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Smart Grid Communication Technologies in the Brazilian Electrical Sector

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Abstract

Intelligent electrical grids can be considered as the next generation of electrical energy transportation. The enormous potential leads to worldwide focus of research on the technology of smart grids. This paper aims to present a review of the Brazilian electricity sector in context with the integration of communication technologies for smart grids. The work gives an overview of the generation, transmission and distribution of electrical energy in the Brazil and a brief summary of the current electricity market. Smart grid technologies are introduced and the requirements for the Brazilian power system are pointed out. Various technologies for communication within an intelligent network are presented and their characteristics, advantages and disadvantages are compared to the Brazilian conditions. In addition, a summary is given of current pilot projects for Smart Grid technologies within Brazil, as well as a presentation of individual selected projects.

Keywords: smart grids, communication technologies, intelligent network, communication infrastructure

1. Introduction

With about 200 million inhabitants, Brazil is one of the most populous countries in the world. The total area is about 8.5 million km², making it almost as large as Europe. The country is rich in natural resources such as gold and bauxite and has one of the world's largest oil reserves. Brazil is considered as a global player since long time and has the sixth largest economy in the world. The great economic potential is mainly characterized by the progressive industrialization. Thus it is not surprising that the Brazilian electricity sector is

by far the largest in South America. However, the strong economic development is accompanied by an increasing requirement for energy. In recent years, the growth of demand for electricity was 4.6 % on average per year [*1*].

Brazil has enormous energy potential in the use of water power but this cannot be achieved without serious intervention in the nature environment. For this reason, the Brazilian government is very interested in a modernization of the traditional power sector. Alternative energy sources, such as solar and wind energy, in combination with smart grids can greatly contribute to relief and increasing effectiveness of the electrical network. Furthermore, the security of supply and the power quality can be increased, which is essential for a competitive global economic policy.

The potential of smart grid technology is worldwide considered as very large. All major economies of the world have already begun to shift their focus of research on smart grids. A particularly important point for the successful integration of a communication infrastructure in a major electricity network is the communication technology. Worldwide, many concepts are already available and are currently being tested in various pilot projects. Therefore, it should be the task of this work to give an overview of the Brazilian electricity sector in context with the integration of smart grids.

The paper is structured as follows: After the introduction, a summary of the Brazilian electricity sector is given. Emphasis is on the generation, transmission and distribution of electrical energy in Brazil and the electrical market. After a brief overview of the communications sector, there is an introduction in smart grids in Brazil. Afterwards, the current communication technologies and standards for smart grids will be presented in context with the Brazilian needs. Finally, there is an overview of current smart grid pilot projects in Brazil, a presentation of selected projects and the conclusion.

2. The Brazilian electrical sector

The history of the energy sector in Brazil is marked by major state reforms. The model of a completely state-dominated energy sector existed until the early 90s. Temporally, it proved to be a good system to prevent big crises. However, strong subsidy based policies led to strong revenue shortfalls and led the system into the 80s to the brink of a complete collapse. The main reasons were insufficient investment, corruption and big delays in the progress of large power plant projects. A great deal of uncertainty and skepticism also prevents larger investments of private capital in the energy sector. The growing energy demand of the population and industry could therefore not be sufficiently countered [*2*].

In 1996 there were great reforms in the conditions of the energy sector under the project RE-SEB (Reestruturação do Setor Elétrico Brasileiro). The slow expansion of power plants and transmission lines could not longer face the growing energy demand of the economy and the population. In the first step, opportunities were created to integrate the private sector into the system. This led to a higher privatization of some distribution companies and a large participation of private capital to the expansion of the transmission and the distribution system. However, the share of public transmission companies remained very high, while the distribution sector is today dominated by private companies. To create monitoring bodies, a number of governmental institutions were founded, which are supposed to control the

electricity sector [*3*]. Table 1 gives an overview of the main institutions and their role in the energy sector.

