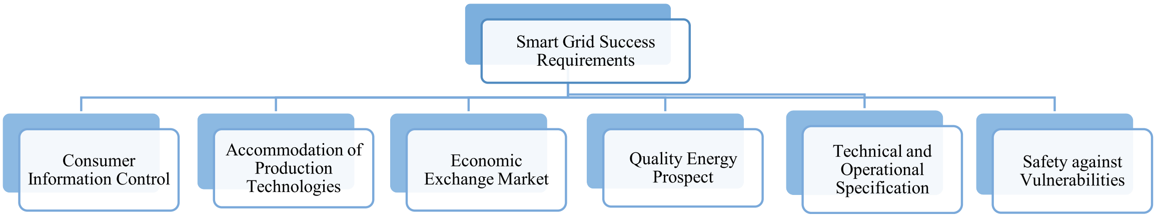

**Fig. 3.** Smart grid success requirements.

### 2.1. *Consumer information control*

The first requirement is that electricity consumers have to be better informed about their consumption. In fact, these consumers can also have access to information helping them to adapt it in line with the network management needs. For example, variable incentive tariffs over time can be given and home automation equipment whereby the modulation of load should be highly automated to require only a minimum of human supervision.

### 2.2. *Accommodation of production technologies*

The second requirement is that a "smart grid" should be capable of accommodating any type of production technology, including new scattered generators, as well as storage devices. This requirement has a technical component: for example, to ensure that these new devices do not create congestion or imbalance between supply and demand, but also create the regulatory and economic conditions for the deployment of these devices of private economic agents.

### 2.3. *Economic exchange markets*

The third requirement is that economic exchanges between smart grid players take as much as possible the form of markets. Creating competition conditions between smart grid players would be conducive to both economic efficiency and innovation.

In prospective scenarios, it can thus be assumed that the electricity market will undergo profound changes, allowing the emergence of new formats such as local market prices, or new products such as the erasure of loads and the capping of production. New markets can thus provide an outlet for the players who will be able to supply these products [17,24].

### 2.4. *Quality energy prospect*

The fourth requirement starts from the observation that not all consumers have the same need in terms of quality of supply: the needs of residential customers are not necessarily the same as those of certain industrial processes. The smart grids could make it possible to supplement an offer of a standard quality level with new and finer methods of quality control, for example in the diagnosis and treatment of voltage variation phenomena.

### 2.5. Technical and operational specification

The fifth requirement is a technical and economic optimization specification. Indeed, smart grids should make it possible to optimize the use of assets (lines, transformers, etc.) by using new levers – which still need to be invented – to try to drive the network closer to its limits. Thus smart grids could consist, on the one hand, of new operational levers allowing, for example, to vary consumptions and productions in order to meet network constraints and, on the other hand, new technical solutions enabling observation of the network by sensors, telecoms and information processing tools in order to improve knowledge of the state of the network and thus enable a finer control of the new operational levers mentioned above. When operating the grid, the question will then arise of the ability to choose and activate the most effective lever at the least cost depending on the current situation. Moreover, well before the operational phase, these levers will have to be modeled and taken into account during the planning phase of the network, that is to say in the choices for designing the network and potentially new operational levers themselves, or in other words, in investment decisions in general. For example, one might imagine that a "smart grid" lever requires a certain capital investment, but allows to avoid another one by delaying the need to strengthen the network. Such a lever could also induce operational costs for its activation or maintenance, have a positive or negative impact on losses in the network, etc.

Also, it is recommended to develop so-called "predictive" maintenance methods to better understand the aging phenomena of the equipment in order to replace them ideally "just before the breakdown", in order to maximize the service life of the equipment minimizing blackout occurrences.

### 2.6. Safety against vulnerabilities

The sixth requirement is the safety of the system. It is thus stated that a "smart grid" must be an infrastructure capable of resisting to the various disturbances of its environment as much as possible. The disruptions envisaged may be minor, such as a local short-circuit which the network must be capable of eliminating without human intervention and guaranteeing a rapid resumption of service; or major ones, such as generalized outages against which a plan of defense, and reconstruction of the network after the incident, must be prepared. The defense plan and the network reconstruction are of course already carefully prepared by the network operators. However, future evolutions of these mechanisms are to be expected due in particular to the arrival of dispersed generators. A smart grid worthy of the name should therefore be protected against these different types of vulnerability.

