Distributed generation and virtual power plants

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Distributed Generation and Virtual Power Plants

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***Abstract*- The paper describes the main characteristics of distributed generation (DG) and Virtual Power Plants (VPP). Distributed generation refers to the production of electricity near the consumption place using small-scale generating units. The distributed energy resources are renewable energies and cogeneration (simultaneous production of heat and electricity). A Virtual Power Plant is a cluster of DG installations (such as wind turbines, photovoltaic power plants, small hydro etc.) and any other sources of power that can cooperate together in the local area, and are controlled by a central control entity. The VPP is tested for different merit order values and grid connections (on-grid and off-grid) to track if this order is respected.**

***Index Terms*-- distributed generation, distributed energy resources, renewable energy, virtual power plants, merit order**

I. INTRODUCTION

The increased interest in renewable energy and production of heat and electricity near the load, combined with the storage and demand side management, would result in considerable changes in the system operation, where a substantial share of electricity is produced by technologies associated with the distributed generations (DGs). Despite the obvious benefits of the DG's integration in the distribution networks, their introduction into the traditional distribution network imposes new challenges of the system operation. All these challenges can be addressed by a smarter grid. Different approaches for this new electric system model are under development, e.g. active distribution network (ADN), cells, microgrids, virtual utilities, and virtual power plants (VPPs).[18]

Distributed generation (DG) refers to the production of power near the consumption place using cogeneration units and renewable energy sources (RES).

The Virtual Power Plant (VPP) is a new concept, the idea being born a few years ago. The main concept is based on the distributed generators which are connected, controlled and visualized as a single entity through a information communication technology (ICT) structure. This entity can include any other sources of power that can be aggregated and cooperate together in the local are, like photovoltaic (PV), wind turbines (WT), combined heat and power generators (CHP). This is a good solution for harnessing RES, considering the fact that these sources have problems when they are connecting to power networks due to the lack of transmission capacity in the power network and the variability of the power output due to the variations of their primary energy source.

The VPP researches focus on the design and development of VPP ([8]), control and management of a VPP ([7],[17],[21]) integration of DG and RES in the VPP ([2],[6],[20]) optimization and dispatch of a VPP ([3],[9],[11],[13],[23]). In this paper the merit order of a VPP containing different DER is tested to see if is respected.

VPP can reduce the load in the power network due to the fact that the power is generated and consumed locally without being sent through the transmission lines in other remote areas. This leads to a reduction or even an elimination of the energy loss factor. Also, energy storage must be used in order for the VPP to work better.

The peaks of power demand can be optimized by Distribution System Operators if the a VPP exists because the VPP generates power locally, and also the central generation can be operated in more stable conditions.

II. DISTRIBUTED GENERATION

The "distributed generation" (DG) term refers to the production of electricity near the consumption place. The distributed generation resources are the combined heat and power or cogeneration (CHP) units and the renewable energy sources (RES).

Renewable energy is energy from natural resources such as wind, sunlight, tides, waves, geothermal heat and biomass.

The most commonly used DG technologies and their typical module size are:

- Wind Turbine: 200 W - 3 MW;
- Photovoltaic Arrays (PV Arrays): 20 W - 100 kW;
- Small Hydro: 1 - 100 MW;
- Micro Hydro: 25 kW - 1 MW;
- Geothermal: 5 - 100 MW;
- Ocean Energy: 100 kW - 5 MW;
- Biomass Gasification: 100 kW - 20 MW;
- Battery Storage: 500 kW - 5 MW.

Distributed generation is characterized by some features which have not been present in traditional centralized systems:

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- the power generated is relatively small and has variations dependent on the availability and variability of primary energy source;
- the power flow is bidirectional, in comparison with the central generation system where the power flow is unidirectional;
- location in the network area dependent of the presence of the primary energy source.

The DG can play an important role in:

- reducing the transmission losses;
- improving the power quality;
- improving the reliability of the grid;
- providing better voltage support;
- reducing the greenhouse emissions.

The major obstacle for the distributed generation has been the high cost. However, the costs have decreased significantly over the past years.

