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# Distributed Generation in Future Grids: Will "Energy Islands" Become a Reality?

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*Summary:* **In modern distribution grids, more distributed generation technologies emerge. The most far-going implementations are 'energy islands' with a high degree of autonomy from the central grid. This paper considers different technological barriers that emerge with increasing penetration of such systems: power quality, control problems, safety issues, environmental aspects, the availability of primary energy resources and economic aspects.**

**Key words:**
*distributed generation,
power quality,
energy storage,
microgrid,
grid stability*

## 1. INTRODUCTION

### 1.1. Distributed Generation technology

The latest years many technologies known as '*Distributed Generation*' (DG) equipment have become available, for instance building-integrated photovoltaic systems, wind turbines, fuel-cells, small-scale gas turbine based CHP (combined heat and power generation) units and so on. These appliances have in common that they produce electricity from a locally available energy source, which can be renewable energy (RE). The amount of energy converted is relatively small compared to the ratings encountered in large centrally distpached power plants. They are situated close to the electricity consumers, and may even be integrated in their installations, leading to the sometimes used synonym '*Embedded Generation*'.

The electricity produced by such DG units has its own particular characteristics, often due to the availability of the primary source or driving factor: e.g. wind, sun, heat demand in a CHP application. This makes the supply of the electrical energy less guaranteed, but on the other hand environmentally friendly resources can be employed.

In general it is hard to tell where the limit of DG technology is situated. Its definition is heavily debated, but in general most people understand it as electricity generation systems of small to moderate size (less than a few MW), usually implemented in the electricity distribution system and not necessarily owned nor controlled by utilities. As such large wind farms are generally not understood as DG.

### 1.2. Complementary technologies

DG power generation technology is complemented by energy storage technologies such as advanced battery types, supercapacitors, superconducting coils, and flywheels. They leave open the possibility to better match supply and demand accounting for the difficult to control generation at different time scales. In this manner, an enhanced power quality and reliability can be achieved. DG and storage together form the core of future 'Distributed Power' systems.

Though, to achieve a good match between storage-assisted generation and consumption, the load should preferably also be somehow 'controlled' in an intelligent way in order to save or shift electricity consumption. Therefore, some consider loads as a sort of 'Distributed Resource' that can be used to better employ locally available power.

All of these developments were possible due to the evolution in digitally controlled power electronics, forming the grid interface of the Distributed Power system elements, both generation and storage, and many loads. The performance of such systems could even be increased when a suitable communication infrastructure is present.

Hence, it is to be expected that a larger part of the electrical energy is to be produced, consumed and managed locally in a sort 'Energy Island' or 'microgrid' and some people are even tempted to ask whether a backbone power grid is still required. Behind this evolution many driving factors are present, such as the will to employ more renewable energy sources (the European goal is to go from the 6% level of 1995 to 12% by 2010) or local energetic 'opportunities' such as waste heat. This has to be considered in a society not eager to expand the power system, but still with increasing demand. For this and other reasons, it is not expected that the security and quality of supply will stay at the level of the past, certainly the extreme high levels of security of supply known in continental Europe (UCTE zone) will come under pressure. Some dream of 'doing it on their own' in an 'Energy Island'.