## 3. Integration of renewable energy in a smart grid system

In parallel with the development of renewable energies, electricity uses are undergoing profound changes. Some already existing have taken a considerable growth. Others, such as electric vehicles and heat pumps, are growing and will increase the consumption of electricity, which is already rising sharply [6]. A future typical scenario of intelligent implementation in grid system is highlighted in Fig. 4.

These changes force the control of the electrical grid because:

- Electricity consumption is subject to strong seasonal variations. Energy consumption is higher in winter than in summer. It is subject to daily peaks and drops.
- The means of electricity production are increasingly variable, due to the intermittence of their renewable sources.
- The development of decentralized production leads to a considerable increase in the production sites and injecting energy into distribution networks designed for transport not collection.

These constraints make it necessary to review the usual rules for electrical grid operation and require adaptations in terms of observability and electricity grid conduct.

The massive insertion of renewable energies on power grids poses technical problems, particularly for grid operators.

The first concern is the location of production facilities. In fact, the integration of decentralized production leads to the bidirectional operation of networks traditionally designed to carry energy only in one direction.

The second relates to the management of intermittent means of production in the electrical system. For low penetration rates, the impact of intermittent production is limited and can be handled by the electrical system. On the other hand, when the penetration rate increases, imbalances can occur [29].

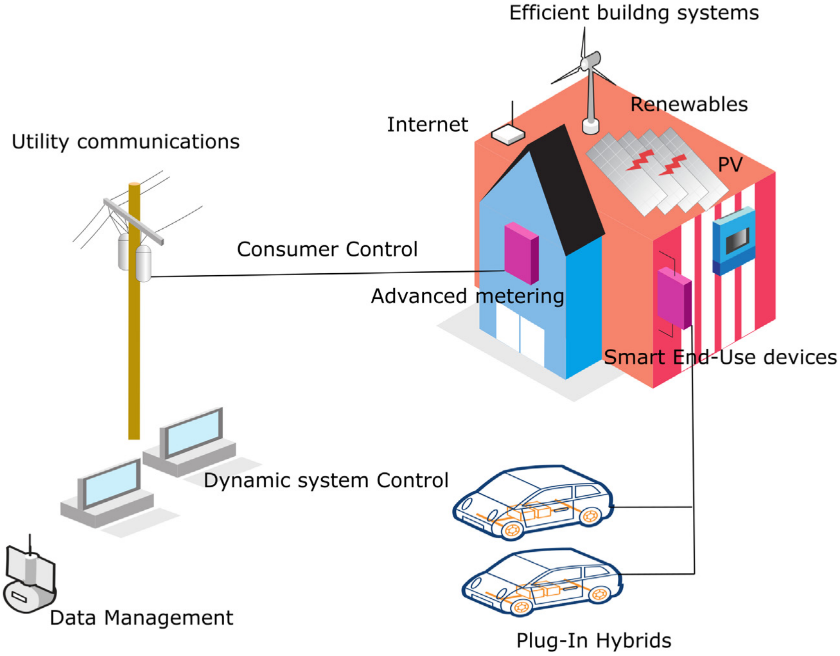

**Fig. 4.** A typical scenario of intelligent implementation in the electric grid system [5].

Three main factors influence the appearance of imbalances:

- The impact on the grid is stronger when production is not correlated with consumption.
- The need for investment is higher when development takes place in less densely populated areas where transport and distribution networks are more accurately designed.
- The magnitude of the network adaptations required for the insertion of small-scale installations at low voltage is very strongly dependent on their level of concentration.

The integration of renewable energies into power grids requires adaptation of the infrastructures and management of the electrical system.

Intermittence, non-controllability and a need to manage production/consumption balance at the local grid are a challenge for distribution system operators and will require an evolution of the electrical system management [26]. Fig. 5 presents the demand and supply planning for electrical power companies and grid operators.

In order to facilitate the integration of renewable energies into the electrical system, networks will need to be managed more responsively, using smart grid technologies. These technologies include many tools and systems for managing networks (communicating metering, electricity storage, market models, inverters and controllable loads, etc.). The new information and communication technologies will also intervene in order to optimize energy flows and, in particular, to ensure the balance between supply and demand. By developing observability, predictability, steering and flexibility, smart grids will better manage the intermittence of renewable energies [16].

Here are the main parameters when smart grid interferes in renewable energy system:

- Develop observability (forecasting).
- Interact with decentralized production.
- Develop demand management.
- Grid flexibility.