DGs can be used in an isolated way, supplying the consumer's local demand, or integrated into the grid supplying energy to the electric power system, or a combination of these.

These generating units are generally connected to the power systems at the distribution level or consumers level. The central generation is presented in Fig. 1, while the distributed generation is presented in Fig. 2.

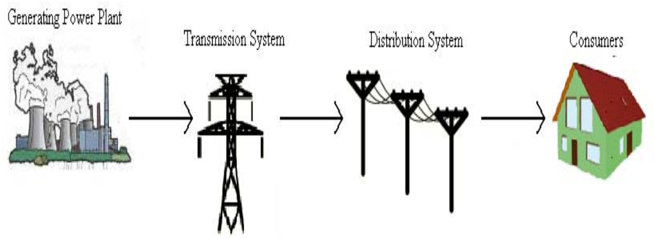

Fig. 1. A unidirectional centralised delivered power generation system

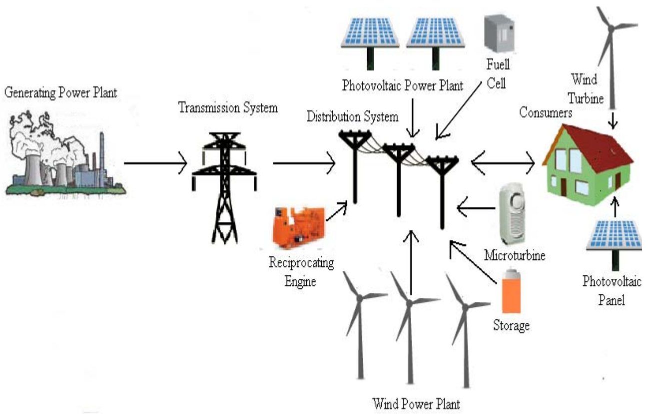

Fig. 2. A bidirectional system with distributed generation

Distributed generation is the key to meet growing power demand, provide benefits to consumer by improving the quality of life, relieves utility to supply additional loads and opens the opportunities for power trading in competitive environment.

III. VIRTUAL POWER PLANTS

The Virtual Power Plant is complementary to the classic central power plants by creating new suppliers with small, distributed power systems linked to form virtual pools that can be operated from a central control station.

A Virtual Power Plant comprises a multitude of DG installations (such as wind turbines, micro hydro etc.) and any other sources of power that can cooperate together in the local area, and are controlled by a central control entity.

Fig. 3 illustrates a model of the virtual plant. Consumers have to be supplied with energy.

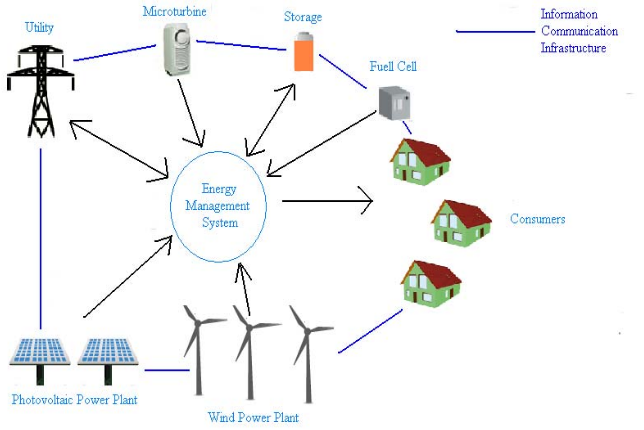

Fig. 3. A model of a Virtual Power Plant

Three different approaches to VPP can be used:

- Centralized Controlled Virtual Power Plant (Fig. 4), where the control logic is the responsibility of the VPP, and the market and production planning is separated from the distributed energy resources (DER). The advantage is that the VPP can use the DERs to meet market demand.