In 2004 under the government of Luiz Inácio Lula da Silva there were further fundamental reforms that shaped today's Brazilian energy market. A fully controlled environment was created to prevent competition within the markets. The privatization of the largest generator companies was stopped. The new system should primarily improve the prediction capability and reliability of the network, ensure price stability for consumers and also to attract long-therm investors. A comprehensive legal framework program controls the supply and the steady expansion of intrinsic sector activities of generation, transmission and distribution of electrical energy. These legal foundations form the basis of the Brazilian energy sector today [*2*], [*3*].

Table 1: Regulating institutions in the Brazilian energy sector

Name	**Abbreviation**	**Task**
Ministry of Mines and Energy	MME	Monitoring and following the energy policies in Brazil
Electric Sector Monitoring Committee	CMSE	Monitoring the supply continuity and security
Energy Research Company	EPE	Forecasting and long-term energy balance
National Energy Policy Council	CNPE	Advisory body to the presidency of the republic and has the objective of elaborating Policies and guidelines for energy planning; international energy policy
Brazilian Electricity Regulatory Agency	ANEEL	Economical and technical regulator and supervisor
Electric System National Operator	ONS	Operation, control and maintenance of the electrical grid
Chamber for the Commercialization of Electric Energy	CCEE	Commercialization of the electric market

2.1. Generation

The currently installed capacity of 123 GW is provided by nearly 3,000 power plants. Further 41.5 GW of power plants are approved or are under construction. Fig. 1 shows the energy mix of Brazil in the second quarter of 2013. With a share of 64% hydro power is the most important source of electrical energy in the Brazil making the country to the second largest producer of electric energy out of hydro power worldwide. It is estimated that the existing potential of untapped hydro power in Brazil is about 140 GW, i.e. far beyond the current electricity demand of the entire country. The share of electricity generation by thermal power plants is comparatively small. The main power fossil power sources are natural gas, oil and coal. Brazil has two nuclear power plants and plans to build a third one. All together, the generated electric energy in 2012 was 507 TWh. The major part of the

generated electric energy is consumed by the residential segment (40%). Only about a quarter is consumed in each industrial and commercial sector [*1*], [*4*], [*5*].

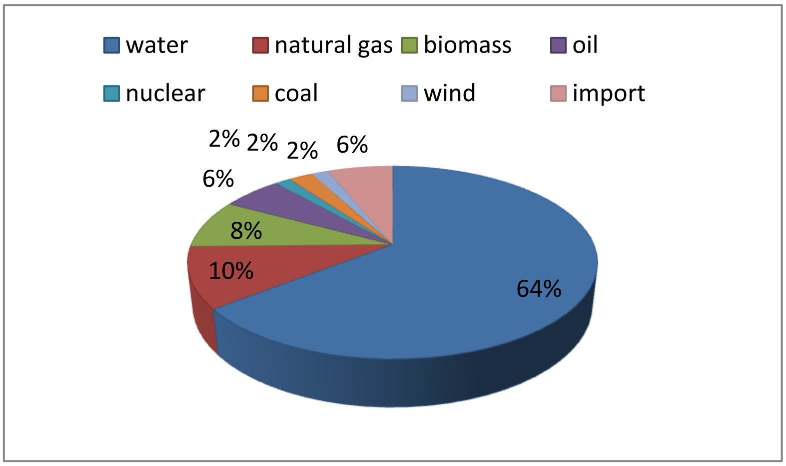

Fig. 1: Energy mix in Brazil 2013 [*4*]

The Brazilian power system is greatly dominated by the use of hydroelectric power plants. Currently, across the whole country there are about 1100 hydropower plants in operation with installed capacities from a few kW up to several GW. With an installed capacity of 14 GW the storage hydropower plant of Itaipu is the second largest power plant in the world. It is operated together with Paraguay at the river Paraná near the Iguacu waterfalls and has a 17 % share of the Brazilian electricity generation (share of Paraguay's electricity generation: 72 %). 78 other projects are under construction or being planned including another major project in Belo Monto with a planed installed capacity of 11 GW [*4*], [*6*].

