Evolution of Power to Smart Energy Systems

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***Abstract*—The electrical system is presented as a large "energy transformation engine" that takes different forms of energy to convert it to electrical energy given its wide usage and its increasing demand in the future. As a result of the new technologies the reliability of electricity supply will be increased dramatically, something useful for society that will depend more and more on this source of energy. This paper explores the evolution of the electrical system by considering the example of the Colombian Power system. The current situation is analyzed and a future scenario is formulated, leading to a comparison of the main benefits of its evolution towards the Smart Grid concept. The evolution will bring new interesting perspective to electrical engineering which will need adjustments starting in the form that the engineers of the future are trained.**

***Index Terms*— Energy systems, smart grids, energy balance, energy storage.**

I. Introduction

THE electrical power system is more than 100 years old. It has been providing good service to society with some sporadic problems – blackouts. However the amount of energy that a country uses today is only in a minor portion in form of electricity. The majority of the energy directly used is in form of petroleum, coal, gas, biomass and others forms of energy.

On the other hand the efficiency of the electrical system converting the traditional forms of energy (hydro, coal, gas and a minor portion of wind energy in Colombia) is rather low. In effect although the hydro energy is converted efficiently thermal energy, in particular from older technologies, reaches an efficiency that globally is low compared with other forms of energy.

The inefficiencies of the electrical systems are converted into a big environmental CO_2 impact in countries such as USA - with most of the energy derived from fossil fuels. It is estimated that the electrical sector alone is responsible for about 40% of the CO2 emissions as shown in the Figure 1.

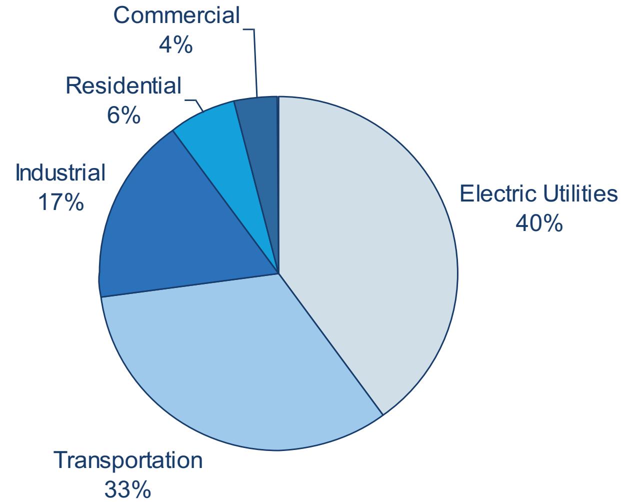

Fig. 1. CO_2 Emissions in the USA [1].

The previous aspect is now being compensated by the use of various sources of sustainable energy with two different characteristics: 1) They are closer to the final energy user and 2) They mitigate the impact on the environment. These important aspects combined with the storage of electrical energy in large amounts lead to the fact that the conventional power systems - where decisions were instantaneous and power related - are slowly transformed into energy systems with decisions that impact the system over a period of time.

This paper explores a vision of the electrical system evolution by considering the example of the Colombian Power system. The electrical system is presented as a large "energy transformation engine" that takes different forms of energy to convert it to electrical energy given its wide usage and its increasing demand in the future. When necessary, data from other sources were considered to depict a possible energy scenario for Colombia way into the future.

All the above are concepts that are part of the "smart grid" which in the author's opinion has its real roots in the evolutionary aspect object of this paper.

II. Smart Grids Components Related to Energy Systems

A. Definition

A Smart Grid is the evolution of the current electric grid by applying technologies, tools and techniques to bring knowledge to the electric systems for a better performance in terms of the DOE of the USA. A Smart Grid will have higher reliability, economic balance, and will reduce the impact to the environment using new technologies. One of the most important technologies that is considered in the introduction of the Smart Grid is the Advanced Metering Infrastructure (AMI), making the electric industry more consumer-interactive [2]. A full-feature electronic meter is now

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available, increasing the possibilities of the utility and costumer to control the electric energy supply. With AMI the amount of available data will be much higher than the current state and the demand management may become a reality.

