Decentralized energy systems and services Technologies, policy and regulatory challeges

Abstract

Distributed Generation (DG) is a future power system configuration, proposed to primarily address various issues related to integration of distributed energy resources and increased demand of reliable electricity supply. It can provide higher supply reliability to high value customers, and clear economic and environmental benefits compared to traditional power systems. This paper summarizes the results of investigations on various technology, policy and regulatory issues faced by the development of DG. A number of barriers for DG and development required further are identified and presented. The potential economic benefits and contributions to environment achieved through micro-grid technologies are also described in the paper.

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Introduction

A more flexible and reliable power infrastructure is becoming more and more important due to tough requirements of society on electricity and its markets, and the vulnerability of the interconnected power system to grid failure caused by unexpected natural phenomena, which also intensify the burden on traditional electrical system. A restructured electric distribution network combined with small distributed energy resources (DER) units can provide different level of system reliability and service.

Distributed generation (DG) is typically located at or near load centers, it can run on renewable energy resources, combined heat and power (CHP, or cogeneration), reciprocating engine generators and small combustion turbines that run on diesel or natural gas, fossil fuels or waste heat. The equipment ranges in size from a few kilowatts (kW) to tens or, sometimes hundreds of megawatts (MW) (Lisa, 2005).

DG can be used to meet customer's power needs such as:

- higher power quality for electronic and other sensitive equipment;
- energy or capacity to the utility;
- reactive supply and voltage control from generation;
- system black-start; and
- heat or steam for use at or near the site.

Role of DG

DG is a future power system configuration providing clear economic and environmental benefits compared to expansion of our legacy of modern power systems. New and improved technologies are putting DG within the reach of more consumers.

Efficient use of resources

CHP systems which capture the waste heat produced during generation in industrial processes, heating or cooling (using absorption chilling technology) (Lisa, 2005), are much more energy-efficient than producing heat and power separately. It can maximize efficiency and minimize cost by sizing the project to match thermal load, and optimize use of natural gas and other fuels.

Improved reliability and power quality

A reliable system should need sufficient power supply to satisfy demand at all times, the ability to withstand unplanned outages of the electricgrid caused by natural events, and suitability of electricity for servicing loads. The presence of generation close to demand can enhance the power quality and reliability of electricity delivered to sensitive users, reduce reactive power consumption and improve voltage stability, provide the high reliability of supply into the service area to make systems more secure, particularly when combined with energy storage and power quality technologies.

Reduced investment risk

DG requires less project capital and less lead-time than large power plants, and can better match gradual increases in demand. It can reduce the risks to utilities from such eventualities as increase in fuel prices, technological obsolescence and regulatory risk.

Smaller, more modular generators, especially at existing business or industrial facilities, are easier to install than large power plants. Generating power at or near the point of consumption also reduces the need to install new transmission and distribution lines, so it can cut utility costs by delaying, reducing or eliminating the need for investments in distribution and transmission facilities.

Reduced environmental impact

Some types of DG, including some renewable energy resources or CHP systems, produce power with less environmental impact than conventional generation. An additional environmental benefit of these systems is the reduced carbon emission and consumption of expensive fossil fuels compared to separate production of electricity and useful thermal energy (by utilizing the heat generated with electricity concurrently, the thermal efficiency of fuel sources usage can achieve 90%-95% compared with 30°-55% for conventional power stations or 65% for ordinary boiler), thereby contributing to the commitments of developed countries or some regional governments to meet their carbon emissions reduction targets, such as proclaimed under Kyoto Protocol. DG also can provide an economic incentive for mitigating environmental problems.

Peak shaving

DG can reduce demand on the utility system when grid is most congested and power costs are highest. Customers could operate their DG units to participate in demand response programs. And utilities could make use of DG units to reduce their costs during the highest cost (peak load) hours.

Islanding operation

An improved quality of service for customers due to islanding operation could be achieved by DG in case of distribution network outages. Islanding operation is used to maintain the power supply of high value demand such as hospitals or communication sites, and plays a positive role in improving the security and quality of supply at the medium or low voltage levels.

Promotion of power market

Increasing the number of DG suppliers selling capacity and energy increases the competition in the power market. Further, in transmission-constrained areas DG may mitigate the exercise of marketing power and improve the efficiency of power markets.

Technologies development

The development trends of DG result in a lot of challenges. They can be subdivided in four spheres as follows (Thomas, 2006):

• *Technical*
Effect of DG on system control and grid services; effect on power quality, stability, safety and protection technology in grids.