Compared to conventional power generation by thermal power plants, barely any greenhouse gases are emitted by the use of hydropower. In contrast, there are also major environmental concerns, as the construction of a storage hydropower plant requires an enormous area for the formation of the water reservoir. During the creation of the water reservoir of Itaipu over 800 km² of agricultural land and 600 km² sub-tropical rainforest were flooded and destroyed. In addition to the questionable environmental aspects, the use of large-scale hydroelectric plants has a strong influence on the reliability of the entire power network. The reservoirs and rivers of hydropower plants are fed by an extensive network of streams, especially from the Amazon region. Regional dry periods and late rainfall seasons can cause the rivers and reservoirs to have not enough water. This seasonality dependence was responsible for major energy crisis in 2001. An unusually long dry period resulted in extremely low water levels in most the reservoirs and rivers, so that the supply of the electricity grid could not be guaranteed anymore. Only with the help of an extensive demand-cutting a total blackout of the power supply could be prevented [*2*].

To avoid this kind of scenario, the Brazilian government aims at increasing the use of thermal power plants, as well as alternative energy sources. Fig. 2 shows the evolution of the energy mix of 2001 until 2013. Although hydropower is still the main source of energy, an increase in conventional energy generation can be seen [*7*].

In addition to hydropower, the use of biomass for energy generation is the second most important source of renewable energy. Brazil is one of the world's largest producers of sugar

cane for ethanol synthesis. This process produces large quantities of biological waste and is responsible for a large share of electricity generation out of biomass [*4*].

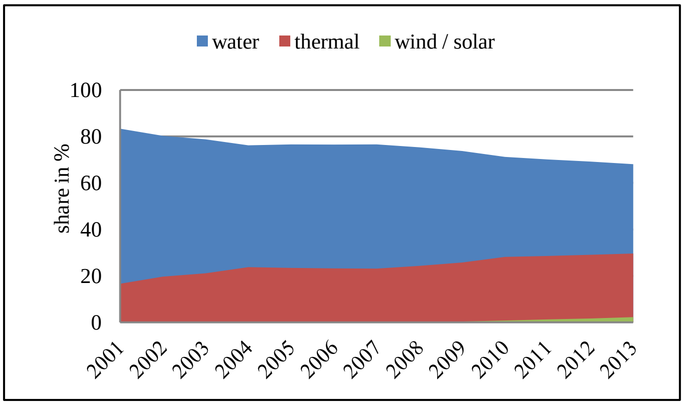

Fig. 2: Evolution of energy mix in Brazil [*4*]

The exploitation of wind and solar energy is still very low in Brazil. The installed capacity is only 2.1 GW in 2013 (1.6 % of total). Nevertheless, the existing potential is enormous. In the northeast of Brazil alone there is estimated untapped wind power equals to 140 GW. Furthermore, the amount of average sunlight intensity is about four times as high as in Europe [*8*]. As part of various projects and activities of the government, the expansion of wind energy, photovoltaic and biomass power plants should be increased. An example of the government’s efforts is the PROINFA program to promote wind farms, small hydro and biomass power plants. As part of this program, 119 projects were implemented with a total installed capacity of 2650 MW [*9*].

2.2. Transmission

The transmission of electrical energy demand is particularly high in Brazil. Most hydropower plants are located near big rivers in the Amazon region. However, the main consumer centers can be found primarily in coastal areas. This uneven distribution of energy generation and consumption requires very long transportation distances and therefore transmission lines with partially over 1800 km. Different voltage levels and transmission paths are used. The standard method of energy transmission is high alternating current voltage up to 765 kV [*10*].

