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Smart and micro grid model for renewable energy based power system

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SUMMARY

The current energy crisis has fueled research in renewable energy. It is well known that renewable sources of energy would help in alleviating our dependence on perishable energy sources. A transmission and distribution network that could efficiently deliver the power generated from renewable energy to the load would further liberalize the world from fossil fuels. Full potential of renewable energy sources can be exploited by a smart grid, leading to a completely sustainable electricity supply system. The main objective of this paper is to emphasize the importance of smart gird and micro grid model for power systems connected with renewable energy resources.

Key words: *renewable energy, wind, solar, PHEV, smart grids, micro grids.*

1. INTRODUCTION

This paper provides a brief overview on characteristics of various renewable energy (RE) sources confined to power systems. The real challenge to the power industry does not lie in a *100 %* efficient renewable energy source, but how you can integrate several types of energy sources into the grid which is less predictable. An overview on renewable energy sources and its comparison to conventional energy source is presented. The key to this issue is how to account for the variability of these sources when connected to the grid. To accommodate this variability the grid has to be smart, this is described in the second section. Renewable energy sources like wind and solar could be directly connected to the grid. For localized renewable sources (such as residential) an optimal method to integrate them to the grid would be, by utilizing the micro grid concept. Micro grids are discussed in the third section. A general consensus is to have a long term vision of completely replacing fossil fuels with renewable sources which would be connected to the smart grid or to micro grids. A combination of several micro grids would form a smart grid. That means, taking into proper account the critical importance energy efficiency (often ignored in treatments of renewable energy), energy security, and the kind of governance systems which will be needed to drive forward a very different energy economy.

2. RENEWABLE ENERGY SOURCES

Weather and climate cannot be directly controlled like fossil fueled generation. Electrical power networks were designed to operate by electricity generated in a few large power stations which work by fuels that are readily available on the international market which are controllable to varying degrees. Significant increase of the input from renewable energy sources requires a revision of how power systems are designed and operated in order to accommodate these sources better. These resources are available in the form that either they have to be converted into electricity and their electrical output has to be conditioned before it can be fed into the grid [1].

Using energy as efficiently as possible is the most effective way to manage energy demand. Saving energy is cheaper than making it.

Renewable energy generator may be described either as standalone or grid connected. In a standalone system a renewable energy generator (with or without backup generator or storage) supplies most of the demand. In a grid connected system the RE generator feeds power to a large interconnected grid, which is also fed by a variety of other generators. The crucial distinction here is that the power injected by the RE generator is only a small part of that generated by the total number of generators on the grid [1].

The point on the network to which a RE generator is connected is referred to as the point of common coupling (PCC). PCC is described as the point on the grid which is very near to the generator to which loads can be connected. Hence, PCC is the point of maximum disturbance in the network [2].

Table 1 Comparison of various energy sources and their challenges pertinent to power systems [1]

Energy Source	*Typical Unit Size*	*Variable*	*Predictable*	*Dispatch-able*
Coal	*500 MW*	*No*	*Yes*	*Yes*
Nuclear	*500 MW*	*No*	*Yes*	*No*
Gas CCGT	*Up to 500 MW*	*No*	*Yes*	*Yes*
Gas Open Cycle	*100 MW*	*No*	*Yes*	*Yes*
Hydro with reservoir	*Up to 500 MW*	*No*	*Yes*	*Yes*
Pumped Storage hydro	*Up to 500 MW*	*Yes*	*Yes*	*Yes*
CHP	*Up to 100 MW*	*Usually*	*Usually*	*No, as it is heat lead*
Solid waste	*Up to 40 MW (at present UK)*	*No*	*Yes*	*Yes*
Wind	*Up to 5 MW*	*Yes*	*Not accurately*	*No*
Landfill gas	*1 MW*	*No*	*Yes*	*Yes*
Run of river hydro		*Yes*	*Not accurately*	*No*
Photovoltaic Cell	*1 kW domestic; up to 100 kW commercial*	*Yes*	*Not accurately*	*No*
Wave	*No commercial examples yet*	*Yes*	*Not accurately over long term*	*No*
Tidal	*No recent*	*Yes*	*Yes*	*No*

