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Global Warming Mitigation Using Smart Micro-Grids

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Additional information is available at the end of the chapter

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1. Introduction

While focusing on some critical points such as decreasing global warming and ambient pollution, better utilization of renewable energy resources, energy management and improvement of power systems operation becomes the field of attention for many modern societies, power and energy engineers, academics, researchers and stakeholders everywhere are pondering the problems of depletion of fossil fuel resources, poor energy efficiency and environmental pollution. Besides, the conventional power grids and their assets that span large areas of the earth and form huge interconnected meshes, not only have a close relationship with social and economic activities, but also generate a substantial amount of criteria air pollutants, as evident by the continuing development of new rules under the clean air act for the electric power sector. One of the main disadvantages of such networks is their reliance on large centralized power generation units which produce particulate and gaseous emission pollutants. In other words, coal-fired power plants together with fossil fuel power stations that make a large portion of generation companies (GenCos) are the major contributors in pollutants include Greenhouse Gases (GHGs), fine particulates, oxides of nitrogen (NO_x), oxides of sulfur (SO_x) and mercury (Hg), which are thought to cause global warming. They are also contributing to carbon dioxide (CO₂) emissions as well as producing solid waste in the form of fly ash and bottom ash. Therefore, a new trend for modernization of the electricity distribution system and generation sector has been proposed to address these issues suitably. This plan of action mainly focuses on generating energy locally at distribution voltage level through incorporation of small-scale, low carbon, non-conventional and renewable energy sources, such as wind, solar, fuel cell, biogas, natural gas, microturbines, etc., and their integration into the utility distribution network. Generally, such energy choices are regarded as dispersed or distributed generation (DG) and the generators are termed as distributed energy resources (DERs) or microsources. On the other hand, conventional power grids which are mostly passive distribution networks

with one-way electricity transportation are in the era of major modification and alteration into active distribution networks (ADNs) with DERs and bidirectional electricity transportation (Chowdhury et al., 2008a,2008b). In this regard, flexible and intelligent control systems must be incorporated in ADNs to exploit clean energy from renewable DERs. Advanced systems and key technologies should be also employed for integration of DERs. With low incorporation of renewable energy sources (RESs) the total effect on grid operations is confined, but as the penetrations of such resources increase, their mutual effects increase too (Angel & Rújula, 2009 ; Clark & Isherwood, 2004). Nevertheless, harness of RESs, even when there are good potential resources, may be problematic due to their variable and intermittent natures, thus RESs cannot necessarily be operated in a conventional manner. Instead, RESs behaviors can be predicted via expert estimators and the forecast information is exactly the kind of information that an ADN must uses to improve system efficiency (Chowdhury et al., 2008c, 2008d).

2. Smart Micro-Grids: A true way to mitigate global warming

It was mentioned earlier that existing transmission and distribution systems in many parts of the world use technologies and strategies that are many decades old. They make limited use of digital communication and control technologies. To update this aging infrastructure and to create a power system that meets today’s growing and changing needs, developed societies try to create intelligent means which use advanced sensing, communication, and control technologies to distribute electricity more effectively, economically and securely. Additionally, there are some important side benefits for the consumers such as potential lower cost, higher service reliability, better power quality, increased energy efficiency and energy independence that are all reasons for an increased interest in distributed energy resources and focusing on what are called “Smart Micro-Grids”, as the future of power systems. Although the term “Smart Grid” is frequently used today, there is no agreement on its definition. In other words, the concept of intelligence in Smart Grid design and how it will be measured is unclear. The U.S. Department of Energy (DOE) mentioned in one of its recent issues that a Smart Grid uses digital technology to improve reliability, security and efficiency of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources (U.S. DOE, 2008). Later, in June 2008, a meeting of industry leaders was held at the U.S. Department of Energy and seven different characteristics were declared for the Smart Grid concept:

1. Better utilization of conventional assets, optimization and efficient operation,
2. Accommodation of all generation and storage options in power grids,
3. Supply of power quality as a great need of today’s industry,
4. Prediction of events and fast response to system disturbances in a self-healing manner,
5. Robust operation against attacks and natural disasters,
6. Active participation of consumers,
7. Introduction of new services, products and markets.