As promising alternative for energy transfer via high voltage AC power lines, the high voltage direct current transmission is considered. Currently, there are only a few active DC transmission lines in Brazil. There is one connecting the bi-national operated hydroelectric power plant in Itaipu with the bulk consumer region of São Paulo. It is used to transfer the excess energy of the Paraguayan side to the Brazilian grid. The DC transmission can be considered particularly for this case, not only because of the large transmission range but also because of the indifferent power frequency standards between Paraguay (50 Hz) and Brazil (60 Hz). In connection with the major project Belo Monte, the world's first direct current transmission line is planned in the range of 800 kV to transport the energy in the south of the country [*11*].

Until 1999 there were two separate transmission subsystems in Brazil: the northeast and the south. Today a coherent transmission network, the National Interconnect System (SIN), with a total length of more than 100 000 km exists. There are 40 transmission concessions available in Brazil. The majority of the transmission companies are owned by the government. Nearly 56000 km belongs to the state-controlled company Eletrobras [*12*]. Fig. **3** shows the current transmission network in Brazil. A very high concentration of transmission lines can be found in coastal regions in the east and in the south of the country, because of the great number of consumers in this area. International connections of the transmission system are available with Paraguay at the bi-national hydroelectric power plant Itaipu and with Uruguay, Venezuela and Argentina. The installed capacity thus increases by about 8200 MW [*13*].

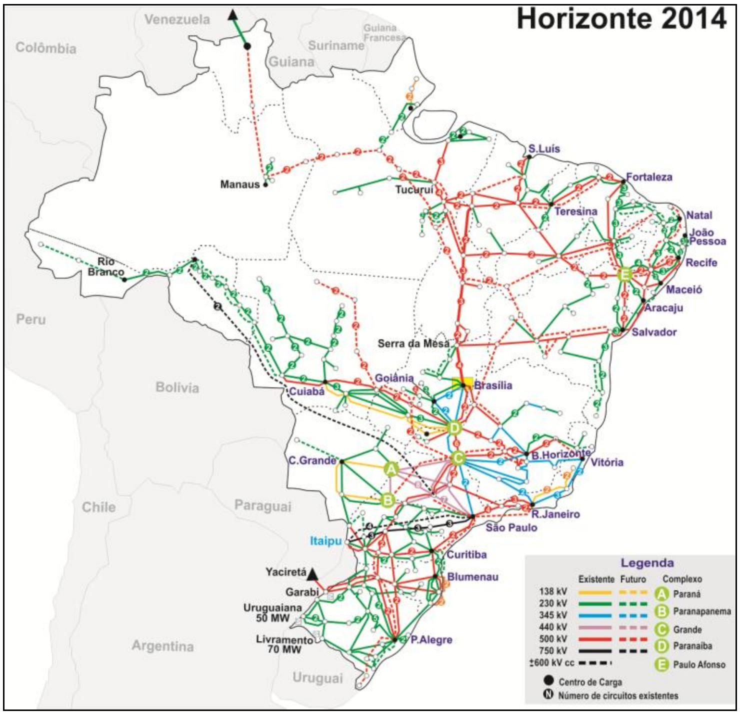

Fig. 3: Brazilian transmission system [*10*]

The natural and terrain characteristics in the Amazon region, requires special properties for constructing the transmission lines. For example there are widely flooded areas and particularly high rain forests. To overcome these areas and to minimize the environmental impact, the supporting structures must be built exceptionally high. One example is a section of a transmission line in northeastern Amazon, which bridges the rainforest with a 280 m high power pylon [*14*].

The extension of the power transmission network is performed by the EPE. This company together with the ONS is responsible for all design work and controlled by the Ministry of Mines and Energy. As well as in Europe, the N-1 criterion is the most important directive for planning new transmission lines. Once the new design plans are published, auctions for the construction and operation of the transmission line will be held under the direction of ANEEL. The successful bidder receives an operation concession which will be re-assigned by new auctions after 30 years. This auction model could achieve an increased participation

of private capital in the transmission sector. However, a majority of supplements still goes to state controlled companies such as Eletrobras [*5*].