In the context of renewable energy sources, Plug in Hybrid Vehicles (PHEVs) deserves a special attention. Hybrid vehicles like the Toyota Prius use relatively small batteries to provide low-speed and starting power, switching to gasoline for distances over a few miles and speeds over about *25 mph*. Plug-in Hybrid Electric Vehicles (PHEVs) are being developed with larger batteries that will be charged during off-peak hours. They allow the driver to use exclusively electric power for *30 – 50 miles* of driving, switching to gasoline for longer trips. PHEVs offer customers the fuel at gasoline-equivalent prices of less than *$1.00 per gallon*. In order to travel at freeway speeds, PHEVs will require about *8 kW* of electrical capacity that can be delivered to the drive train. If they have to be charged on *110 Volt* home circuits, they can only have about *2 kW* flowing from or to the grid through a residential circuit. At a modest additional cost for residential *220 Volt* wiring, they could be rewired by *8 kW* grid connections. Application of PHEVs in smart grid is explained in detail in section 4 [3].

3. THE SMART GRID

As mentioned before, a smart grid would play a vital role in integration of renewable sources to the grid. Devices such as wind turbines, plug-in hybrid electric vehicles and solar arrays are not a part of the Smart Grid. Rather, the Smart Grid encompasses the technology that enables to integrate, to interface with and to control intelligently these innovations.

There is a general misconception that smart grid is mostly an advanced metering infrastructure (AMI). However, this is not the case. AMI is only a part of a smart grid. A perfect definition of a smart grid is not viable; instead, a smart grid could be defined according to the needs of the network. In different countries the need for smart grids requires different technology integration. For instance, in USA the transmission grid reaches to *99 %* of its population. In comparison to that in a developing country like India the transmission grid reaches only to *80 %* of its population. In countries like India where power thefts are common, the smart grid must focus mainly on energy security [4]. The following are a couple of pictures that has been implemented in Brazil (Figure 1) and South Africa (Figure 2) to counter power thefts.

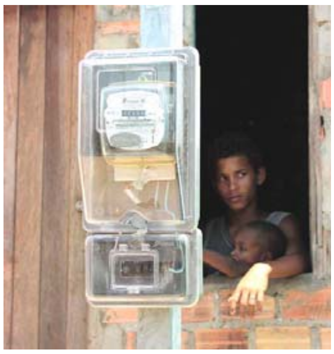

Fig. 1 Slum residents such as this mother with her child in Salvador, Bahia, Brazil now have a legal electricity service: the meter is a standardized "metallic kit" used to lower costs of slum electrification and to reduce stealing electricity [5]

Fig. 2 Highly visible "maypole" type distribution system in Khayelitsha, Cape Town, South Africa makes electricity service drops less susceptible to theft [5]

On the other hand, Oncor – a major transmission and distribution company in Texas defines a smart grid having the following features:

a) *VAR Management – Capacitor Automation*. Such an automated system could provide VAR support to the wind generators where it is required. At night when the load is less the transmission line capacitance is high so there is the increase of the system voltage. The extra VARs could be absorbed with the help of an inductor.
b) *Automated Switching* – Consider a scenario where two substations are enabled to communicate with each other. This would mean that the substations ping each other at regular intervals. During normal operating condition (Figure 3) points 1 and 3 are normally closed (NC) while point 2 is normally open (NO).

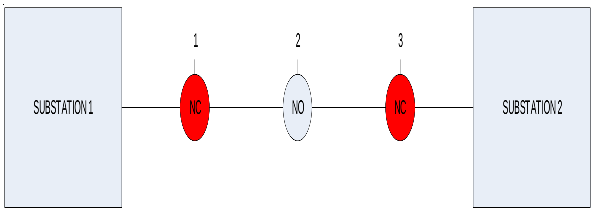

Fig. 3 Normal operating condition

In case of a fault between point 3 and substation 2 (Figure 4), point 2 becomes NC and points 3 is NO. Thus, power supply is ensured to the customers between points 2 and 3.

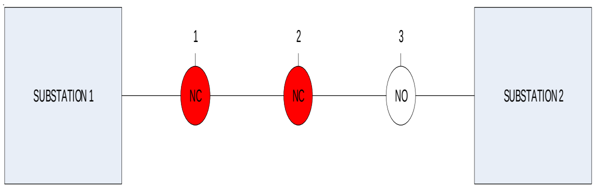

Fig. 4 Operating condition in case of a fault between point 3 and substation 2

Once the system is secured back to safe operating conditions points 2 and 3 revert back to NO and NC respectively.

c) *Distribution feeder protection* – Retrofitting is the easiest way to upgrade any system. Oncor plans to retrofit all its analog protection devices to digital which will enable fast switching.
d) *Embedded Distribution Fault Recorder (DFR) technology*.
e) *Advanced Metering System (AMS)* – All of Oncor's customers should have advanced metering systems by 2012.