While details vary greatly about the definition of a Smart Grid, a general definition can be made as follow: A Smart Grid is an intelligent, auto-balancing, self-healing power grid that accepts any source of fuel as its input and transforms it into a consumer's end use with minimal human intervention. It is a course of action that will result in better utilization of renewable energy resources and reduce environmental vestiges as much as possible. It has a sense of detection to understand where it is loaded beyond capacity and has the ability to reroute power to lessen overload and impede potential outages. It is a base that provides real-time communication between consumers and the utility in order to optimize energy harvesting based on environmental benefits or cost preferences. However, it should be noted that deployment of Smart Grid technologies will occur over a long period of time, adding successive layers of functionality and capability onto existing equipment and systems. Although technology is the focal point, it is only a way to achieve the goal, and the smart grid should be defined by more extensive characteristics (Anvari Moghaddam et al., 2010b, 2010c, 2011b). How the Smart Grid differs from conventional grids we know today, is illustrated in Figs. 1, 2. Conventional networks are designed to support large power units that serve faraway consumers via one-way transmission and distribution grids (Fig.1), but the future grids will necessarily be two-way real time systems, where power is generated not only by a large number of small and distributed energy resources but also by large power plants(ABB, 2009). Power flow across the network is based on a mesh grid structure rather than a hierarchical one (Fig. 2).

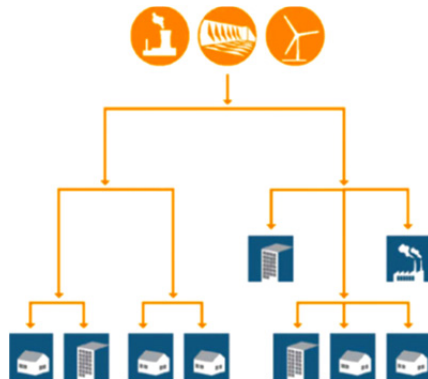


Figure 1. Conventional power system

Likewise, the term “Micro-Grid” in its whole vision, is an exemplar of a macro-grid in which local energy potentials are mutually connected with each other as well as with the L.V utility and make a small-scaled power grid. In such a network, DGs are exploited extensively both in forms of renewable (e.g., wind and solar) and non-conventional (micro-turbine, fuel cell, diesel generator) resources, because these emerging prime movers have lower emission and the potential to have lower cost negating traditional economies of scale (Anvari Moghaddam et al., 2011c, 2012). In addition to DGs, storage options are also used widely to offset expensive energy purchases from utility or to store energy during off-peak hours for an anticipated price spike (Divya & Østergaard, 2009;

Kaldellis & Zafirakis, 2007). In a typical Micro-Grid, DERs generally have different owners handle the autonomous operation of the grid with the help of local controllers (μ c or MGLC) which are joined with each DER and Micro-Grid central controller (μ cc or MGCC). Moreover, the central control unit (CCU), which is a part of MGCC, does the optimization process to achieve a robust and optimal plan of action for the smart operation of the Micro-Grid



Figure 2. Future power system (Smart Grid)

2.1. Impacts of Smart Grids on energy efficiency and low carbon economy

From a utility point of view, implementation of a Smart Grid can yield several advantages over the conventional one, as shown in Fig.3. A Smart Grid can organize operations and enable utilities to tap into new paths to save energy and reduce environmental footprints to levels greater than would otherwise be attainable (Abbasi & Seifi, 2010).

As the figure shows, selected mechanisms empowered by a Smart Grid, represent pathways to energy savings and/or emission reductions, although some of these benefits overlap across the various goals. For example, indirect feedback to customers using improved billing is related to improvements both in operational efficiency and customer energy use behavior. Similarly, greater options for dynamic pricing and demand response are related to customer service enhancement as well as to demand response activation. It's also notable that some of the ways associated with the mentioned goals are slightly indirect or their energy savings potentials are difficult to express on a national standard, because they include complex market, institutional, and behavioral interactions that can vary considerably across the nations (European Commission, 2006). Considering different mechanisms have been identified earlier, this section of the work highlights the more direct ways for energy savings and reduced carbon emissions in order to get better insight into the Smart Grid environmental benefits. As shown in Fig. 3, two of the pathways can directly reduce carbon emissions while inducing energy savings: (i) higher penetration of RESs and their greater integration into the grid environment and (ii) further utilization of plug-in hybrid electric vehicles (PHEVs) and facilitation of their deployments.