2.3. Distribution

Until the end of the 90s, there was no clear separation of the generation, distribution and transmission by the legislation. In 2000, the independence of distributors in Brazil was decided. Under the supervision of ANEEL the distribution network was divided into regional concessions depending on individual local criteria. Today, these areas are operated by 63 distribution companies of which the majority is in private hands. The regulation of the distribution is followed by a policy document (PRODIST) that defines the responsibilities and requirements for the operation, expansion and planning for the distribution grid operator [*15*].

In Brazil, all power lines operated below 230 kV are considered as distribution lines. The standard voltage for residential consumers is usually 110 V or 220 V, depending on the region, with a frequency of 60 Hz. Altogether, there are almost 70 million connection points to end users, of which 85 % are residential customers. The common transportation constructions are overhead lines, especially in rural areas and small cities but there are also underground cable systems in big cities. The responsibility for connection, maintenance and service quality contributes to the competent regional distribution grid operators [*10*].

The average failure rate and downtime of the Brazilian power system has decreased since the reconstruction of the energy sector. When ANEEL was founded in 1996, there was an average of 21 interruptions with a total outage duration time of approximately 26 hours per year and users [*15*]. Fig. 4 shows the evolution of the System Average Interruption Index (SAIDI) in Brazil for the period from 2001 until 2012. It can be seen that the failure rate is generally lower but could not meet the specifications issued by ANEEL since 2009. With about 18 hours of downtime the SAIDI of Brazil is much higher than the SAIDI of Europe (e.g. Germany 2011: 15.31 min [*16*]).

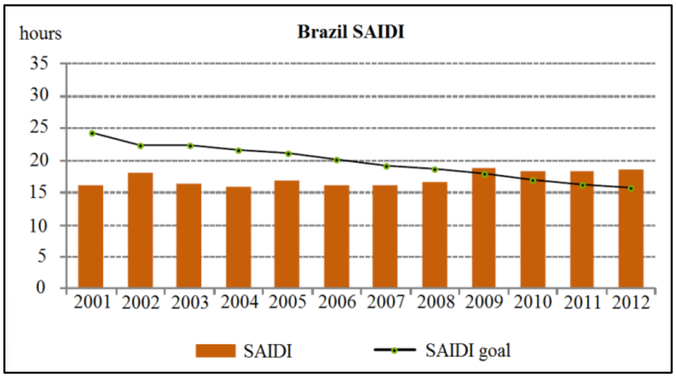

Fig. 4: System Average Interruption Index of Brazil [*12*]

Another problem in the distribution sector is the unusually high loss of energy. With a percentage of about 14 %, the loss rate is almost twice as high as in Central Europe. This value is not only related to the technical losses. The large divergence and poverty in the population leads to a disproportionate high share of non-technical losses due to theft and crime. While in some distribution networks there are virtually no non-technical losses in large cities with extensive slums the loss values can be reported up to 30 % [*3*]. Fig. 5 shows an example of electrical energy theft in a slum of Rio de Janeiro.

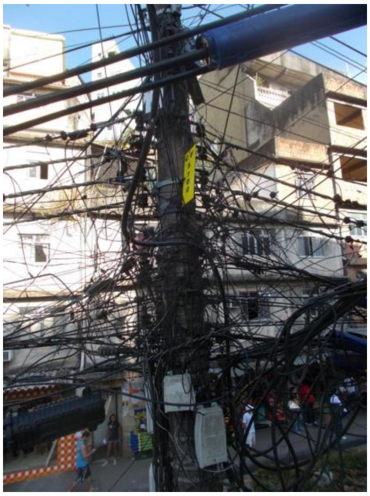

Fig. 5: Energy theft in a slum of Rio de Janeiro

2.4. Market

The electricity market in Brazil is the largest in Latin America. Nearly 99 % of the population has access to electricity which corresponds to almost 200 million people. The market model to ensure the supply in Brazil is based on long-term contracts between agents on generation and consumer side. The basis of this model was laid in 2004. It specifies that the utility companies need to ensure the complete supply of the customers through contracts with generation companies. For this purpose, two platforms, the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL), were created on which the agents may conclude contracts between the producers and provider.