B. Distributed Generation

Limitations on the transportation of large blocks of energy with new transmission lines has conducted to adopt Distributed Generation – DG, with sustainable forms of energy as a solution that bring energy closer to the user and thus more efficiently .

DG is considered as power generation on a small scale that connects to the distribution system near the sites of consumption and which is generally not included in the system's central dispatch. The interconnection of DG has an impact on the normal operation and has effects on the protection system. Although the connection of generation to the distribution system introduces more complexity in the operation of the system, the advantages identified regarding reduction of losses, improvement of voltage profiles and increases in the use of clean sources of electricity production, indicate that the use of DG should be encouraged.

C. Energy Storage

Energy storage is now a reality. The best and well-known example of storage are the batteries. The level of energy stored passed from kW to MW with a large discharge time (more than 10h) but still at high cost. The main uses of energy storage are: relieve overloaded parts of the grid thus allowing peak shaving, restore power to costumers during an outage and improve the use of Distributed Generation [3]. Some expected benefits are: [4]

- Improve the reliability
- Reduce the peak of the demand profile
- Reduce cost of other equipment such as transformation by reducing the maximum demand
- Improve voltage and frequency regulation
- Better use of renewable energy sources

The main technologies for energy storage are [5]:

1) *Pumped energy storage:* Hydro power plants equipped with the possibility of storing water, normally daily supply, that is pumped back to the reservoir have been in service for long period of time. This old technique is seen as a good way to use cheap energy during night time and be ready to generate energy during peak hours. Power plants in the range of hundreds of MW are those targeted for this type of energy storage.

2) *Compressed Air Energy Storage:* The Compressed Air Energy Storage (CAES) consists in storing compressed air when the energy cost is low. The air is compressed at special places like geological formations, mines, caverns o depleted gas wells. Later when it is needed, the compressed air is released to a thermal station and blended with the fuel input to the turbine. The power ranges from 15 MW to 800 MW.

3) *Sodium Sulfur Batteries:* The sodium sulfur (NaS) batteries were designed for electric cars in the 1960s. Later the Japanese improved the design and are now used to store wind energy and improve the grid reliability [6]. In a pilot project American Electric Power (AEP) installed a 1.2 MW NaS battery in a substation. The manufacturer (NGK Insulators Ltd, Japan) plans the battery to last for about 15 years, with 4,000 to 5,000 charging cycles at 90% of its full capacity.

4) *Flywheel Energy Storage:* "A flywheel is an electromechanical storage system in which energy is stored as kinetic energy of a rotating mass" [7]. In this system the rotating rotor stores energy. The rotor operates in a vacuum and spins on bearings to reduce friction. The rotor contains a motor/generator: the motor to charge the system and the generator to discharge it. The range of power ranges from 40 kW to 1.6 MW for times of 5 - 120 seconds. Due to the short time operation, its main application is the substitution of UPS.

III. COLOMBIAN ENERGY USAGE IN 2008

Colombia, in terms of energy, has many alternatives due to its geographical position and to its natural resources. It is clear that Colombia depends on fossil fuels and even when hydro power is considered renewable and contributes for a large percentage of the electricity supply, the country does not have a clean energy policy.

Figure 2 shows the conditions of energy usage in Colombia considering all sources used and the different demand sectors for the year 2008 for which data was available [8]. As expected the main supply of energy is derived from Petroleum while only about one quarter of the energy is derived from renewable energy (which includes biomass and hydropower). Now, considering a simplified model of sources and efficiency