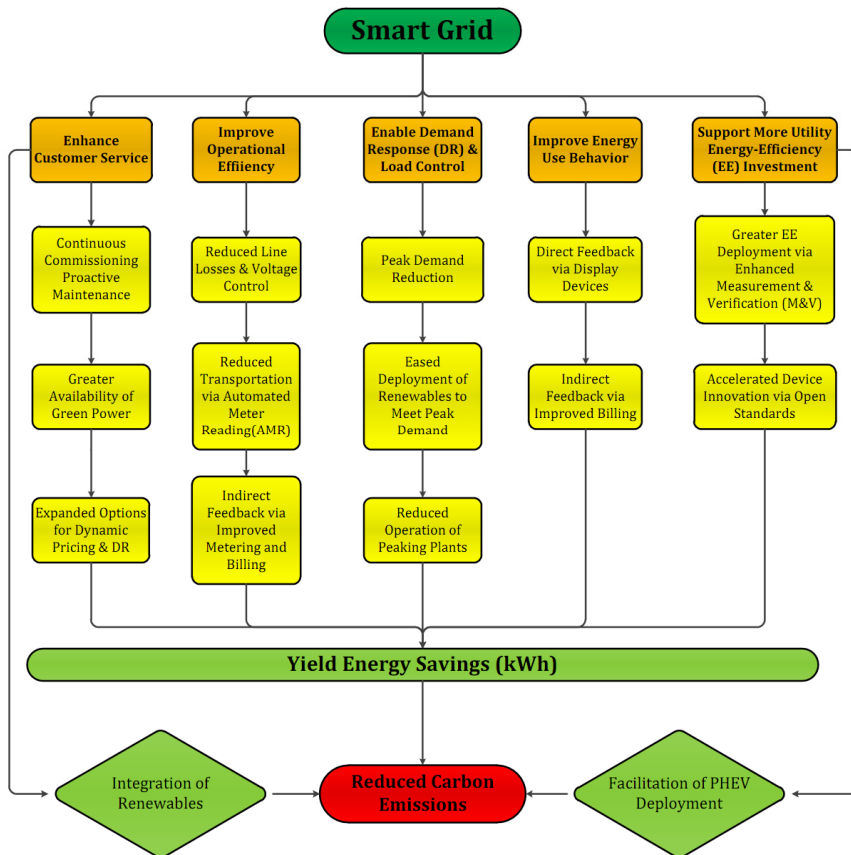


Figure 3. Smart Grid mechanisms for energy efficiency & emission reduction

2.1.1.1. Integration of renewable energy sources

A Smart Grid facilitates more seamless integration of RESs and other DERs including energy storage options due to its advanced control and communications capabilities. Earlier studies have indicated that energy storage can compensate for the stochastic nature and sudden deficiencies of RESs for short periods without suffering loss of load events, and without the need to start more generating plants (Anvari Moghaddam et al., 2010a, 2011a). Moreover, with higher penetration rates of renewables such as wind and solar in the overall supply mix, utilities will decrease their carbon emissions and will be better situated to meet their corresponding states' renewable portfolio standard (RPS) mandates. In a same manner, customers not only receive a greater share of green power from the utility, but also integrate their individual microsources and/or renewable options (e.g., rooftop photovoltaic systems) into the grid for participation in net metering programs. From the other point of view, all advantages of non-conventional or renewable low-carbon generation technologies and high-

efficiency combined heat and power (CHP) systems can be achieved through implementation of a Smart Micro-Grid (Battaglini et al., 2009 ; Esmaili et al., 2006). In this regard, energy and power can be produced in an efficient manner through capturing waste heat by using the CHP-based DERs, while environmental pollution can be reduced extensively by generating clean power with the help of low-carbon DERs. Although DERs appear in various types and range from Micro-CHP systems based on Stirling engines, fuel cells and microturbines to renewable ones like solar photovoltaic (PV) systems, wind energy conversion systems (WECS) and small-scale hydroelectric generation, the choice of a particular DER depends strongly on the climatic conditions, regional anatomy and fuel availability (Hajizadeh & Golkar, 2007 ; Hammons, 2006). Similarly, application of biofuels and different storage technologies such as Compressed Air Energy Storage (CAES) and ultra-capacitors are investigated comprehensively with regard to a certain geographical location and some environmental constraints (Koeppel, 2008). Moreover, to lessen the greenhouse gas emissions and mitigate global warming, most of the countries including the European Union(EU) and UK, are advocating the schemes associated with further exploitation of RESs as well as better integration of DG systems as part of the Kyoto protocol. Besides, with the continuous depletion of fossil fuels as a result of growing needs in energy sector, most of the utilities are looking for non-conventional/renewable energy resources as an alternative.