   Oncor's AMS would include:

   i. 900 MHz RF mesh network. The electric meters are wireless connected just like in an ad hoc mesh network.
   ii. Every 15 minutes data would be obtained from each meter. This would mean 3 million points of interconnection, one for each customer.
   iii. Integrated remote disconnect capability – The grid operator could remotely disconnect your electricity supply in the case of an outage or a lapse in monthly bill payment.
   iv. Integrated ZigBee communication – This is a form of communication used in the "last mile". It forms a part of the human area network. ZigBee is a wireless protocol which is similar to Bluetooth technology. It is primarily used in building automation to monitor and control loads in buildings and houses.
   v. Last gasp capability (outage management) [6].

The costs of installing these technologies would be forwarded as surcharge (~*$2.00*) for the next 12 years in the tenant's monthly bills. It is worth mentioning that with such sophisticated communication networks and vast information of data, transmission and distribution companies could be involved in gaming (in a deregulated market), by selling such information to load serving entities (LSEs) and the market could be manipulated.

A general consensus is that the smart grid must have the following advanced technologies integrated:

i. Renewable and Distributed Systems Integration – Development of technologies, tools and techniques for systems integration of renewable sources, distributed generation, and demand response to reduce peak load, broaden generation diversity, and enhance asset utilization.
ii. Real time visualization and Controls – Development of real-time information, analysis, and control capabilities to achieve an automated, smart, reconfigurable, and secure electric transmission and distribution network. This means that the smart grid should facilitate two way communications. Today's grid delivers power in a radial fashion. That is, power flows from central power stations to the loads. With the introduction of renewable sources and PHEVs the scenario would be a mesh network rather than radial. When the grid becomes "smart" its configuration would change depending on system conditions. To model reconfiguration (self healing) of the system based on real time, artificial neural networks (ANNs) could be employed.

iii. Energy Storage and Power Electronics – Development of high-voltage, high-power, cost effective energy storage systems. Development of power electronics for high voltage, high-power, and high-speed applications [7].

Another vital configuration envisioned for the smart grid design is redundancy. The conventional power grid configuration is radial where power flows from generation to the loads, see Figure 5. The future grid configuration would have a grid equivalent to that of a mesh network. Thus redundancy will be built into the system with more critical loads having more transmission lines delivering power to it. Figure 6 shows that every load in the grid has more than one way to draw power. Such configurations would make the grid robust and reliable.

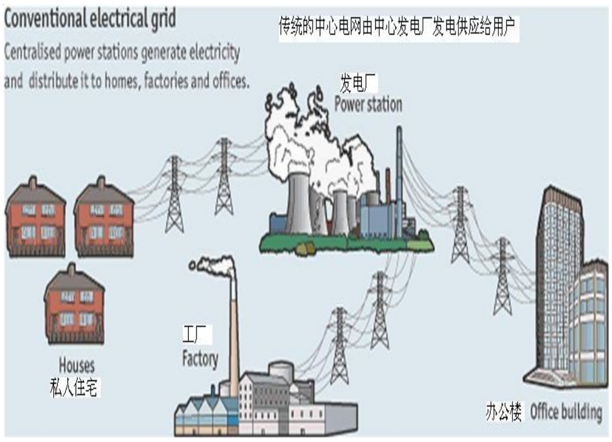

Fig. 5 Conventional power grid configuration [8]

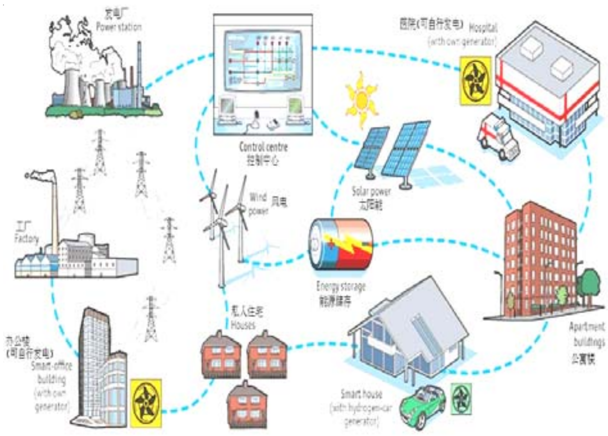

Fig. 6 Future power grid configuration [8]

4. SMART GRID & RENEWABLE ENERGY

PHEVs, renewable sources and smart grids fit together incredibly well, but well defined standards are required to optimize the economic opportunity presented by this combination. It is interesting to see how the technologies complement each other in the following scenario:

Case I: *Normal Day*

* 8:00 AM – Overnight, PHEV is fully charged on low-cost off-peak power at *$0.05/kWh*, the equivalent of gasoline at less than *$1.00 per gallon*. The driver commutes from home to work. It is plugged in at work and recharges during the shoulder hours of the day.
* 5:00 PM – PHEV is fully charged to drive home. Both trips are on electric power. Half the normal cost of gasoline is saved.