• *Legal*
Rights and obligations of grid operators and system operators.

DG requires less project capital and less lead-time than large power plants, and can better match gradual increases in demand.

• *Economic*
Effect of DG on the economics of grid and power market.

• *Social*
Acceptance of improved technologies and products by customers.

While the application of DG can potentially reduce the need for traditional system expansion, operating a potentially huge number of DG also creates some challenges for controlling the network efficiently and safely (Thomas, 2006). The main technology problems which DG may have to confront are listed and described below:

• *New safety and protection schemes*
Safety and protection are a topic of pre-standardization. With the growing complexity of distribution systems, safety and protection schemes have to be improved. DG can affect the detection of grid faults since it can provide reverse power flows in system feeders, and it contributes short-circuit current to system which depends on its availability. The system including DG should be planned to allow safe and reliable grid operation by changing some boundary conditions. So, more flexible protection schemes with adaptable protection devices should be developed. For example, in order to account for DG with varying contribution to the short-circuit current, some dynamic parameterization of the protection devices should be studied.

• *New grid operational control approaches*
With the increasing share of fluctuating power generation and the growing number of small DG units, new grid operational control are mainly to achieve 1) improvement of the controllability of

The relevant standardization issues include safety, control, protection, measurement, testing and certification procedures, and trading regulations.

DG to improve system management and enforce the grid, 2) Power compensation of the generators supplied by the fluctuating sources, 3) Improvement of load management and prediction tools, and 4) providing ancillary services with the aim of stabilizing the system, such as developing fault-ride-through capabilities and frequency control or voltage control.

- *Integration of system management*

To achieve the new grid operational control approaches, and simplify the energy dispatch and the provision of ancillary services, appropriate information, communication and automation technologies for types of generation, load and storage devices should be considered for integration. For example, the control concept of large-scale virtual power plants (VPP), which are investigated by the new European project FENIXs.

- *Definition of system interfaces, protocols and data structure*

As key elements for future, efficient system monitoring, state estimation and control, interfaces, protocols and data structures should be fast, reliable, fault-tolerant and flexible. Using the improved forecasting methods and real-time risk management, the high quality of supply will be achieved by ancillary services with dynamic dispatch of generators, loads and storage devices.

- *Development of DG units*

Besides having significant advances in performance and quality, DG should have a high flexibility of the system's components to interconnect the market-oriented and distributed power system. It has the properties such as auto-mated configuration, convenient communication and easy upgrade. It can be a "Plug & Play" device to facilitate installation, operation and maintenance of DG.

- *Testing methods and pre-standardization*

With the decentralization in the power supply structure, a huge number of DGs interconnect with the grid. This results in the necessity for system standardization in order to guarantee the compatibility of the connected devices and develop the common requirements and quality criteria for automation, information and communication technologies. The relevant standardization issues include safety, control, protection, measurement, testing and certification procedures, and trading regulations.

- *Impact of DG penetration on grid*

It is important to demonstrate the applicability of high DG penetration in the system with real conditions or environment including laboratory and field experiments. Laboratory experiments may have some specific limitations but the field experiments can simulate real conditions. The detailed study will provide the operability of the DG developments.

- *Regulatory and contractual integration aspects*

Since regulation and legislation of binding conditions have influence or will even determine the grid's structure and the control approach, it is necessary to assess the interdependency of technical solutions and regulatory and contractual options in detail to demonstrate promising technical solutions under different regulatory and contractual conditions in different areas.

- *DG integration strategies*

Different region needs specific DG integration strategies. With the aim of a sustainable energy supply in the future, integration strategies need to be re-defined, market barriers need to be overcome, new structures have to be explored and utilized.

These challenges can be addressed by micro-grid partially, which coordinates types of DG in decentralized way, thereby permitting them to provide their full benefits and reducing control burden on the grid. The typical micro-grid structure is described in Fig.1 (Merrill, 2009).