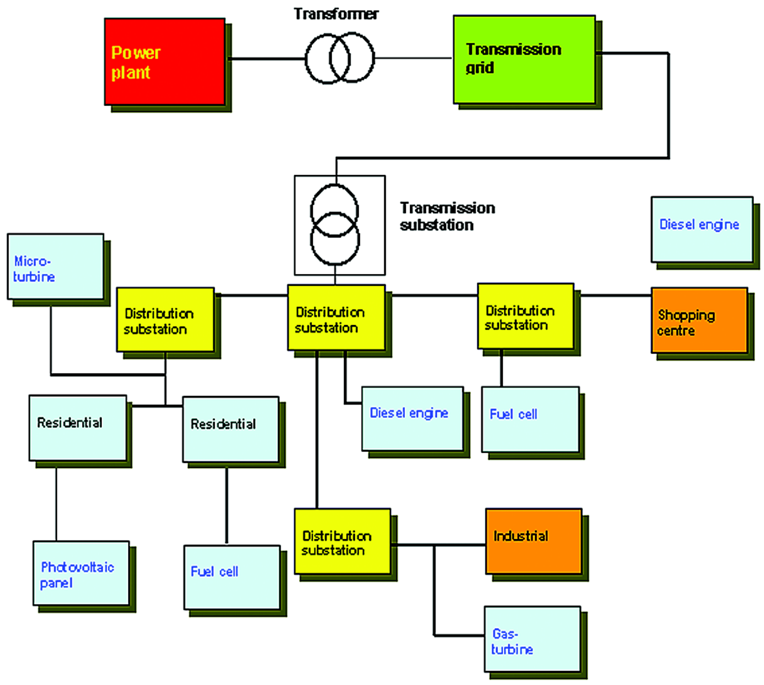


Fig. 1. Distribution grid with a high penetration of DG technology

## 2. DG INTRODUCTION ASPECTS

In order to allow a large-scale penetration of DG, perhaps later on leading to 'energy islands' with some form of autonomy, many issues are to be investigated still. The focus in research is now shifting from DG technology on its own, towards its grid integration and optimal deployment. In different large research projects in the EU and also in the US, the suitable penetration levels of DG are investigated. The following aspects are to be considered in this respect.

### 2.1. Reliability and Power Quality (PQ)

Many of the DG systems rely on resources that have little or limited predictability. Therefore, keeping in mind the idea that the generation needs to match the demand as closely as possible, in order to maintain the same level of reliability of supply, some sort of backup power has to be "contracted" elsewhere. For this reason it is unlikely that an energy island can operate totally detached from the upstream high voltage grid for a longer sustained period. In the normal grid connected situation, the only power flow remaining will be the remaining balancing current.

Internally in the grid, local voltage sweeps can quickly arise as bidirectional power flows, in a grid that used to know only a unidirectional top-down power flows, and cannot be avoided. Local 'bursts' of active and reactive power distort the voltage profiles very quickly. It is difficult to immediately correct this since DG units, having power electronic front-ends that have to be considered as practically 'inertia-less' generators unless some advanced form of energy storage, to be considered as virtual inertia, is applied. The 'inertia' comes from the grid, with centrally controlled power plants that can be regarded as one giant flywheel containing very fast balancing power, reflecting in the large 'short-circuit power', i.e. a very low internal impedance, of the power system backbone.

Further on, the widespread use of power electronic inverters with non-linear characteristics possibly increases typical Power Quality problems such as harmonic distortion. However, with recent technology with fast switching components used to compose the input waveform, this problem is not that acute anymore. On the other hand, these systems could (theoretically) be used in such a way that the PQ is enhanced locally, at a certain price: they are in principle identical to the systems used to set up 'active filters' (for harmonic cancellation) or 'static compensators' (generating reactive power, necessary to stabilize the voltage). Unfortunately, currently most DG front-ends have to be set up too 'passively' and inject only active power and leave the control of the voltage parameters to the central system. It is likely that this will change in future and DG units may also deliver 'ancillary services'.

### 2.2. Control Question

The decentralized control problem is perhaps the most challenging. Here, a large number of small unpredictable generators and related storage devices or active load systems has to work together to cover a local fluctuating energy demand. A higher-level control system seems inevitable, but a dependable communication infrastructure for sending around the appropriate information needs to be present.

Sometimes it is advisable, for instance in case of grid problems, that an energy island would decouple and go into island mode. Going back to the connected system sounds easier than it is in reality: resynchronisation of the low-inertia energy island with the stiff power system is a tricky action.

The main difficulty is the fundamental difference between working as a 'current source', when passively injecting power in the grid with the stiff power system providing stability and working as a 'voltage source', where the DG units need to stabilize the energy island's frequency and voltage on their own. The latter requires a considerable amount of 'reserve' (or stored) power in order to smooth out the voltage distortions.

### 2.3. Safety

Naturally, the safety of the system is to be guaranteed at all times. This is less simple than it seems since the fault current not only comes from the power system (a large voltage source) in a unidirectional way, but also from the DG units (dispersed current sources), making the detection of erroneous situations far more complicated using classical 'fuse-and-relay' methods.

Imagine the following example: a short circuit arises close to a DG unit. This behaves as a current source and thus provides a considerable amount of the fault current, but not enough to trigger over-current protections. Theoretically, this may be going on unnoticed by standard protections. Also when the fault happens on parallel grid branches far away from the DG unit, it may be disconnected as a 'collateral effect' by some 'selective' top-down protection for its (limited) contribution to the fault current, thereby making the extent of the problem larger than in the DG-less situation.

Therefore, a more complicated, 'active' protection system with some form of communication will be required to keep up the same level of safety in future.