Case II: *Hot Day*

The grid operator is aware of the high temperature imminent in the day, the loads will be high. The car receives a signal from the grid either via cellular or wireless technology that power prices are expected to exceed the price of gasoline that morning, and again in the afternoon.

* 8:00 AM – The car automatically tells the driver it has selected to use gasoline power to commute to work, thus conserving the battery. Once the driver reaches work, the PHEV is plugged back into the grid. For the next hour and a half, the grid draws down all the stored energy in your batteries dry, providing *8 kWh* and *12 KWh* into the grid. Driver's account is credited at *$0.20/kWh* for that power, four times the overnight charge. It is also above the replacement cost of gasoline that might be required if the driver needs to use the car during the day.
* 10:00 AM: Power prices subside, and the grid starts recharging the car, but this time it's more expensive mid-day power at *$0.10/kWh*, but still cheaper than gasoline.
* 3:00 PM – Batteries are fully charged.
* 4:00 PM – A major generating plant fails. The grid calls on your batteries as a form of spinning reserve, to replace the power of the failed generating plant. The grid operator determines that the system can meet demand until 5:00 PM by relying on PHEV power, and does not need to start up a reserve generating plant, since it is cheaper to draw down PHEV batteries on-peak, and let people drive home on gasoline that day. The car batteries are depleted when the driver leaves work. This case is similar if the wind suddenly dies out.
* 5:30 PM – The driver leaves office for home running the car on gasoline and the battery is charged to 3/4 the capacity. PHEV is plugged back at home and the grid draws power. The battery is drained. Driver's account is once again credited *$0.20/kWh* for this power. Overnight, the car fully recharges on low-cost off-peak power [3].

In the above timeline of events the benefits of a PHEV enabled smart grid system are:

i. PHEV draws power from the grid when electricity is cheaper than gasoline. The grid draws power from the PHEV when it determines that drawing electricity from PHEVs would be cheaper than running the responsive reserves. Also, the grid would only draw power from the PHEV when the price of gasoline is higher than electricity. Thus customer is guaranteed to save money.

ii. This type of reserve would be reliable and can be brought online instantaneously.

iii. This would also reduce effects on the environment caused by the peaking power plants.

iv. In Southern California, about 1 million new cars are sold each year. If *10 %* of these were "Smart PHEVs" some *100,000* would be added each year. After 5 years, there could be up to *500,000* PHEVs that are smart grid compatible. If these were *2 kW* connections, using existing *110 Volt* circuits, the grid operator would have up to *1,000 MW* of capacity available; if they were *8 kW* connections using *220 Volts*, the grid operator would have up to *4,000 MW* of capacity available. Undoubtedly, the potential reserve capacity is significant [3].

Additionally, there are other sets of renewable sources like solar which follow the load profile during the day. This along with PHEVs would help in offsetting the limited wind supply during the day. Utilities can utilize telecommunication networks to identify the current location of the PHEV. Also, "hexagonal cells" used in telecommunication networks could be used to locate the number of PHEVs in each cell and harnessing this information to dispatch. For instance, a "cell" in Dallas, Texas would have higher number of PHEVs available during day time on weekdays. The driver could be informed that if he plugs his PHEV to the grid within a 5 mile radius (the radius of the "hexagonal cell") of his current location, he could receive a higher price for electricity than gasoline prices. The potential of such a system could be realized in a nodal market than in a zonal market, where the price for electricity is different at every node.

In the future the grid operator would have diverse set of resources at his disposal, and a complex set of choices, all RE sources (PHEVs, solar, wind) are treated as individual resources, not as a single system, but the economic and environmental benefits are equal or greater than if they were dispatched as a single system.

5. MICRO GRIDS AND RENEWABLE ENERGY

Having RE sources such as fuel cells, micro turbines and PV cells combined with energy efficient domestic appliances would make homes self sufficient. Figure 7 explains this concept.