Micro-grid for electricity

Micro-grid can be implemented on part of or entire feeders of a distribution substation while facilitating large-scale deployment of alternative renewable energy sources (medium-size wind/photovoltaic plants, biogas fuelled power plants, small hydro and biomass) or combined heat and power (CHP) gen-

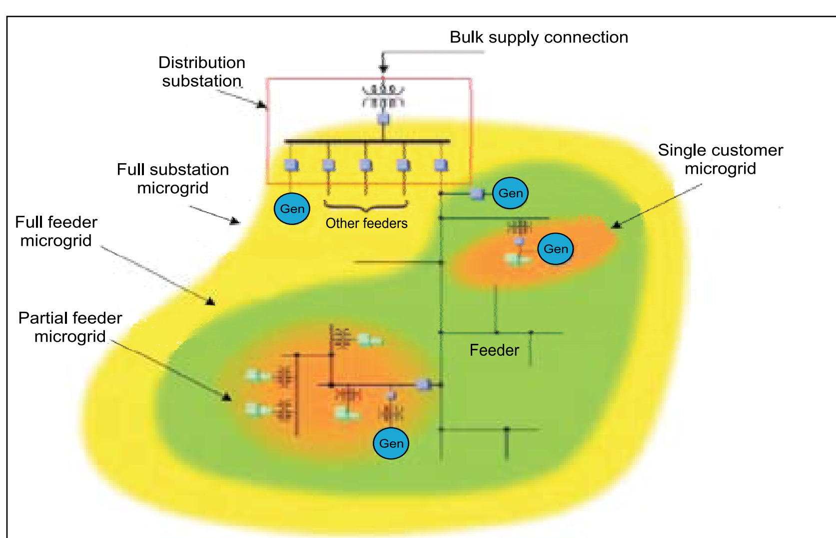

Fig. 1. Micro-grid structure

eration) (Johan and Farid, 2008). A utility micro-grid can offer ancillary services including compensate reactive power of local loads and maintain voltage profile or supply thermal energy through electricity generation.

Commercial and industrial micro-grid

Normally it is defined as critical or sensitive load which demands high quality and reliability of power supply. It can support advanced power management and distributed control strategies to serve industrial/commercial load demand, and help managing generation and demand for peak shaving or during the independent mode of operation. With its real-time control of power generation and consumption, commercial and industrial micro-grid can be considered as a constant or controllable load with predetermined power consumption from the utility grid.

Remote micro-grid

Remote micro-grid is usually used for power supply applications in remote communities and nonintegrated areas. These energy requirements can be supplied by installing DG to form autonomous grid which supply electricity and heat to the customer. The types of DG depend on the geographical characteristics and resource availability (such as wind-turbine, solar PV and small-hydro).

Policy and regulation

Status

Interconnection standards

Generally, the present regulatory practices have addressed sensibly the technical requirements for connecting DG to distribution systems in order to maintain safety and power quality including the development of new standards associated with DG technologies, connection practices, protection schemes, ancillary services and metering (Pudjianto and Strbac, 2008).

There are some international standards for DG including IEEE 1547 series standards, Canada C22.2 NO.257 standards (interconnecting inverter-based distribution network with electric power systems) and C22.3 NO.9 standards. The most influential standard for interconnecting distribution generation with electric power systems is IEEE 1547, which benefited from earlier utility industry work documented in IEC and IEEE standards (e.g., IEC EMC 61000; IEEE 929, 519, 1453; etc.) and ANSI C37 of protective relaying standards. Standards for DG is used to ensure that the operation of its interconnecting will not affect the security and stability of utility grid. The uniform standard for DG interconnection technology includes the following requirements and specifications generally:

- *Steady-state thermal constraints*

Confirm the requirements concerning the voltage level at the connectionpoint and the size of the generating plant.

- *Voltage regulation*

The value of the reactive power generated and the control mode (reactive power control or power factor) are determined by the steady state voltage requirements. e.g., control the voltage at Point of Common Coupling (PCC) within the fluctuation range.

- *Frequency regulation*

Provide the system frequency within the normal deviation range.

- *Synchronization requirements*

Confirm the voltage deviation, frequency deviation and phase angle deviation.