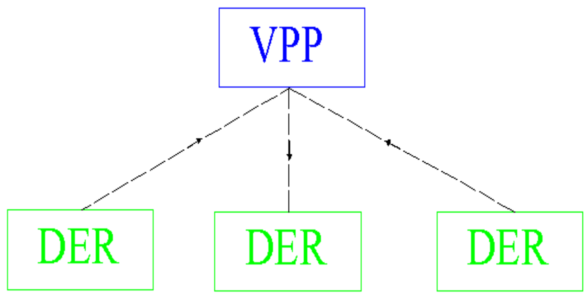

Fig. 4. The Centralized Controlled Virtual Power Plant design

- Distributed Controlled Virtual Power Plant (Fig. 5), where VPPs have different hierarchies modelled by defining VPPs on different levels. A local VPP is responsible for the coordination and supervision of a limited number of DERs, while the decisions are taken at a higher level VPP. This advantage is that simplifies the responsibilities and communication of the individual VPPs.

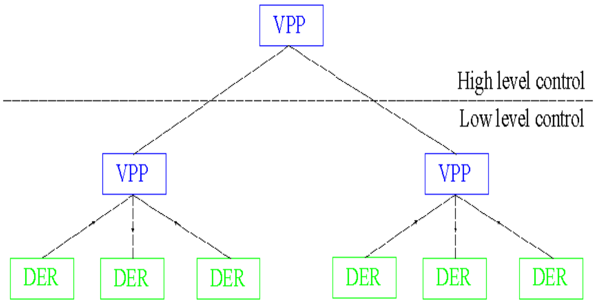

Fig. 5. The Distributed Controlled Virtual Power Plant design

- Fully Distributed Controlled Virtual Power Plant (Fig. 6), where every DER works in an independent way, participating and reacting to different states of the power system and market.

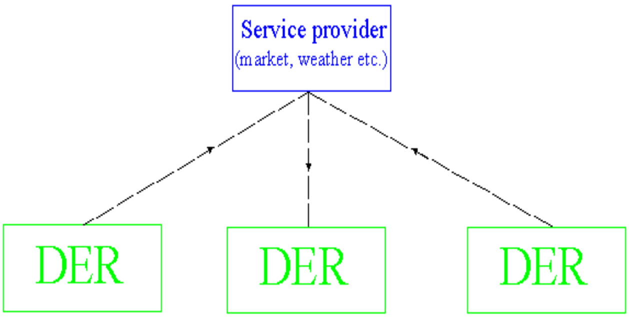

Fig. 6. The Fully Distributed Controlled Virtual Power Plant design

The VPP can play an important role in:

- reducing the CO_2 emissions due to the environmentally friendly sources;
- improving the reliability, security of supply and flexibility (high redundancy) of electricity supply, due to the multiple grid connections and provided system services;
- reducing the transmission losses due to fact they are close to the consumers;
- facilitating further introduction and optimum integration of small-scale renewable energy technologies in the energy supply chain;
- is working like a (distributed) central power plant and not only it supplies electricity into the grid, but also provides system services such as: active filtration of disturbances on the grid or compensation of reactive power;
- it enables delaying the investments required to reinforce electricity network infrastructure;
- enables Energy Distribution Companies (EDC's) to deliver 'tailor made total energy services' to individual customers, simultaneously optimizing electricity production and distribution at potentially lower costs;
- offers end-users more degrees of freedom and thus choices for a cost effective and environmentally sound energy supply solution at potentially lower costs, acting as a strong driver for technological innovation.

IV. CASE STUDY

A VPP is defined (Fig. 7) using the DIgSILENT PowerFactory software [24] for the test system presented in Fig. 8.