**Develop observability** to monitor the network state at any time (fault, congestion, voltage variation, etc.), anticipate incidents and facilitate decision-making to optimize the network and make it safer. The multiplication of sensors, such as communicating meters, will thus enable precise measurements of the energy flows on the network and

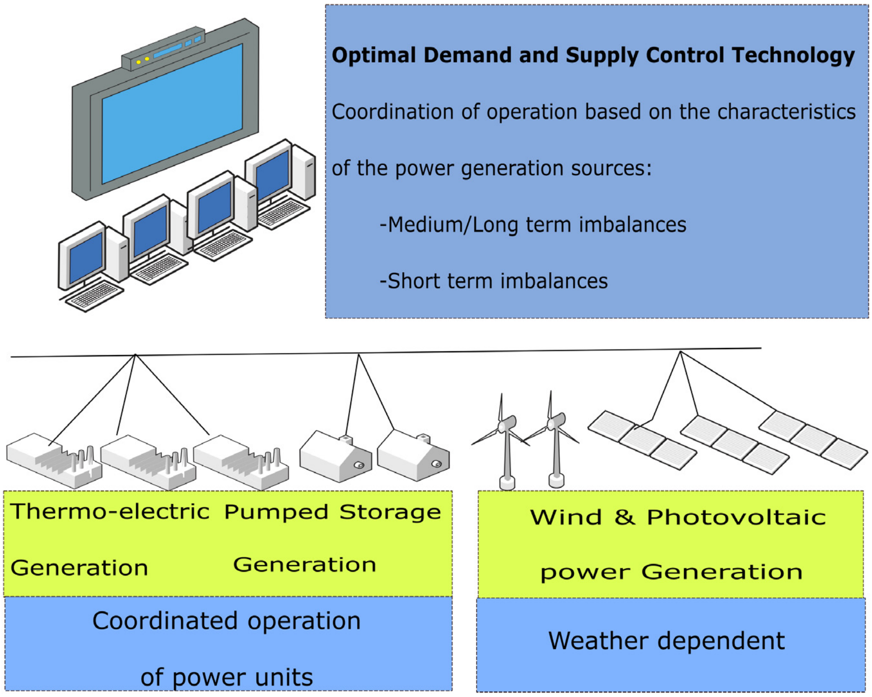

**Fig. 5.** Demand and supply planning for electrical power companies and grid operators [2].

to maintain the balance and stability of the system. For this, many countries are currently developing tools for **forecasting renewable production** in order to better manage the production/consumption balance and thus to improve the integration of this production into the networks [14]. Fig. 6 shows a power grid with renewable energy sources, storage system and smart controller.

Meteorology also plays a major role in improving the integration of renewable energies into networks. Weather forecasts allow for statistical and/or correlative correlations between meteorological hazard and production. Thus, a small gap between forecasts and production will be satisfactory in order to maintain a balance between supply and demand and thus preserve the system balance.

Also, in order to better integrate decentralized production on the networks while respecting the stability and quality of the system, control and management tools have been put in place. It is about **interacting with decentralized production** by developing the automation functions (voltage and power settings, reconfiguration after fault) [11,30].

By aggregating decentralized productions through a local “virtual center”. The creation of “virtual power stations” allows real-time intermittence to be avoided thanks to the combination of local electricity markets and hardware/software couples capable of balancing, in real time, demand and production of electricity.

Moreover, **demand management** makes it possible to better manage the production/consumption balance by using tariff signals to limit users consumption during peak periods and to consume during off-peak periods [32]. It is a question of tracing consumption on the production of renewable electricity. Given that the amounts of electricity produced and consumed must always be equal, that renewables are by nature intermittent and that it is very difficult to store electricity, the grid can then trip certain consumption loads in order to preserve the balance of electricity system.

Communication and data management infrastructures must be designed to integrate decentralized production into the system.

Smart grid technologies will allow for the **flexibility** of networks to be developed and thus to manage the intermittency and variability of renewable energies. FACTS (Flexible Alternative Current Transmission Systems), static compensators and capacitors allow the transfer of more energy to existing power lines while improving voltage stability and increase the resistance of the electrical network to system oscillations and disturbances [3,10].