- *Protection system*

The behavior of DG units may be different depending on the type of its

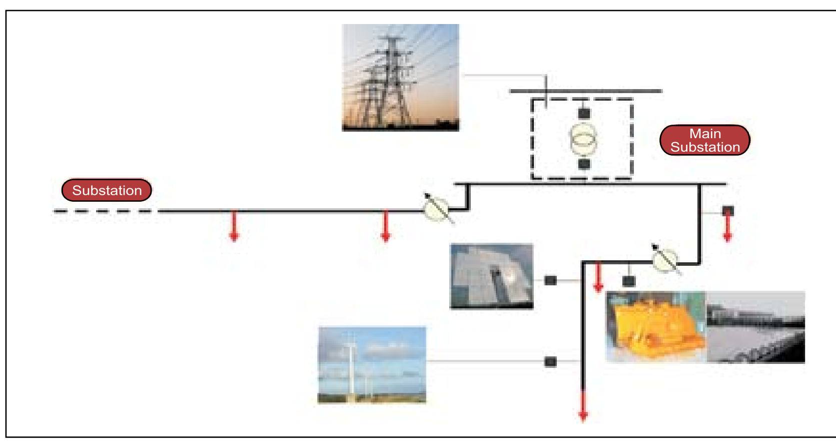

Fig. 2. Schematic diagram of utility micro-grid

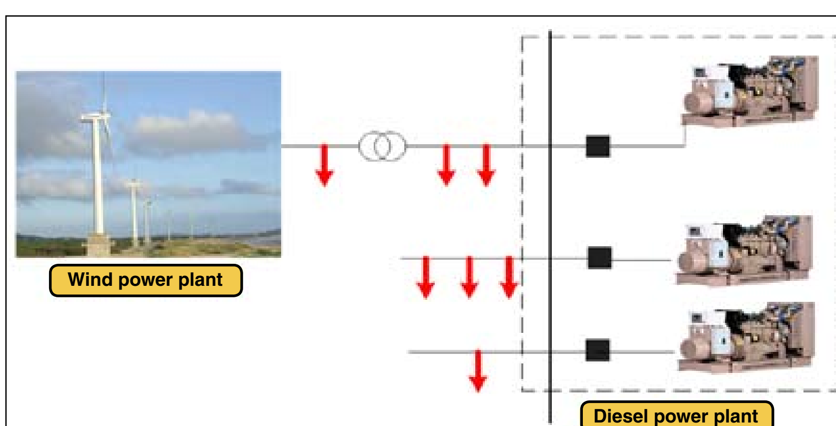

Fig. 3. Schematic diagram of remote micro-grid

generators (synchronous, induction or inverter). Protection system is used to ensure that the protection and automatic control systems equipped by the distribution system operator (DSO) operate properly, prevent operation of isolated networks under no-fault conditions, and disconnect the DG plants in the event of a fault condition instantly.

- *Power quality*

Voltage flicker: The flicker produced by a generating plant shall be limited in acceptable range.

Harmonics emission: The harmonic currents injected into the grid shall be limited according to existing national standards.

DC injection: DC injection which may lead to saturation of transformers and motors should be regulated.

- *Reconnection*
- *Islanding*

Incentive mechanisms

- *Initial investment subsidies*

Generally used to support the installation of large-scale renewable energy systems and energy-saving equipment, or to support the general infrastructure development (typically, resource research, training, etc.) in the form of grants.

- *Service contracts*

Service contracts arrangement in the form of grants.

- *Pre-discount*

Provided to end-users for purchasing small-scale renewable energy systems or energy-saving equipment.

- *Production incentives*

Provide subsidies and incentives according to electric power generated from DG, using KWh as the unit generally.

- *Low-interest loans*

Provide low-interest loans to DG producer or enterprises, or to customer purchasing renewable energy and energy-saving equipment.

- *Funds support*

Establish special funds or corporate special prizes to support infrastructure development of DG and its technological improvement projects.

- *Risk investment*

Provide debt investment or equity investments using public funds for DG producer or energy-saving projects.

- *Benchmark price*

Establish benchmark price for DG such as grid-connected solar photovoltaic pricing.

Regulatory Barriers

As costs for DG decline, some regulatory barriers could hinder its advancement:

- *Investment*

Relatively high capital cost for renewable energy generation technology, low electricity prices and high connection cost discourage the new investment.

- *Standards*

Most utilities have their own standards, policies, procedures and contract terms for interconnection to ensure that grid-connected generators are compatible with the utility grid for safety, reliability and other purposes, but there are no uniform technical standards, procedures or agreements (market support mechanisms) which can allow fast, inexpensive and simple interconnection of distribution generation with utility grid and reward DG according to its service to the network (Pudjianto and Strbac, 2005).

- *Price*

Generators have outages periodically for planned maintenance, and sometimes they have unscheduled shut downs. Customers may not produce enough electricity for their load demand or close the generators to purchase power from the utility. So Rates for backup power can not reflect actual costs properly.