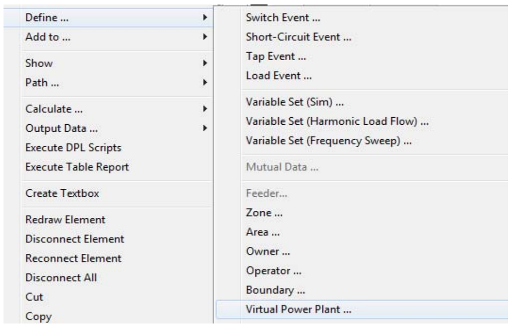

Fig. 7. VPP defining

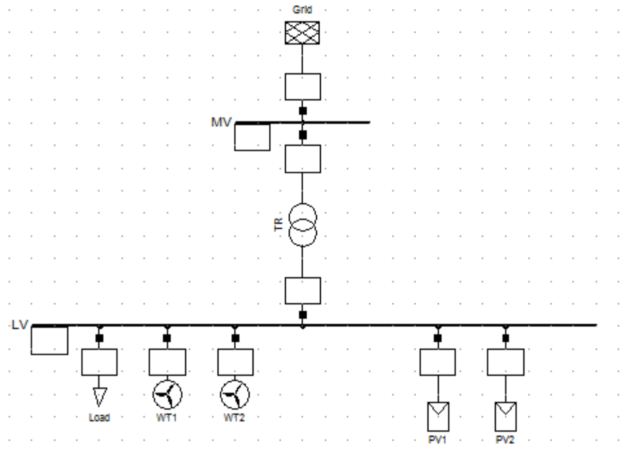

Fig. 8. One-line diagram of the test system

The test system has 4 DGs with the characteristics presented in table I. The system includes a 0.5 MW load and a feeder to supply the power if DGs can not cover the load. The VPP is tested for different merit order values and grid connections (on-grid and off-grid) to track if this order is respected. The merit order is presented in table II.

TABLE I
DISTRIBUTED GENERATORS CHARACTERISTICS

Generator	Generating type unit	Installed power [MW]
1	WT1	0.2
2	WT2	0.3
3	PV1	0.1
4	PV2	0.15

TABLE II
VPP MERIT ORDER

Generator	Merit order A	Merit order B
WT1	1	4
WT2	2	3
PV1	3	2
PV2	4	1

The merit order as defined in the two cases (A and B) are presented in Fig. 9 and Fig. 10.

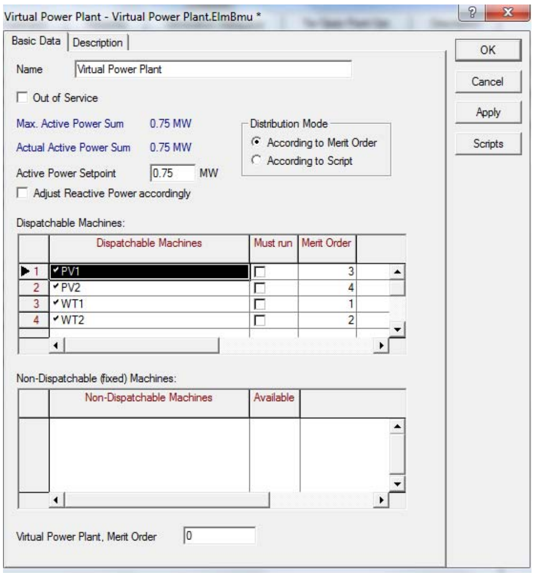

Fig. 9. Merit order in case A

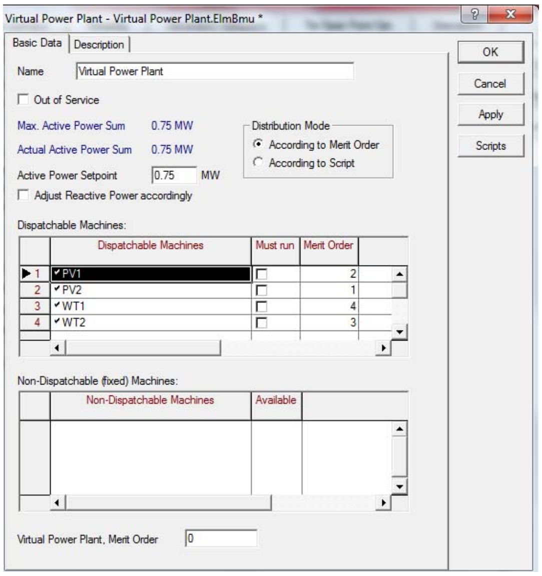

Fig. 10. Merit order in case B

In the first case the merit order is A and all the DG are on-grid. The merit order is respected and a surplus of 0.25 MW is supplied to the grid. In the second case the merit order is B and all the DG are on-grid. The merit order is respected and also 0.25 MW are supplied to the grid.