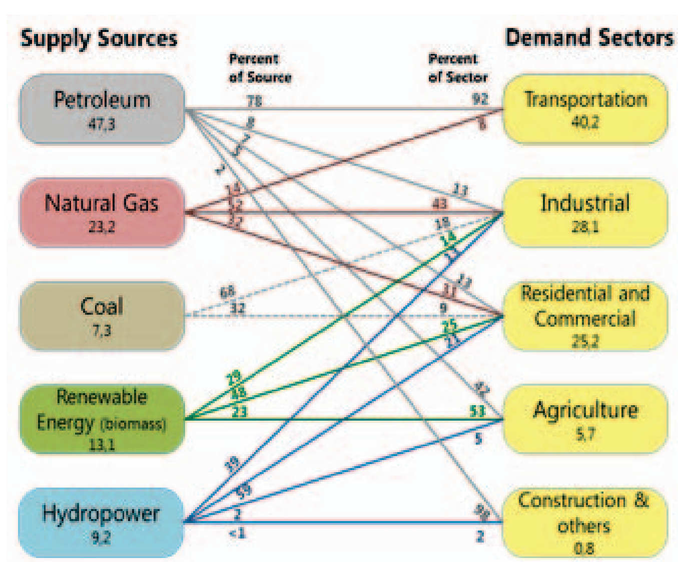

Fig. 2. Energy usage at Colombia by Source and Demand Sector

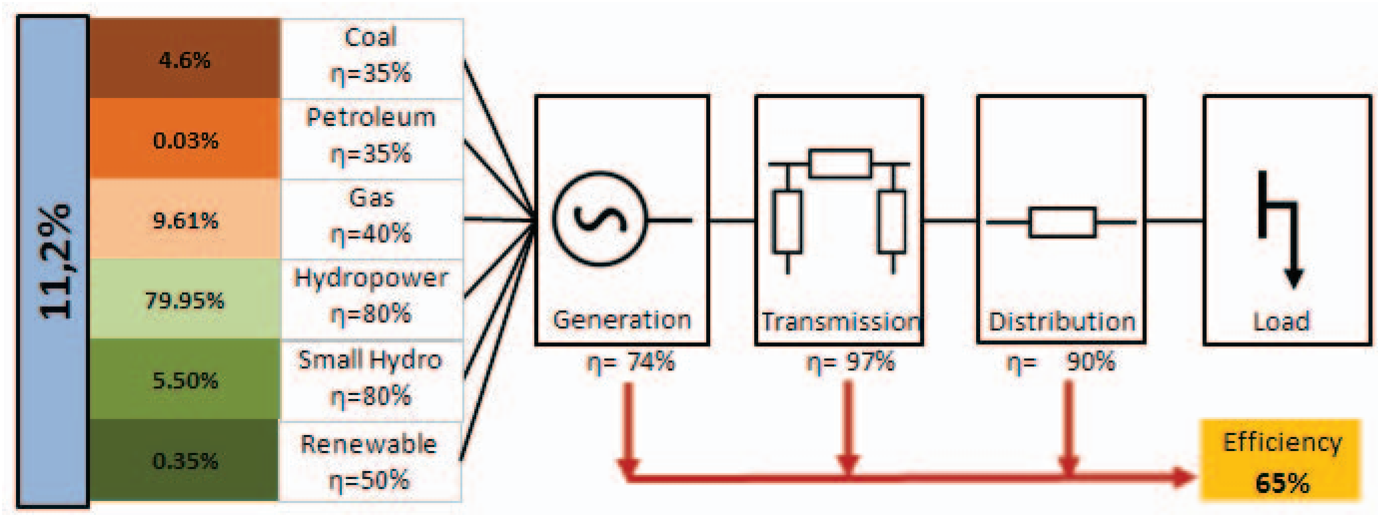

Fig. 3. Colombian overall energy efficiency of the electrical sector in Colombia 2008.

of the generation, transmission and distribution process, figure 3 presents a gross calculation of the overall efficiency of the electrical sector in Colombia. In this calculation average efficiencies have been introduced for the different stages that are involved in the processes that allow the transformation of energy from production to electrical usage. As shown, today in Colombia almost all the energy is converted using the three processes involved: generation, transmission and distribution, and although some generation of electricity goes directly to the distribution process this portion is very small not changing significantly the magnitudes shown. Finally, in the Colombian Energy Sector only about 11,2 % of the total energy consumed is the object of transformation by the electrical system.

The following conclusions can be derived from figure 3:

1) The overall estimated efficiency is in the order of 65%, which is rather low despite the large hydropower contribution with an efficient transformation process.

2) The low efficiencies of older plants using fossil fuels decrease the system efficiency. These plants are mostly used to cover the peak power, which leads to the conclusion that the low load factor in the Colombian electric system is one of the reasons of the low efficiency.

As a global conclusion from this analysis it seems imperative that the overall efficiency of the power system shall be substantially increased in the future to make a "smarter" use of energy mitigating the impact on the environment.