Mass architecture and reinforcement of interconnections appear as complementary solutions to FACTS to improve the flexibility of the electrical system [23]. Indeed, by offering the possibilities of smoothing production to compensate

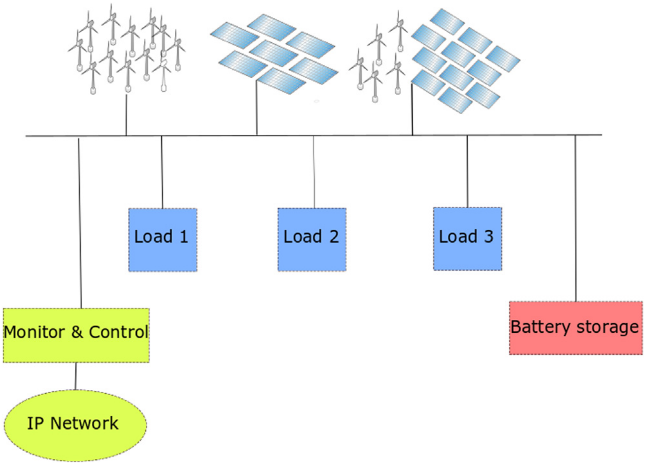

**Fig. 6.** Power grid with renewable energy sources, storage system and smart controller [4].

for the intermittency of renewable energies, they will enable to better integrate renewable energies into the electrical system. Once the physical infrastructure is assured, the second task of the manager is to manage the electrical system, specifically the flow of electrical energy. The network is an electrical system governed by physical laws. The actions carried out on the transmission network are multiple: injections of production plants, withdrawals from large industrial sites and the distribution network, interconnections with neighboring countries, etc. The management of electricity flows consists in ensuring, in real time, the good coordination of all the actors involved, while respecting physical constraints. This requires not only a technical knowledge of the state of the network, but also a predictive knowledge of production and consumption (as well as safety margins) all related to the energy markets.

Fig. 7 shows the implementation of solar and wind energy into the grid.

## 4. Grid reliability

The stability of an electrical network can be summarized mainly by the grid capacity to evolve around a balance point. The balance can be assured while the power produced is equal to power consumed.

The causes of the grid defects are essentially of two types:

- Endogenous causes that correspond to internal components failure such as insulation defects.
- Exogenous causes which correspond to external aggressions (damaged cables, plants or objects thrown by the wind on bare wires, incidental interventions by third parties, vandalism acts).

These defects are dangerous for people and materials and must be managed immediately either by protections associated with cutting organs or “tuning systems”, allowing the fault current to be reduced to very low values.

As shown in Fig. 8, there are four major imbalances that induce grid reliability and lead to incidents:

These imbalances can be related. It is quite common that a blackout is initiated by only one of these phenomena which initiates others.

Before implementing grid reliability, it is important to understand that power variations are linked to an overall system magnitude which is frequency.

Without a balance between produced and consumed power on the grid, frequency will deviate from its nominal size inducing a wrong functioning of the system.

There are two main properties that can be used to manage imbalances:

- The first is linked to an instantaneous reaction: the inertia of rotating machines injecting power over the network. In fact, in case of a sudden change in power of consumption or production, the release of a quantity of energy in the rotating machines of large production plants for example will lead to a low evolution of the frequency. This variation fortunately gives to the network operators time to manage the imbalance on the grid. Indeed, when the frequency decreases, it shows a deficit of production and vice versa.