- *Policies*

Some policies may be outdated or need refinement, such as technical standards designed for centralized generation. In addition, inequality of penalties for intermittency versus ancillary services and transaction costs could hinder the equal access for DG.

- *Incentives/force mechanisms*

Customers can't sell power to utility grid or other customers easily through the competitive bidding process. Lots of small customers may not be eligible to participate in the bidding process because of negotiating rates and other costs. Some utility solicitations may not coincide with the needs of customers, and have little incentive to buy energy from customer-sited generation.

There is lack of incentives/force mechanisms for DSO to change their passive operation philosophy to increase the amount of DG that can be connected. The main revenues of DSO consist of use of connection charges and system charges which are subject to economic regulation and not based on market. The system charge which is on the basis of price or revenue cap regulation does not stimulate DSOs to innovate. Connection charges are regulated in some markets. Since consumers may use part of the local DG production directly, the net outflow and connection charges may be reduced. DSOs will consider DG as a threat and may partially recover connection costs from DG operators, which hinders DG to become integral part of the electricity market.

- *Planning*

Utility planning for energy and capacity needs may neither coincide with the planning for distribution and transmission system, nor with DG. DG may defer or even eliminate the need for some projects of distribution and transmission. And rewarding distributor's based on assets and not based on performance (e.g., kWh/lines rather than supplying services) or reinforcing the distribution networks that reduce the utilities investments. Further, utilities may build their DG primarily to make profits by taking advantage of their own plant's operation.

- *Siting*

Because of size or using cogeneration

technologies with efficiency standards, some DG projects are exempt from the state's siting process. But some delays and additional cost- standards for siting process have not been established, so it does not ensure timely approval of installations.

• *Air quality permits*

If there is lack of clean technologies, emissions of greenhouse gases and other pollutants from DG could lead to serious pollution.

Suggestions

The challenges facing DG need a coherent policy to enable DG to play a more effective role. A coherent policy is essential to deliver sustainable, competitive and secure energy. It should cover a number of key goals and instruments:

Complete the electricity markets

- Uniform technical standards, procedures and agreements for interconnecting DG with utility should be implemented.
- Improved interconnections.
- Build the appropriate framework to stimulate new investment.
- Effective unbundling.
- Boosting the competitiveness and coordination between regulators.
- Adopt tariffs that properly reflect the benefits and costs of serving customers with DG.
- Establish standard purchase agreements for facilities eligible for standard rates.
- Investigate how to consider DG in utility grid planning and acquisition processes to meet distribution and transmission system needs at the lowest cost.

Clearly defined energy policy

- Improved network security through increased cooperation between network operators to increase import dependency and react to the challenges of high energy prices.
- Enhance the infrastructure necessary for the security of energy supplies and make best use of resources.
- Building technology platforms with the option of joint technology initiatives to develop power markets for energy innovation.
- Enable rapid and coordinated reaction to emergency energy supply situations.
- Greater physical security of infrastructure, establish international agreement on energy efficiency possibly through common standards.

Policies for DSO

- Compensation for DSO cost: Develop related mechanisms for removing the disincentives for utilities grid and facilitating cost-effective DG. High penetration of DG will increase the DSO's capital investment and operating cost, and DSOs should be compensated with different methods. For example, DSOs which are currently on the basis of price or revenue cap regulation, may consider the DG capacity or electricity generated as part of price or revenue cap regulation. DG will be included among benchmark assets when calculating the rate of return. The United Kingdom have incorporated DG capacity into the revenue cap regulation formula, and if DG project is certified as "Registered Power Zone (RPZ)", in the first five years, the project DSOs can get further compensation from local government.
- Take into account DG when planning distribution network: The mechanism using price or revenue cap regulation replaced by the control regulation based on the rate of return can incentivise DSO to provide more cost-effective investments; allow DSO to have a certain amount of budget in investments, take into account DG when planning distribution network and consider the investment savings as extra profits for DSO; appropriate financial compensation can

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encourage DG to help in network operation, and increase the utilization of existing equipment and reduce potential investment.