IV. INTERNATIONAL ENERGY FORECAST

The world is facing important changes in the energy offer-demand structure. The world is used to fossil fuels, but in some years they will be very expensive. Besides the environment will not support the current trend and the CO2 emissions will damage the well-being of mankind.

Several agencies and research institutes are considering future scenarios in order to help governments to understand the problems that we will face and help shaping policies and decisions. A good energy outlook to the year 2050 was made by Shell [9]. The recent version of this study, dated 2008, establishes two possible scenarios, which provide alternative views of the future. One scenario is called "Scramble" and the other "Blueprint". The first one sees the future without changing our manners, leading to an undesirable result. The other one considers a future that is the result of taking responsible actions starting today. By means of laws, limits, renewable technology promotions, incentives, etc., the world energy offer-demand structure in the Blueprint scenario will be more efficient. This has many benefits like reducing the CO_2 emissions, reducing the dependence on fossil fuels and the important feeling that human beings will make decisions in the right direction.

Figure 4 shows the final energy consumption by 2050 according to the Blueprint Shell scenario. Considering this scenario, the conclusion is that it will be imperative to reduce the dependence on fossil fuels in the long run which will be replaced by sustainable energy sources. In fact considering nuclear and hydropower together with renewable energy these sources will be more than 70% of the total energy converted by the electrical sector.

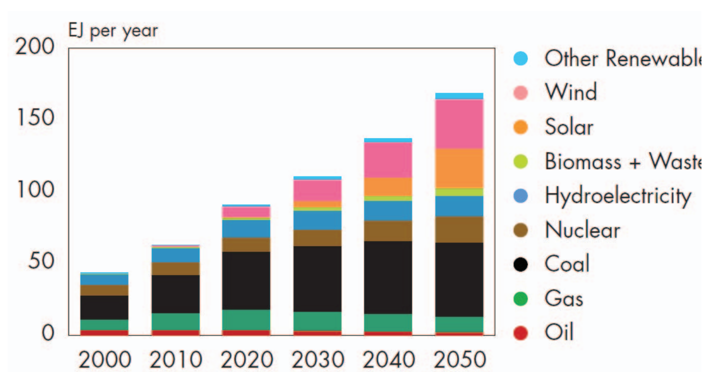

Fig. 4. Final energy consumption of electricity, Shell Blueprint Scenario [9]