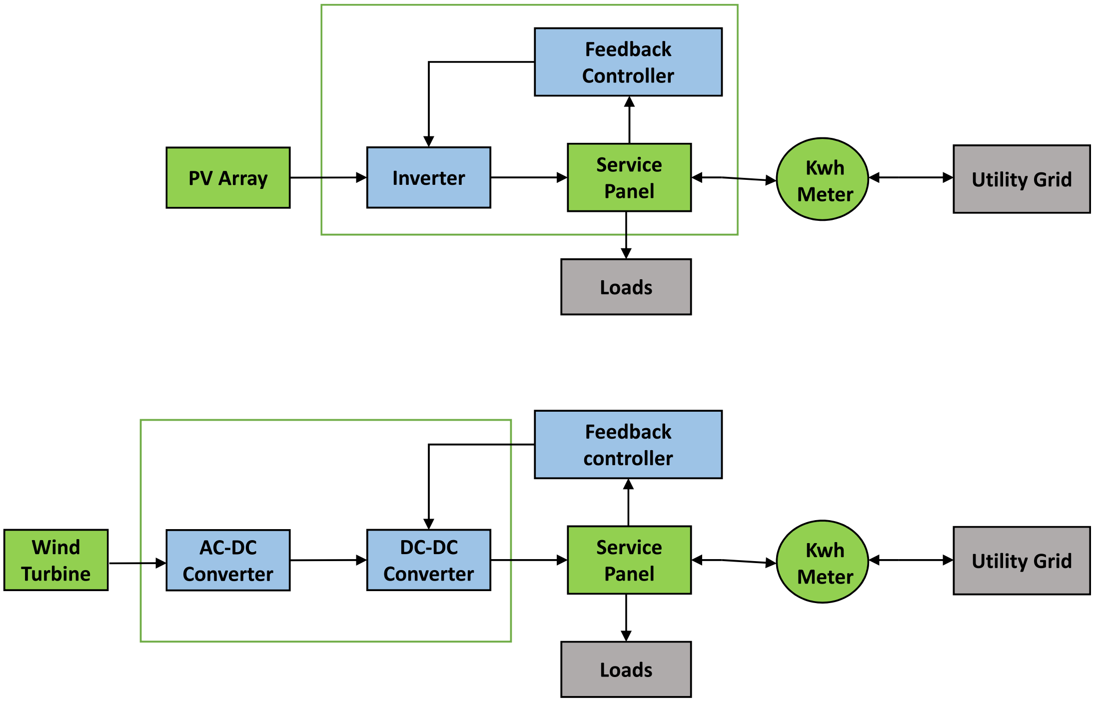

**Fig. 7.** Implementation model of PV and wind energy into the electric grid system.

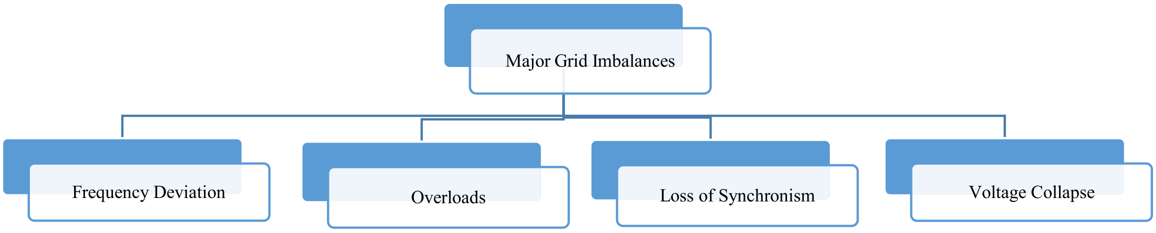

**Fig. 8.** Major grid imbalances.

- The second property is linked to the controlled reaction of production as adjustment levels to allow multi-machine systems to share the balancing effort on several generators for example. This leads us to distinguish a primary and a secondary control. These two types of adjustments are automatic.

### *4.1. Frequency deviation*

In order for the network to operate at a stabilized frequency around 50/60 Hz, the production groups must at all times adapt their production to the power demanded by consumers. Indeed, it is not yet possible to systematically influence the load curve (which is consumed at any moment) and the technological advances in storage still do not allow it to be envisaged on a very large scale. It is therefore necessary to play on the network natural strength and its ability to pool instantaneously all the interconnected means of production. This is achieved in the short term by means of adjustment mechanisms which will concern frequency and voltage. The mechanisms are similar, but the frequency will have a strong link with the active power while the voltage will be related to the reactive power [7,12,31].

Fig. 9 shows a generator connected to the grid response.

Frequency adjustment is therefore essential for the stability of the electrical system. It has three components. The first two are included in the systems services (these are services that producers usually have to supply to the grid as they inject power) and the third is a response at the national level (led by the transport).

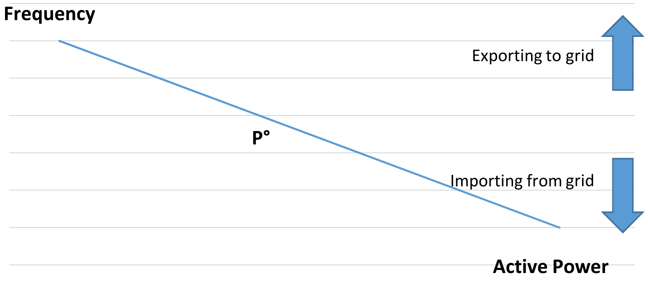

**Fig. 9.** Generator connected to the grid response (frequency versus active power) [15].

- The primary frequency setting allows adjustment relative to a setpoint of power in order to stabilize the frequency but not to bring it back to its initial value! It is an uncoordinated regulation whose design aims to compensate at least for the loss of the largest group in the production fleet.
- The secondary setting is to send a new power setpoint to the generators that participate in this setting. The aim is to reduce the frequency to its initial value and to correct the energy balance deviations between the adjustment zones impacted by the action of the primary control. Regulation here is rather regional.
- Finally the tertiary adjustment is manual. It involves starting additional groups or using other means to temporarily strengthen production. The objective is to reconstitute the primary and secondary reserves and to finalize the harmonization of the energy flows in the network

In order to illustrate the first instability phenomenon that corresponds to the frequency deviation, the second part of the Italian blackout of 28 September 2003 is a clear example. At three o'clock in the morning, that night, and following a cascade of overloads, Italy was isolated from the European network, and in production deficit of more than 7 GW.