2.1.2. Deployment of Plug-In Hybrid Electric Vehicles (PHEVs)

Implementation of a Smart Grid environment will also facilitate the market adoption and accommodate all available options for better integration and interconnection of plug-in hybrid electric vehicles (PHEVs), as the future of clean transportation systems. These battery-like vehicles can be used as substitutions for conventional non-renewable energy sources while they can be plugged into electrical outlets for recharging (EPRI, 2008a). In comparison with the current hybrid vehicles, PHEVs have different operational modes as well as flexibility in applications, thus they can further decrease the reliance on gasoline to fuel the internal combustion engines. Moreover, incorporation of PHEVs will save fuel costs, since they run on the equivalent of 75 cents per gallon or better at today's electricity prices. From an environmental perspective, the deployment of PHEVs will result in a considerable reduction in air pollutant emissions. As an illustrative example, it was announced in 2007 by EPRI and the Natural Resources Defense Council (NRDC) that PHEVs will lead to a reduction of 3.4 to 10.3 billion metric tons of GHGs by 2050, as a function of PHEV fleet penetration and the carbon-intensity of the electricity generation mix (EPRI, 2007a, 2007b, 2008b). Likewise, this EPRI study revealed that PHEVs could result in GHGs reductions of 100 to 300 million metric tons of CO₂ per year, based on a range of planned PHEV market share considering the reference year of 2030. From a utility viewpoint, development of Smart Grid supports further participation of PHEVs in market actions. The ability to charge PHEVs during the night with low energy price tariffs provides operational benefits through improved system load factor, environmental benefits through mitigation of GHGs emissions and economical profits through utilization of base load resources. Development of a Smart

Grid makes it possible to send signals to consumers intelligently on when to charge their vehicles or provide multi-tariff rates to encourage off-peak charging. Alternatively, PHEVs can be used for peak-shaving or power-quality applications by storing electrical energy in their onboard batteries, offering potentially powerful synergies to complement the electric power grid. With an expert coordination among smart vehicles and the Smart Grid, PHEVs may serve as a dispersed generation system itself, providing energy efficiency, stability and environmental benefits for the grid operation. Considering the attributes inherent in a typical PHEV, it is reasonable to assign some share of projected PHEV CO₂ reduction impact to the development of a Smart Grid. On the basis of EPRI research studies, a portion of 10% to 20% can be dedicated to PHEV CO₂ reduction impact in a smart grid environment, which in turn reduces the net CO₂ emissions from 10 to 60 million metric tons of CO₂ in 2030.

2.2. Impacts of Micro-Grids on atmospheric emissions and environmental issues

Regardless of market sensitivity, renewable energy microsourses and other low-carbon generation units can effectively reduce emissions and environmental warming and this is one of the most important reasons to support Micro-Grid design and implementation. To assure eco-friendly operation, the Micro-Grid central controller (CC) should be programmed in a way to make optimal decisions for unit commitment based on the lowest net emission production, considering both displaced emission and local emission from microsourses as objectives. In the presence of market sensitivity, decision-making algorithms become more complex, because market-responsive CC should include “emission minimization” as an additional criterion for dispatch decisions (Chuang & McGranaghan, 2008). This complexity can be handled suitably provided that reasonable and fair emission tariffs are introduced into the market system, i.e., the electricity supplied from the microsourses would be valued through price tariffs following the net reduction in emissions is acquired. In that case, a measure of the net emission reduction is available from the price signals itself. Emission tariffs might be also established on the basis of multi-criteria functions covering several factors such as time, season and location, so that at worst pollution times and locations, the tariffs would be most attractive. In such a situation, emission price tariffs are provided as extra input signals to the CC to dispatch microsourses optimally for minimizing emissions (Cinar et al., 2010). It’s also worthy of note that environmental policy initiatives and existing regulatory guidance should be given due importance for moving toward a cleaner ambient. In this regard, the US Environmental Protection Agency put limits on the amount of emissions from six air pollutants, including: nitrogen dioxide (NO₂), carbon monoxide (CO), sulphur dioxide (SO₂), lead (Pb), ozone (O₃) and particulates. According to recent reports on environmental pollutants it’s shown that conventional power plants and fossil-fuelled vehicles are the largest producers of NO_x gases. Similarly, large gas turbines and reciprocating engines result in sufficient NO_x production when they are operating at high temperature. Conversely, microturbines and fuel cells emit lower amounts of NO_x because of lower combustion temperatures; hence, their application as microsourses would significantly reduce carbon and nitrogen compounds and total hydrocarbons (THC). Besides, many efforts are made at the resent time to develop combined environmental-