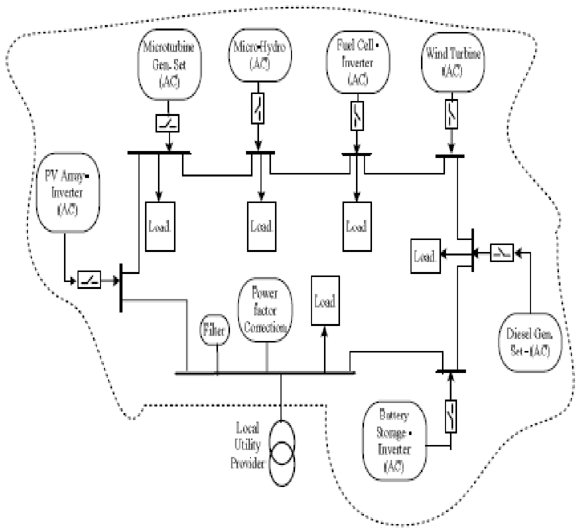

Fig. 7 Alternating current based MG architecture [9]

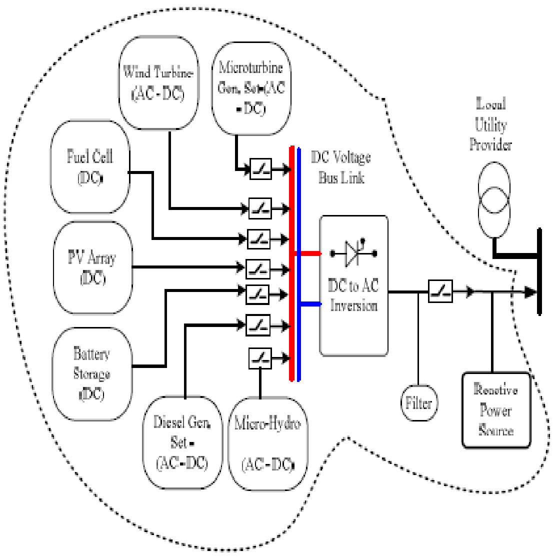

Fig. 8 Direct and centralized alternating current based MG architecture [9]

The idea of self sufficient homes where the peak to average electricity demand ratio is as high as 10 to 20. It would be cost effective to group several houses together as shown in Figure 8. Such small groupings of consumers that benefit from the averaging effect of aggregation (of renewable energy sources) would form a micro grid. This would also help in reducing the number of point of common coupling (PCC) in the system. The issue with such architecture would be that, some homes or offices would be producing more power from their respective RE sources than others in the micro grid.

A point to note here is that it includes a number of consumers and small generators located in close proximity thereby minimizing transmission losses. Unfortunately this is not always true. High voltage lines are generally very efficient. In distribution networks the losses are far greater. For losses to be reduced significantly, the distributed generation has to be located close to matching loads. Hence the micro grid should be designed accordingly. It is also assumed that the micro grid has some storage and is self sustainable with adequate amount of generation to serve its load. Since micro grids would enable islanding it would require virtual power centers actively managing the network with sophisticated local control actions and better protection devices.

6. CONCLUSION

Renewable energy sources embedded into micro grids would transform the distribution network thereby making it more robust and reliable. Expertise from different industries is essential since such integration would involve internet companies, utilities and telecommunication companies. An open based protocol would further propel the race to an internet based power grid.

To modify the grid to the one that is discussed is a colossal task but it must be done. However, it is not impossible, existing technology has all the ingredients for smart grids and micro grids. The real challenge lies in integrating different technologies and encouraging new business models.

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MODEL PAMETNE I MIKRO MREŽE ZA ENERGETSKI SUSTAV NA BAZI OBNOVLJIVE ENERGIJE

SAŽETAK

Sadašnja energetska kriza potaknula je istraživanja obnovljive energije. Poznato je da bi obnovljivi izvori energije smanjili našu ovisnost o štetnim izvorima energije. Prijenosna i distribucijska mreža, koja bi mogla efikasno dostavljati energiju iz obnovljivih izvora, oslobodila bi svijet fosilnih goriva. Puni potencijal obnovljivih izvora energije mogao bi se iskorištavati pomoću pametne mreže koja bi u potpunosti napajala strujom održivi električni sustav. Osnovni cilj ovoga rada je naglasiti važnost modela pametne i mikro mreže energetskog sustava koji je spojen s obnovljivim izvorima energije.

***Ključne riječi**: obnovljiva energija, vjetar, solarni, PHEV, pametne mreže, mikro mreže.*