After numerous sheddings following the decoupling of decentralized production which has fallen below their regulatory frequency, the frequency has finally diverged beyond normal value. Italy then found itself in the dark.

### 4.2. *Overloads*

The second phenomenon of instability is overload. Smart grid should be able to sense system overloads and reroute power in order to limit outages [34]. Transmission system technologies help to improve network controllability and maximize power transfer capacity [27]. In fact, overload phenomenon occurs when there is a significant imbalance between production and load. This is what happened in Italy in 2003 before the frequency deviation [25].

Indeed, and during the night, Italy usually imports energy to store as potential energy in altitude reservoirs. That night, the import was slightly above the import capacity because a first line between Italy and Switzerland tripped. Later that the other lines, connecting Italy with the rest of Europe tripped due to the overload [21].

Sudden overload can also create technical losses and sudden changes in voltage which can damage the material structure and decrease life time material [22].

### 4.3. *Loss of synchronism*

The third phenomenon of instability is related to the loss of synchronism.

Alternators are also called synchronous machines because their speed is proportional to the electrical network frequency. Since the electrical frequency is the same throughout the network, then the alternators all rotate synchronously.

To simplify, there is a link or a couple synchronization between generators.

In case of heavy stress on the grid such as a short circuit, generators may lose the synchronism and begin to oscillate at low frequency. This phenomenon was recorded during the incident of January 1997 when perturbations have appeared between Eastern Europe and Western Europe.

These rotor oscillations have created significant power exchanges between the two zones, but fortunately not enough to trip the line between France and Germany.

If greater short circuit occurred, this synchronism can be lost and the control unit operator or the protections have the only choice to disconnect the machine.

The main problem is that once the power plant is disconnected, it will affect the production/consumption balance. This is called loss of synchronism between two zones initially synchronous.

### 4.4. Voltage collapse

The fourth phenomenon of instability is the voltage collapse. The inability to support the network voltage due to the lack of reactive power sources which may cause some generators to lose synchronism. Power quality gets then worse because of voltage fluctuations, flicker and harmonics [33].

This voltage collapse is often linked to a more complex phenomenon which are voltage control devices known as load adjusters.

When high voltage drops in the transmission system, the load regulator passes a plug to maintain the voltage and therefore calls more current. A strategy should be then developed to find out the optimal reactive power injection in order to improve the voltage stability of the system [20].

For example, one case of voltage collapse has occurred, in 1987, in the west of France, where four production groups have tripped. Energy producers have failed to maintain sufficient voltage, so a voltage collapse has occurred for several minutes.

### 4.5. Control measures

Because of all these parameters, emergency measures can nevertheless be implemented to protect the grid when confronted with important events.

Three types of actions can be distinguished from a temporal point of view:

- Preparation: By anticipating events and specifying the margin adjustment levels, possible curative actions can be anticipated and risky events can be contained within reasonable limits.
- Monitoring: In real time, all the specified systems should respond and all electrical grid parameters must be within safe margins via cyclical analyzes.
- Curative actions are implemented in real time if the system is no longer able to face the imbalance.

When a fault occurs, the circuit breaker acts to protect the equipment and persons, cutting off the power supply. The operator of the control room is informed of the incident and begins to locate the fault by means of fault detectors associated with remote-controlled switches. Indeed, the detectors show the path taken by the fault current. The fault zone is thus identified and is then isolated by the maneuvering organs surrounding this zone. The healthy network portions between remote-controlled structures are then re-powered. All these phases should be carried out automatically by a self-healing function deployed in all the control rooms of a smart grid system. This function increases the safety of remote maneuvers and their effectiveness.

As example of emergency measures that can be taken in such case, there is the start-up of emergency groups or a temporary overload of the generators in terms of reactive or even active power. It is then possible to apply a reduction of the voltage set point or even blocking the load adjusters. This will make it possible to avoid the voltage drop phenomena.