### 2.4. Environmental issues

Introducing noisy generators and toxic chemicals, e.g. in fuel cells and batteries, is not desired in densely populated areas. Also, in case of natural gas-based units, local emissions are inevitable. It is even a question whether the regular operation of the large centralized backup power units will not result in a less-efficient operation of the central power plants with relatively higher emissions as a consequence. So, there clearly is a price for being capable to harvest environmentally friendly renewable energy as well.

### 2.5. Availability of transport infrastructure for primary energy sources, i.e. natural gas

Non-RE-based DG units mainly use natural gas input. Many times, the motivation for their introduction is saving expensive network upgrades. This is often a false reasoning, as it will lead to putting a larger stress on the (parallel) primary energy supply network. In this way the network congestion problem is just shifting from the electrical grid to the gas distribution grid.

### 2.6. Economic aspects

Deploying DG infrastructure requires a large investment for the equipment and network alterations necessary for control and safety. The payback is complicated in a liberalised market in which little risk is taken and one has to benefit from avoiding heavy price fluctuations or penalties for peak loads or non-scheduled consumption patterns, unless when DG was the only (costly) option in case grid expansion was ruled out.

Otherwise, one has to rely on special tariffs and subsidies, for instance in the form of 'green power certificates' and a portfolio obligation for the retailers, that are available for some forms of more environmentally friendly power generation. Even then it is difficult to weigh this financial benefit against the cost of having a not so reliable power source, bringing along more backup power related costs. Even though it may be ethically motivated, there is always the risk for over-subsidization with prices artificially kept high, a situation contrary to the free market paradigm.

There remains the question who will finance the backbone power system. This represents a large investment with a very long pay-back time. This grid is usually financed through some regulated transmission tariff payable to the power system operator, function of the rated power of the link and to the exchanged energy. Installing a DG unit and more extremely, implementing an energy island, means that less energy is retrieved from the grid and the financial contribution to the investment pay-off is decreased. Nevertheless, the grid, in which the transformers and lines are designed for the in fact unchanged maximum capacity, is still there in the same form for reasons of balancing capability and emergency backup. For this reason, in some countries, 'departing fees' are charged on the installers of DG units. If not, the financial burden on the remaining customer would become higher with every new DG unit. A similar problem occurs when special transmission tariffs are forced on the transmission grid operator for renewables and CHP-units: again the missed income in transferred to the regular customers, being a hidden tax for supporting DG.

On the other hand, additional PQ-related ancillary services, such as voltage support, could be offered to the network operator as well, providing an extra source of income and indirectly a lift of the socialised costs associated with grid equipment investments. The current lack of financial incentives and market mechanisms allowing to benefit from all such technological capabilities is not yet available.

## 3. CONCLUSIONS

In general, it is difficult to say what the limit to the introduction of DG technology in distribution grids is. In fact it is a subject of many international research projects. Different parameters need to be accounted for, such as the voltage stability, power quality and reliability of supply. These depend on many different characteristics of loads, grid topology and supporting transmission grid backbone. The fact that connection rules differ from region to region makes it all ever more complicated. Some even pose the question whether it is necessary to keep the current standards of reliability and go for an asocial 'each on its own' attitude. In practice, one tries to keep up the reliability of the supply, which is a conservative attitude, but understandable in the situation in which a society heavily depends on a reliable power supply.

One should certainly not only focus on the difficulties the introduction of DG brings along and also consider the benefits of it. In a well-considered set-up, the reliability of the whole system increases. Peak power demands put less strain on a thoroughly loaded power system. Above all, there is a potential to reduce the cost of electricity by using locally available resources, reducing transport losses and omitting (postponing) costly investments in the infrastructure.

In case real decoupling 'Energy Islands' would emerge, a totally different situation arises in which all ancillary services, the 'short-circuit power' and 'inertia' have to be provided by local DG systems. This represents and enormous technological challenge, but also an opportunity to make maximal use of local resources and tune the reliability to the specific local requirements. This sounds ideal, but is (still) very costly and difficult to justify in the current uncertain economic framework that is different from region to region.

It is almost certain the current centrally supported power system will undergo a revolution in the coming years and decades as electricity consumption will not go down and the difficult expansion of the grid can only be substituted for by installing DG technology. However, it is not certain whether going to the limit and set up more or less independent energy islands is a good idea from technical and both economic point of view. In the near future, some attempts to realise such 'microgrids' will be undertaken throughout the world. It is worth closely following the outcome as they will certainly determine how we are going to use electricity grids in the future.

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