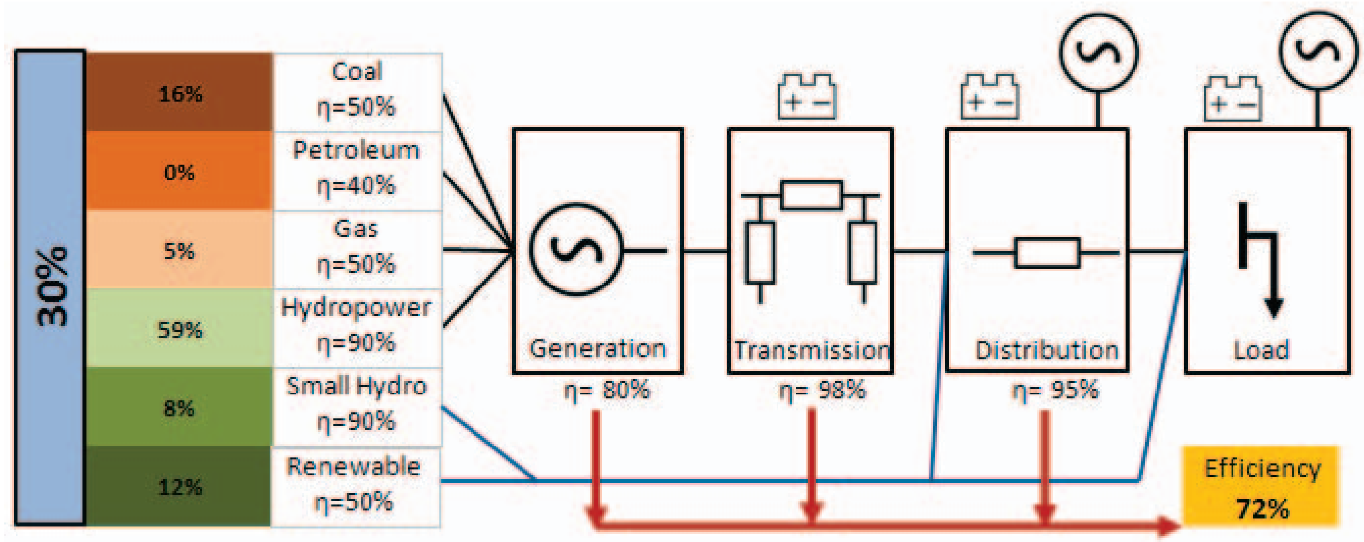

Fig. 5. Scenario of the Colombian overall electrical sector efficiency by 2050.

In addition to the above, the energy input to the electric energy system will increase mainly because the share of electricity for transportation will increase dramatically considering the electrical vehicles entering massively in this time horizon. A substantial amount of energy in this scenario is expected to be close, if not directly, connected to the load thus avoiding the inefficiencies and difficulties of transporting electricity over long distances.

Although not directly shown in the Shell study, the efficiency in the use of energy in the future will certainly increase. The demand management will play an important role by creating the proper incentives for users to level demand and use wisely the scarce energy sources. Demand side management is expected to be a major driver of the energy consumption in the future.

From the environment point of view Figure 6 shows the CO_2 emissions reduction by the implementation of different technologies through time [10]. This view stresses the point that a large amount of CO2 reduction 38% will be produced by the end-use fuel and electricity efficiency which confirms that the electrical sector shall become more and more efficient over time. This aspect is also considered for the scenario shown below.

V. COLOMBIAN LONG TERM ENERGY SCENARIO

The use of energy in the future will be different from what it is today. Colombia does not have a long term energy outlook. Although a forecast for the electric energy consumption expected for the year 2031 exists, the possible scenario in the long term has to be built by combining other scenarios as the one documented by Shell. Figure 5 is a possible scenario for 2050 constructed for the purpose of illustrating the trends that combine the smart grid concepts discussed before.

In constructing this scenario the following aspects were considered:

1) The primary energy sources converted to electricity will be cleaner than today. Although Colombia does not have incentives to promote the use of renewable energies yet, the country have a good potential of wind, solar, biomass and other sources. With these possibilities at least 20% of renewable (including small hydro) generation is considered for this scenario which is well below the amount of renewable energy considered in the Shell scenario with more than 50%.

2) The hydropower will certainly continue to be a major contributor for electric production but the renewable resources will grow faster in consequence a reduction of its market participation from close to 80% to 60% is considered for this scenario.

3) Colombia has a considerable amount of coal resources which will be available way beyond the time horizon explored in this scenario. With new technologies such as coal gasification and other clean forms of using coal in a "smarter" way, the contribution of coal will be important in the future and thus at least 16% of contribution to electricity from this source is considered in this paper.

4) Oil and other forms of fossil fuels will certainly be reduced and because of price increases they will leave room to other forms of energy in particular for electrical energy production. A combined 5% contribution from these sources is considered for this analysis.

5) The total energy converted by the "energy transformation engine" is expected to rise to 30% from the 11.2% in 2008. This conservative amount is below of what is expected in developed countries that will be more dependent on electricity as analyzed by Shell.

In the long term scenario each process is expected to increase its efficiency by the use of energy storage systems in each stage of the path, mostly in the transmission and distribution stages. This improved efficiency will be the result of the materials used in the infrastructure with better properties including superconductivity and enhanced materials for transformation, better flow of energy by the use of