Also, automatic frequency shedding or operator remotely tele-shedding decisions can be taken.

Finally, if all previous measures have failed, the operator can execute a rapid network decoupling allowing for minimum viable grid parts.

## 5. Conclusions

Different notions have been approached in this paper highlighting that network stability is linked to the ability to achieve a balance between production and consumption. However, following findings can be listed:

- The frequency change depends on the load/production imbalance.
- The electrical system is relatively fragile. This fragility is increased by the market growth, the grids' interactions and the integration of renewable energies. However, preparation and monitoring significantly reduce any risk of generalized incident.

- The network topology depends on the interconnection of its structures: thus, any equipment problem can lead to synchronism loss. This synchronism breakdown between two zones can succeed in saving part of the electrical system.
- In case of frequency deviation, the primary reserve acts. If the imbalance magnitude is greater than the power control, the action of the primary reserve is not sufficient to stop the frequency deviation.

It should also be noted that there are two main criteria solutions:

- Structural solutions such as reinforcements of the grid by adding new equipments.
- Operational solutions such as adequate operator preparation and material verification in order to allow a successful implementation of real time reactions.

Also, the shared challenge with local and regional authorities lies in the collective capacity to develop tomorrow solutions, to broaden know-how through digital technologies and to develop employment by taking over the demonstrators for structuring the Smart Grid sector through training. This new step in the history of distribution networks has led to the gradual transformation of the distributor's business, in particular the management of HTA and BT networks, network studies and the creation of new businesses of data services. Thus, the public distribution network will be able to contribute durably to accompany the economic and solidarity development of the territories.

## References

[1] S.M. Amin, B.F. Wollenberg, Toward a smart grid: power delivery for the 21st century, IEEE Power Energy Mag. 3 (5) (2005) 34–41.

[2] A. Bose, Smart transmission grid applications and their supporting infrastructure, IEEE Trans. Smart Grid 1 (1) (2010) 11–19.

[3] J.H. Chow, S.G. Ghiocel, An adaptive wide-area power system damping controller using synchrophasor data, in: Control and Optimization Methods for Electric Smart Grids, Springer, 2012, pp. 327–342.

[4] A. Demeo, M.L. Peterson, Community smart grid utilizing dynamic demand response and tidal power for grid stabilization, Smart Grid Renew. Energy 4 (2013) 465–472.

[5] Electric Power Research Institute Intelligrid, Technical Report. http://intelligrid.epri.com/.

[6] X. Fang, S. Misra, G. Xue, D. Yang, Smart grid — the new and improved Power grid: a survey, IEEE Commun. Surv. Tutor. 14 (4) (2012) 944–980.

[7] L. Fangxing, Q. Wei, S. Hongbin, W. Hui, W. Jianhui, et al., Smart transmission grid: vision and framework, IEEE Trans. Smart Grid 1 (2010) 168–177.

[8] H. Farhangi, The path of the smart grid, IEEE Trans. Power Energy 8 (1) (2010) 18–28.

[9] V.C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, et al., Smart grid technologies: communications, technologies and standards, IEEE Trans. Ind. Inform. 7 (4) (2011) 529–539.

[10] Muhammad Irfan, Jamshed Iqbal, Adeel Iqbal, Zahid Iqbal, Raja Ali Riaz, AdeelMehmood, Opportunities and challenges in control of smart grids – Pakistani perspective, Renewable Sustainable Energy Rev. (2016) http://dx.doi.org/10.1016/j.rser.2016.12.095.

[11] Maya Jegen, Xavier D. Philion, Smart grid development in Quebec: A review and policy approach, Renewable Sustainable Energy Rev. (2017) http://dx.doi.org/10.1016/j.rser.2017.06.019.

[12] E. Kabalci, Y. Kabalci, I. Develi, Modelling and analysis of a power line communication system with QPSK modem for renewable smart grids, Int. J. Electr. Power Energy Syst. 34 (2012) 19–28.

[13] Thi-Tinh-Minh Le, Nicolas Retiere, Approximation of the frequency response of power systems based on scale invariance, Math. Comput. Simulation (2015) http://dx.doi.org/10.1016/j.matcom.2015.08.015.

[14] S. Leva, A. Dolara, F. Grimaccia, M. Mussetta, E. Ogliari, Analysis and validation of 24 h ahead neural network forecasting of photovoltaic output power, Math. Comput. Simul. (2015) http://dx.doi.org/10.1016/j.matcom.2015.05.010.