Within the concept of the free market, the participants have the opportunity to act under their own conditions. They can set their own prices and quantities of exchanged electrical energy. These bilateral contracts are concluded directly between producer and provider. Free consumers and energy intensive industries are allowed to trade freely as well. The consumer is obliged to prove that the contractually exchanged amount of electricity is able to cover 100 % of the demand. If it turns out that the power demand cannot be covered, the consumer must expect substantial fines. The Electric Energy Commercialization Chamber (CCEE, acronym in Portuguese) is responsible for maintaining the security of supply and takes care of the compliance of the contracts. The CCEE is also in charge, if there should be disputes and disagreements between suppliers and buyers [*17*].

Within the concept of the regulated market the electrical energy from the generator is passed to the consumer via energy auctions which are led by ANEEL and CCEE. The goal of this auction model is to ensure that the lowest possible price reaches the end-consumer. To

optimize the overall system of generation, transmission and distribution, the EPE tries to determine the optimal composition between source of generation and consumer. The next step is the auction phase, in which the company that offers the required amount of energy for the lowest price gets the bid. The legal basis for the energy delivery to the end customer is provided by bi-lateral contracts called the Contracts for Commercialization of Electricity in the Regulated Environment (CCEAR, acronym in Portuguese) [*17*].

Besides the two market models, the distribution network operators have more options to purchase electricity. By Distributed Generation (DG) it is possible for small producers (less than 30 MW) to feed electrical energy directly in the distribution grid. This energy can be generated from different sources such as small hydro power plants, wind or solar farms and biogas power plants. The energy that is fed into the distribution grid may be up to 10% of the total load and is contractually sold directly to the distribution network operator. An advantage of DG is that the cost of transmission is reduced, as well as losses in the distribution since the decentralized small power plants can be built close to the consumer. Several projects have already been funded by the government to increase the share of alternative energy sources in the electrical grid [*2*], [*18*].

The two presented market models can be of interest for different participants. The free market model has the advantage that the contracts conducted by producers and consumers can be adapted to make sure that the agreement has favorable condition for both parties. However, only consumers with an annual energy load of 500 GWh are allowed to participate in the free market. If the consumed energy exceeds this value, the company must acquire the electrical energy in the regulated market. In contrast, the generators can always choose the environment for their energy transactions [*19*].

The tariffs paid by the consumer consist of the sum of production costs and a fixed value for transmission, distribution and commercialization of the electrical energy. Depending on the kind of consumer there is a variable pricing system in Brazil. The end users are thereby divided into two groups. All consumers with voltages between 2.3 kV and 69 kV or power consumption greater than 75 kW pay variable tariffs depending on time of day and peak load situations. The price may be several times higher in peak load periods than in off-peak situations. All consumers with voltage less than 2.3 kV, i.e. residents or communities in rural areas, are bound by a constant tariff rate to the owner of the local distribution concession. In addition, because of the hydro-electric characteristic of the Brazilian Electric System, there is a seasonal pricing model. Depending on the level of the water reservoirs of hydro power plants there are additional fees for the consumer [*20*].

3. The Brazilian communication sector

The history of the communications sector in Brazil can be divided into different stages of development. From the early 80s to the early 90s the ICT market in Brazil was subject to strong governmental control. By high inflation, low demand and high import duties on foreign electronic products only a few specialized companies could be established. In the mid of the 90s there was an increased demand, especially in personal computers. By the liberalization of the ICT market and the removal of import duties a lot of foreign companies such as Compaq and IBM established in Brazil. They were able to offer the required electronic hardware much cheaper and made joint ventures with local private and state-owned enterprises. The ICT market developed very fast over the following years. In 2010 the market grew by more than 21 % to a size of $166 billion [*21*].