economic optimization (EED) algorithms for dispatching DGs and microsources considering cost of operation and atmospheric emissions like NO_x , SO_2 , CO_2 , etc., as weighted objective functions simultaneously (Lagorse, 2010; Momoh, 2009). For CHP-based microsources, usually heat optimization is at the head of concern and optimization of electricity is observed at the second step; i.e., according to customers' heat requirement, the amount of power production from CHP is determined. It's nice to mention that for large-scale CHP systems there are many technical and environmental constraints that must be met during the operation and they are mainly as follows:

1. Demand-supply balance: at any hours of a given day, the amount of heat generation must be equal to the heat demand.
2. Energy efficiency: the maximum electrical power generated in the process should be used to supply the electrical loads and surplus of demand must be provided through other microsources or purchased from the market.
3. Emissions cap: The NO_x , CO_2 and SO_2 emissions must be maintained at specified limits.

According to the importance of the optimization variables, shadow prices, which are used to quantify the importance of each variable, might be developed to provide appropriate weighting factors to each of the above-mentioned constraints. Such prices might be a function of the real-time price, the demand, the time of use and the season. Shadow prices might be also defined hourly for each type of pollutants during the operation period for generating both electrical and heat energy. All the mentioned parameters would be calculated and used by the Micro-Grid's CC to arrive economically at an optimal dispatch solution using an iterative procedure. During the optimization process, both seasonal and diurnal trends and area-wise variations of emissions should be given right weighting factors for appropriate scheduling and controlling the operation of generators. For example, the amount of ozone emission is augmented in late spring and during the summer when ambient temperature is high. In a similar manner, peak ozone concentrations occur significantly downwind of emission sources, mainly due to the lengthy reaction times. Moreover, ozone concentration is increased in more crowded areas at considerable distances downwind from urban areas. Thus, during the warmer periods of times, it is wise to reduce NO_x emission in or near dense populated places to decrease ozone formation. CHP-based microturbines, which play an important role in Micro-Grids, can effectively address the corresponding issue. Beyond the above-mentioned points, there are some other parameters that must be provided for controlling hazardous pollution and mitigating global warming. Such extra information includes: fair rate incentives based on specific pollutant production, displaced emissions, expected temperature, and etc.

2.2.1. Minimization of pollutant deposition using microsources

As discussed in previous section, Micro-Grid is considered as a small-scale, medium or low voltage (MV/LV) combined heat and power (CHP) system for supplying electrical power and energy needs of small local loads. More than one Micro-Grid may also be integrated to

constitute power parks for supplying larger load demands. In this regard, the microsources inside a typical Micro-Grid serve as primary means of energy producers while they are using diverse types of low-carbon generation technologies. As an example, combined heat and power (CHP) system is a popular kind of DER useful for Micro-Grid applications. Such cogeneration system has the advantage of energy-efficient power generation via utilization of waste heat (see Fig. 4).