[15] P. Li, W. Wang, X. Yang, S. Wang, H. Cui, C. Gao, A droop control method of micro sources based on divided self-adjusting slope coefficients, in: IEEE International Conference on Power System Technology (POWERCON), 2010, pp. 1–6.

[16] Mitsubishi Electric (2013) Environmental technology R & D achievements. Available via Online. http://www.mitsubishielectric.com/company/environment/report/products/randd/smartgrid/. Cited 06 2013.

[17] S. Mohagheghi, J. Stoupis, W. Zhenyuan, L. Zhao, H. Kazemzadeh, Demand response architecture: Integration into the distribution management system, in: Proc. 1st IEEE Int. Conf. Smart Grid Commun. (SmartGridComm), 2010, pp. 501–506.

[18] N. Mutoh, Senior Member, IEEE, M. Ohno, T. Inoue, A method for MPPT control while searching parameters corresponding to weather conditions for PV generation systems, IEEE 53 (4) (2006) 1055–1065.

[19] Li Peng, Yan Gao-Shi, Clean energy grid-connected technology based on smart grid, Energy Proc 12 (2011) 213–218.

[20] N. Phuangpornpitak, S. Tia, Opportunities and challenges of integrating renewable energy in smart grid system, Energy Procedia 34 (2013) 282–290.

[21] F. Rahman, S. Rehman, M.A. Abdul-Majeed, Overview of energy storage systems for storing electricity from renewable sources in Saudi Arabia, Renewable Sustainable Energy Rev. 16 (1) (2012) 274–283.

[22] Renewable and Sustainable Energy Reviews 66 (2016) 499–516, http://dx.doi.org/10.1016/j.rser.2016.08.002.

[23] R. Rigo-Mariani, B. Sareni, X. Roboam, Fast power flow scheduling and sensitivity analysis for sizing a microgrid with storage, Math. Comput. Simulation (2015) http://dx.doi.org/10.1016/j.matcom.2015.11.010.

[24] Sana Sahbani, HassaneMahmoudi, AbdennebiHasnaoui, Mustapha Kchikach, Development prospect of smart grid in Morocco, Procedia Comput. Sci. 83 (2016) 1313–1320.

[25] G.M. Shafiullah, Amanullah M. T. Oo, A.B.M. Shawkat Ali, Peter Wolfs, Smart grid for a sustainable future, Smart Grid Renewable Energy 4 (2013) 23–34.

[26] G. Strbac, A. Shakoor, M. Black, D. Pudjianto, T. Bopp, Impact of wind generation on the operation and development of the UK electricity systems, Electr. Power Syst. Res. 77 (9) (2007) 1214–1227.

[27] EmodiNnaemeka Vincent, Samson D. Yusuf, Integrating renewable energyand smart grid technology into the nigerian electricity grid system, Smart Grid Renewable Energy 5 (2014) 220–238.

[28] B.C. Wang, M. Sechilariu, F. Locment, Power flow Petri Net modelling for building integrated multi-source power system with smart grid interaction, Math. Comput. Simulation 91 (2013) 119–133, http://dx.doi.org/10.1016/j.matcom.2013.01.006.

[29] C. Wei, A conceptual framework for smart grid, in: Proc. Power and Energy Engineering Conference, Chengdu, 2010, pp. 1–4.

[30] M. Wolsink, The research agenda on social acceptance of distributed generation in smart grids: renewable as common pool resources, Renewable Sustainable Energy Rev. 16 (2012) 822–835.

[31] YasinKabalci, A survey on smart metering and smart grid communication, Renewable Sustainable Energy Rev. (2016) http://dx.doi.org/10.1016/j.rser.2015.12.114.

[32] M. Zaibi, G. Champenois, X. Roboam, J. Belhadj, B. Sareni, Smart power management of a hybrid photovoltaic/wind stand-alone system coupling battery storage and hydraulic network, Math. Comput. Simulation (2016) http://dx.doi.org/10.1016/j.matcom.2016.08.009.

[33] Jinju Zhou, Lina He, Canbing Li, Yijia Cao, Xubin Liu, YinghuiGeng, What's the Difference between Traditional Power Gridand Smart Grid? -From Dispatching Perspective. National High Technology Research and Development of China (863 Program).

[34] M. Zima, G. Andersson, Wide area monitoring and control as a tool for mitigation of cascading failures, in: Probabilistic Methods Applied to Power Systems.2004 International Conference on, 2004, pp. 663–669.