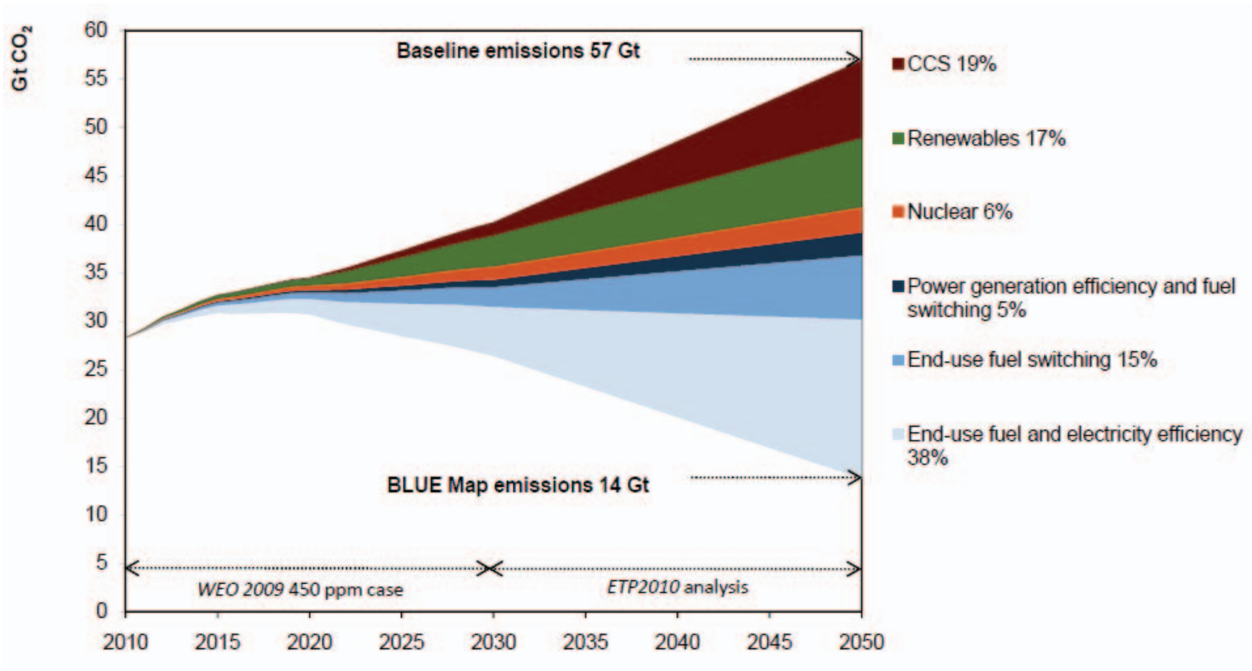

Fig. 6. CO_2 emissions reduction by technologies [10]

FACTS, etc. In the distribution process besides the above, the higher efficiency of 95% includes the fact that less energy will have to use the distribution grid since some DG will feed the load directly. As shown in the figure most of the 20% of renewals will be part of the distribution process.

The proposed scenarios give as a result a 72% efficiency for the overall energy system with is an estimated reduction of losses of about 20% from today´s figures. This number is quite ambitious for today practices but we consider it can be achieved by using the right strategy with the implementation of smarter grids.

In this scenario the instantaneous balance among the production and load will be complemented by a better dispatch of resources because of the expected large energy storage. The effect of storage combined with demand side management policies is expected to flatten the load curve which will mean a better use of energy resources with higher efficiency and less environmental impact. The demand profile and net power flows at the different points of the system will be very important for the grid management based on an AMI which will be a tool of utmost importance.

In this context, DG will represent an important percentage of the total generation improving the system efficiency but grid management will be more complex. In this context, grid automation and information and communication systems will play an important role. They will have to be able to operate with distributed control to ensure the expected system availability.

VI. Conclusion

Efforts to mitigate the impact on the environment with the improvement of the efficiency of the electric grid converted in an energy system are mandatory. The comparison of the 2008 and long term scenario shows that the energy system will transform more and more energy to electricity reaching an important portion of the total energy used by Colombia. The scenario analyzed is still in a long road into the future, but this paper intention is to show that with the adequate policies a new grid with less impact on the environment, the smart grid, can be built.

The big changes expected in the electrical field will certainly need to face challenges that will require a different work force as the traditional engineers that are trained in our universities. The new engineers will face complex problems that range from energy related problems to economic and market related aspects passing by aspects including power, electronics, control, telecommunications, etc. The new challenges will present problems involving different disciplines requiring team work which are expected to be appealing to the new generation of engineers increasing the number of students directed to the electrical related subjects.

Governments, regulators, utilities hand in hand with universities and consumer groups and other entities will play a role in shaping the strategies, policies, economic aspects together with the definition of the required standards and technical aspects of the future energy systems.

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