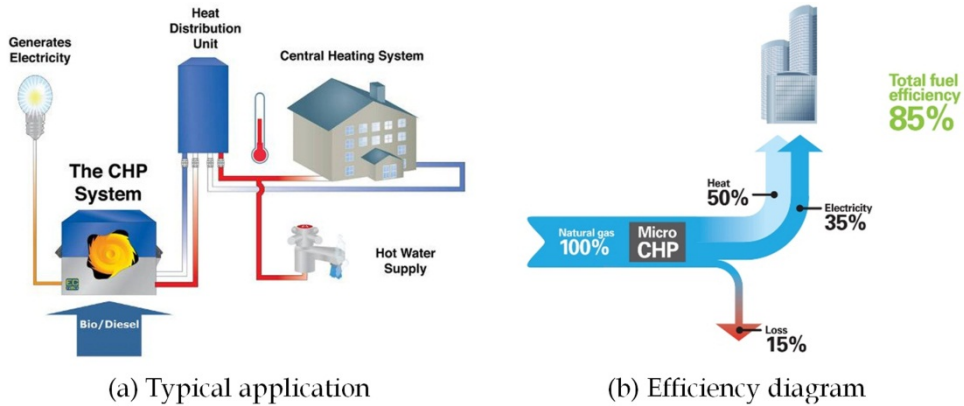


Figure 4. Combined Heat & Power (CHP) system

Unlike fossil-fuelled generation units, CHP-based generators capture and use the waste heat for industrial processes or other local heating purposes. Moreover, the heat reproduced at moderate temperatures (100–180 °C) can also be used in absorption chillers for cooling mechanism. In this way, a CHP system can potentially reach an efficiency of more than 80%, compared with that of about 35% for conventional power plants. The efficiency can be even more when the heat is used locally, in other words, if the produced heat is transmitted over long distances for supplying remote thermal loads, not only the overall efficiency reduces, but also the net operating cost and emission increases. On the other hand, because of lower electrical loss, CHP plants can be situated somewhere faraway from electrical loads and their produced energy can be transmitted over much longer distances, however, it should be kept in mind that such systems must always be located close to the heat loads for better efficiency and performance (Pecas Lopes et al., 2007). On the whole, it has been found that application of CHP micro-energy source yields a reduction of 35% in primary energy use in comparison with conventional power plants and heat-only boilers, 30% reduction in emission with respect to coal-fired power plants and 10% reduction in emission with respect to combined cycle gas-turbine plants. In addition to CHP-based systems, microturbines are also small and simple-cycle gas turbines that are used extensively in Micro-Grids and ranged typically from 25 to 300 kW based on the output power (Saha et al., 2008). Actually, microturbines have several advantages and inherent technologies that are briefly include: recuperation, low NO_x emission technology and advanced material usage such as ceramic for the hot section parts. Microturbines have also various structural and operational features as shown in Fig. 5.

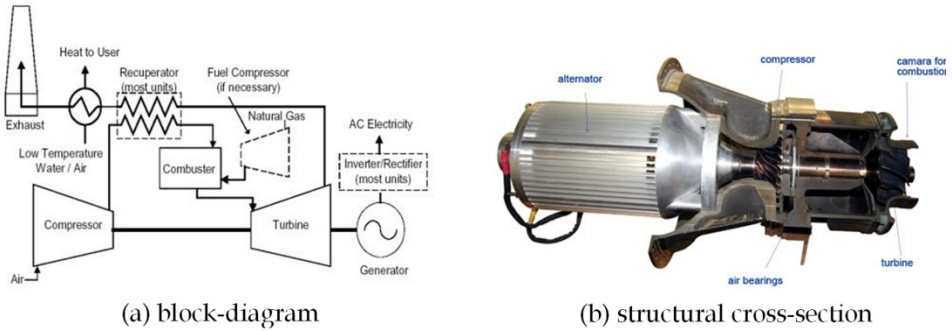


Figure 5. Schematic of a microturbine

From a structural prospective, they are relatively smaller in size as compared to other DERs, have simpler installation procedure and lower level of noise and vibrations. They also have the capability of using alternative fuels, like natural gas, diesel, ethanol and landfill gas, and other biomass-derived liquids and gases. From an operational viewpoint it can be said that, microturbines are designed for 11,000 hours of operation between major overhauls with a service life of at least 45,000 hours. Total cost of such system is lower than \$500 per kW which is competitive with alternatives including grid power for market applications. They can also reach the range of 25–30% in fuel-to-electricity conversion rate while the energy efficiency level can be greater than 80% if the waste heat recovery is used for CHP applications. In addition, microturbines participate actively in clean air action by producing reduced amounts of NO_x emissions which are lower than 7 ppm for natural gas machines. As a matter of fact, the net emission belongs to a microturbine greatly depends on its operating temperature, power output and the control of the combustion process, therefore it can be minimized only through quick and accurate control of the combustion process which is done suitably by the microturbine's internal control system. On the other hand, the central controller of the Micro-Grid (μ_{cc}) may only provide the generation set points for the microturbine considering the net emission production in relation with power level and displaced emissions for both heat and electric power output. The CC may also monitor the remaining oxygen concentration in the engine exhaust for some particular applications. In order to minimize NO_x emission, microturbine manufacturers usually apply various controlling algorithms along with some combustion control methods. For instance, wet diluent injection (WDI) is a controlling approach for NO_x reduction in microturbines where water or steam is injected into the combustion zone to moderate the temperature, however, this method increases CO_2 production, reduces efficiency and shortens equipment life.