In the third case the merit order is A and WT1 is off-grid, while all the other DG are on-grid. The merit order is respected and 0.05 MW are supplied to the grid. In the fourth case the merit order is A and WT1 and WT2 are off-grid, while all the other DG are on-grid. The merit order is respected and 0.25 MW are received from the grid.

In the fifth case the merit order is A and all DG are off-grid, so the load is covered by the grid.

In the sixth case the merit order is B and PV1 and PV2 are off-grid, while all the other DG are on-grid. The merit order is respected and the load is covered by the DG.

In the seventh case the merit order is B and PV1, PV2 and WT1 are off-grid, while WT2 is on-grid. The merit order is respected and 0.2 MW are received from to the grid.

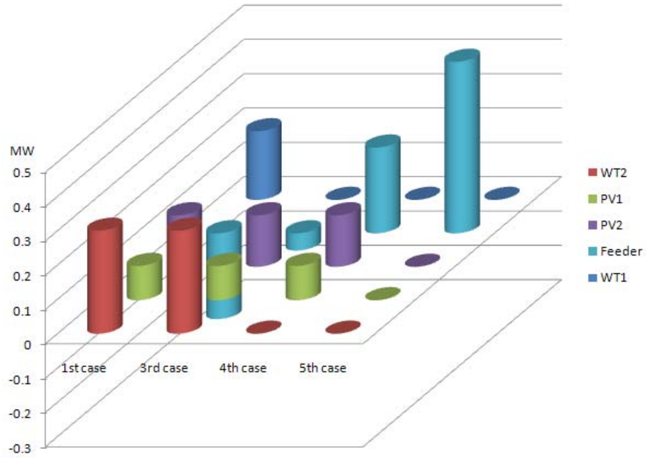

Fig. 11. Results in case A

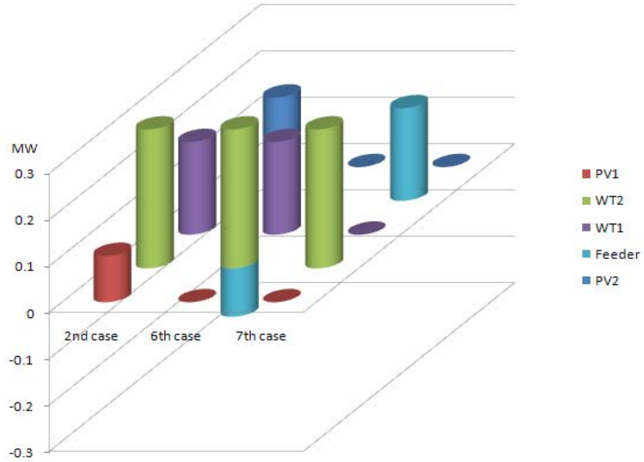

Fig. 12. Results in case B

V. CONCLUSIONS

The Distributed Generation and Virtual Power Plants are new concepts, being part of the Smart Grids alongside Demand-Side Management and Smart Metering. The main concept of Virtual Power Plants is based on the distributed generators which are connected, controlled and visualized as a single entity through a information communication technology structure.

A Virtual Power Plant can be considered for the aggregation of the Distributed Energy Resources increasing the participants benefits. These can be used to supply electricity to a load if they are close to it, like demonstrated in the case study. Also the power output of the distributed generator can be greater than the load, so they are supplying power to the grid, the power flow being in this case bidirectional. It is also demonstrated that the merit order defined in the two cases is respected, the Virtual Power Plant functioning according to this merit order.

The Virtual Power Plant can be used to access the power market, considering that the risk for a single distributed generator is very high. In order to participate at the power market a minimal nominal power is necessary.

The major problem with these distributed generation sources is the availability and variability of their primary energy source. A simple way of resolving this weather dependent power production is to use a storage unit.

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