- Incentivise DSO to improve service quality with DG: The current business of DSOs is strongly influenced by bindings of the economic regulation that has been implemented in electricity markets. And new market structures and regulatory arrangements lead to stabilization strategies, the introduction of competition and the accompanying regulation has led to different behavioral strategies of actors in the electricity market. DG can operate in autonomous mode to improve system reliability, and provide ancillary services such as voltage control, or black start. In order to incentivize DSO to improve service quality with DG, quality of service will be taken into account in regulation policy for DSOs to improve its service quality, promote DSO from the traditional passive regulation management to positive management, and improve the opportunities of DG participation in system operation. The new regulation policy should promote a deeper and longer-term system transformation for DSOs.
- Provide more effective method to promote the implementation of the business unbundling of DSOs.

Policies for DG producer

- DG support Policies: The DG support policies must be compatible with related power markets standard. Electricity generated from renewable energy and CHP should reflect their social benefits, and try not to take a fixed tariff regulation high-permeability circumstances.

- Fee for grid and system usage: DG require to pay a disposable charge for interconnection, and system usage fee periodically. In order to create a fair environment for DG, charges for interconnection should be direct-type (shallow) and subject to government regulation. Government should develop the transparent and standardized method for calculation. The method can not compensate DSO's additional cost because of DG interconnection; this part of the costs can be compensated in the form of system usage fee assessed for all electricity users. System usage fee should reflect the costs and benefits of DG operation, and its calculation method should be compatible with state policy.
- DG involvement in systems and ancillary services: DG should be directly involved in the market services, with no minimum transaction charge or transaction capacitor limitation. Considering the DG capacity is typically small, a number of DG will be integrated through a set of technical and management tools to form Virtual Power Plant (VPP) (Manuel, 2006) as a participator in market activity. DG can provide voltage support according to the needs of DSO to reduced line loss.

Currently, some developments of DG are regarded as threats to the DSO's business. By developing new business activities, diversifying into new business modes, changing the passive operation policy into an active one, DSO can turn perceived threats into opportunities to have access to a wider range of options and incentives available in choosing the most efficient methods to operate their businesses.

Conclusion

Technical challenges such as coordination of the operation between DG and public electricity and active management of distribution networks, in addition to some important commercial challenges such as cost reflective network pricing and development of market for aggregators may be necessary to facilitate efficient integration of the operation and development of DG in the systems. This is in order to extract the additional value from DG such as network investment deferral, reducing the system operating costs, improving service quality and reliability and provision of a variety of services to support network operation during various disturbances.

As changes to the regulatory framework are new to the whole electricity sector, introduction of DG and its competition and the accompanying regulation has led to different behavioral strategies of actors in the electricity market. The potentially rapid development of DG initially may make DSOs enter a defensive strategy: DSOs could mitigate the impact of unfavorable regulatory and market developments on its business which may impact negatively on the development of DG. Obviously the most desirable stage is the entrepreneurial strategy. DG and DSOs will proactively seek to influence regulatory developments, cooperating with regulators to implement new regulatory arrangements so that DSOs are able to develop new activities and achieve more efficient operation.

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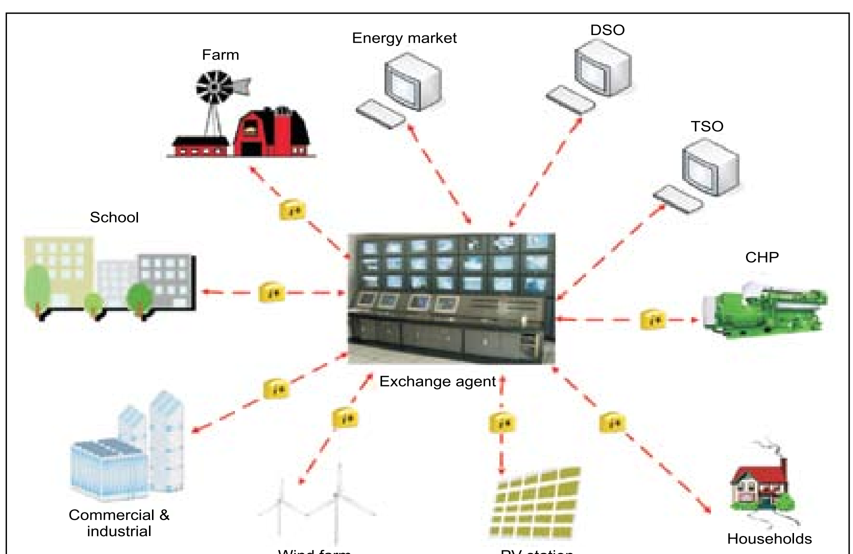

Fig. 4. Schematic diagram of Virtual Power Plant (VPP)