Another type for microsources is regarded as fuel cell (FC) which converts chemical energy of a fuel into electrical energy directly (Fig. 6). Basically, it consists of two electrodes with different polarities and an electrolyte that dissociates fully or partially into ions when dissolved in a solvent, producing a solution that conducts electricity.

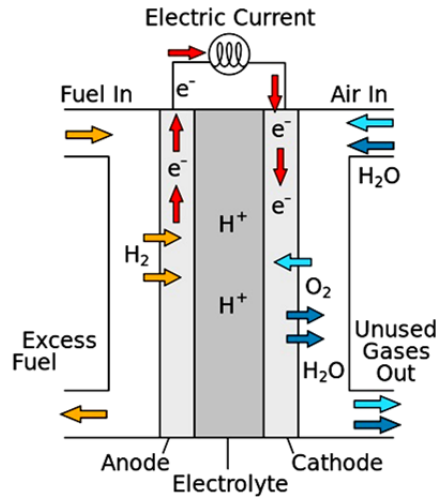


Figure 6. Schematic of a Hydrogen FC

From an operational perspective, the FC is very similar to a storage battery, however, the reactants and products are not stored, but are continuously fed into the cell. During operation, the hydrogen-rich fuel is fed to the anode and the oxidant which is usually air is conducted toward the cathode separately. Through an electrochemical oxidation and reduction process, electricity, as the main output, is produced at the electrodes while heat and water are produced as by-products. Compared to conventional generators, FCs have several advantages. First, they are very clean means of energy production and serves as eco-friendly sources of energy. Because of their higher efficiency and lower fuel oxidation temperature, they emit lower amounts of CO_2 and NO_x per kilowatt of output power. Due to the absence of any rotating parts in FCs' structures, they are robust, low maintenance and almost free from noise and vibration. Moreover, they can run with different kinds of fuels like natural gas, propane, landfill gas, anaerobic digester gas, diesel, naphtha, methanol and hydrogen, therefore, this technology will not become obsolete due to versatility of consuming fuels or unavailability of energy resources. Apart from the mentioned microsourses, solar photovoltaic (PV) is another kind of DER that helps the minimization of pollutants deposition by generating electricity from solar energy. PV systems have several advantages over the conventional generators as are stated in the following:

1. Inexhaustible , clean and free nature of solar energy,
2. Minimum environmental impact,
3. Lower customers' electricity bills due to free availability of sunlight,
4. Long operational lifetime of over 30 years with minimum maintenance,
5. Noiseless operation

Owing to the above benefits, it's found that today's PV systems not only have the potential to supply a big portion of the world's energy needs in a sustainable and renewable manner, but also have the capability to reduce environmental footprints.

3. Technical, economical and environmental advantages of Smart Micro-Grids

It has explained earlier that effective utilization of waste heat in CHP-based microsourses is one of the potential benefits of a Smart Micro-Grid. Besides, good coordination between heat generation and efficient heat utilization is a requisite task for energy optimization in Smart Micro-Grids that can be achieved by using heat generation control and thermal process control features in Smart Central Controller (SCC). Process optimization functions can also be built in the SCC to increase overall system efficiency and reliability (Molderink et al., 2009; Venayagamoorthy, 2009). On the other hand, Smart Micro-Grid has the ability to affect electricity and gas markets significantly, when its share of market participation is encouraged. In this regard, insightful market reforms must be made to allow active participation, while good financial incentives should be provided for owners to invest in Smart Micro-Grids. Once market participation is assured, Smart Micro-Grids can effectively supply quality services for distribution systems as well as ancillary services for the utilities. Similarly, with rising concern for global warming and environmental pollution, most countries are focusing on utilizing eco-friendly plants with low-carbon generators and trying to reduce their emission levels by 50% as per the Kyoto Protocol, considering the reference year of 2050. Regarding this planning horizon, Smart Micro-Grids together with cleaner microsourses and RESs, strongly have the ability to reduce the overall environmental impact caused by existing infrastructures. To fulfill the clean air action, SCCs must be also programmed in a way to make smart dispatch decisions for DGs considering pollution level caused by the net emission in the locality (Figueiredo & Martins, 2010). Likewise, to give due importance and authority to Smart Micro-Grids that would help to mitigate the net greenhouse gas (GHG) and particulate emissions in the environment, rules and regulations must be made subsequently. On the whole, development of Smart Micro-Grid is very promising for the electric energy industry because of the following advantages:

- **Environmental benefits** – Smart Micro-Grids can reduce gaseous and particulate emissions and help to mitigate global warming through incorporation of low-carbon RESs together with close control of the combustion process. Moreover, local distribution of microsourses and physical proximity of them with loads and consumers may help to increase the awareness of customers towards judicious energy usage.
- **Economical benefits** – Smart Micro-Grids can also end in cost savings in multiple ways: first, significant savings may be achieved from utilization of waste heat in CHP mode of operation. Second, no considerable and costly infrastructure is required for heat and power transmission as the microsourses are physically situated close to the customer loads. This way of energy production gives a total energy efficiency of more than 80% as compared to a maximum of 40% for conventional power systems. Third, substantial cost savings can be obtained through integration of several microsourses and construction of clean energy farms. Since each individual farm is locally operated in plug-and-play mode, the transmission and distribution (T&D) costs are drastically reduced or eliminated. Moreover, expert combination of such energy farms into a

unified Smart Micro-Grid can contribute to further cost reduction not only through eliminating the need for energy exchange with the main grid over longer transmission lines, but also by sharing the generated electricity among the local customers.

- **Technical benefits** – From a technical prospective, implementation of Smart Micro-Grids can be beneficial for both utilities and customers. The voltage profile is enhanced through better supply of reactive power for local inductive loads and the whole system as well. The congestions on transmission and distribution feeders are also reduced. Moreover, since a Smart Micro-Grid has a sense of detection to understand where it is loaded beyond capacity, thus it has the ability to reroute power to lessen overload and impede potential outages. In a similar manner, T&D losses can be cut down to about 3% by generating electricity near the load centers while the investments in the expansion of transmission and generation systems can be reduced or postponed by proper asset management. Due to decentralization of supply and better load feeding, reduction of large-scale transmission and generation outages, minimization of downtimes and enhancement of the restoration process through black start operations of microsources, power quality and reliability is enhanced consequently.

It's also noticeable that in the case of market participation, additional advantages can be achieved by Smart Micro-Grids which are mainly as follows:

- **Market power mitigation** - The grid-connected operation of Smart Micro-Grids in a market-based environment will lead to a significant reduction of market power exerted by the large dominant GenCos or through collusion of some market participants.
- **Market price reduction** - Widespread exploitation of RESs together with application of low-cost plug-and-play microsources may result in a reduction in energy price tariffs in the power market.
- **Ancillary services (AS)** - The Smart Micro-Grids may also be used to supply ancillary services such as frequency control or spinning reserve provision.
- **Long-term cost reduction** - The long-term electricity customer prices can be reduced by about 10% through appropriate economic balance between network investment and DG utilization.

4. Conclusion

Energy management systems and power system optimizers accompanied by integration of renewable energy resources and adoption of PHEVs which form a whole Smart Micro-Grid vision, are parts of an integrated approach to mitigate global warming and have the capability of serving as a basic tool to reach energy independence and climate change objectives. In this regard, energy efficiency mechanisms are potentially the most cost-effective, short-term options to reduce carbon emissions compared to other abatement alternatives. Moreover, energy-efficient approaches reduce GHG emissions not only through energy savings but also through the deferral of new generation with the help of technological advancements on the supply-side. In this sense, the more deferral of new generation by means of energy efficiency measures, results the more free time dedicated to

improvements in bringing cleaner and more efficient generation online, thereby providing a bridge between the present and a carbon-constrained future.

On the other hand, an intelligent grid can lead to a revolution in power system operation, a revolution that will take place if new ideas and technologies along with very large penetrations of renewable energies are to be incorporated onto the grid. However, in order to efficiently operate and make good decisions, a Smart Micro-Grid must have information feeding supervisory control unit and Smart Energy Management System (SEMS). This information can be used to create better procedures and capabilities for the Smart Micro-Grid and allow more prudent investments. The optimal integration of decentralized energy storages will be also an extremely important task in the near future for the utilities. Moreover, to reach a pathway toward intelligent structures, first the barriers must be identified and then research, development and demonstrations of operation must be conducted to overcome these barriers.

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