The mobile phone market in Brazil is the fourth largest in the world. About 220 million mobile phone contracts are concluded. Nearly 17.33 % of these contracts include mobile Internet via 3G. Even the standard 2G and 2.5G is still widespread, especially among the poorer population. In consideration of major events such as the FIFA World Cup 2014 and the Olympics in 2016 the 4G standard will be introduced very soon. In contrast to the mobile Internet, only 40 % of Brazilian households have a fixed internet connection. The main reason can be found in the high cost of internet access. Therefore especially low-income earners cannot afford to buy access to the internet. In 2010 the Brazilian government launched a national broadband program. The goal is to provide up to 2014 at least 40 million households with broadband connections [*21*]. For this purpose large area routers have been installed in slums of major cities such as Rio de Janeiro to provide free wireless internet for poor people (Fig. 6).

The ICT market shows a very high potential in Brazil. However, there is a number of reasons that slow the development down. One problem is the complex fiscal politics. High taxes to each step of the value chain leads to multiple taxation for the same product. Furthermore, high interest rates have a negative effect of new investments and there are very complex regulations to establish new companies which curbs down high technology spin-offs from universities. Nevertheless, Brazil has the basic requirements to become a global player within the ICT market [*22*].

Fig. 6: Free internet access point in a slum of Rio de Janeiro

4. Smart grids in Brazil

With the liberation of the distribution market by the legislation in 2004, the first step has been taken away from the traditional centralized power generation towards decentralized power plants. By these new terms, the use of small generators of electrical energy is playing an increasingly important role. Due the possibility to operate in a location near to the consumers, DG contributes to cost reduction of the energy transfer by reducing transmission losses and relieving the transmission networks. In addition, the integration of alternative

energy sources from wind and solar energy is promoted and thus an important step towards reducing carbon dioxide emissions is taken.

The integration of this new distribution system in the Brazilian energy sector requires not only political regulatory steps as subventions and new pricing models. Especially a technological revolution of the traditional distribution system has to be carried out. Due to the growing number of small generators in the distribution network, the energy flow can no longer be considered as an one-way flow. To ensure the stability and the correct balance between power generation and consumption the distribution network needs the capability to be monitored and controlled. The network has to become more intelligent.

Brazil is one of the pioneer countries in Latin America, which deals with the development and research of smart grids since recent years. In contrast to Germany, where a high share of fluctuating renewable energy like wind and photovoltaic demands a fully controlled electrical grid to balance the power flow, the main reasons for the introduction of smart grids in Brazil are [*23*]:

- The reduction of technical and non-technical losses in transmission and distribution of electrical energy
- The improvement of system security, system reliability and power quality
- The integration and control of micro-generation and micro-grids to compensate peak load situations
- Creation of a new energy market through the integration of new flexible pricing models
- Preparation for the integration of electric mobility sector

An intelligent network or smart grid allows a full automatic control and management of the electrical distribution system. The communication between the main hub, generators and consumers creates new possibilities for the stabilization of the entire electrical network by: Advanced Metering Infrastructure (AMI), Advanced Distribution Operation (ADO), Advanced Transmission Operation (ATO) and Advanced Asset Management (AAM). By using the AMI, a bi-directional communication link can be established to the end user via smart meters and thus useful information can be exchanged. The ADO uses this information to optimize the energy flow and collects information about the condition of the distribution system. The ATO uses the information of the ADO to optimize the transmission operation. By using the AMI and the ADO the consumer can have direct access to the market. The AAM is the controlling instance, which uses all the information gathered from the AMI, ADO and ATO to optimize the whole network, enhance the reliability and minimize the failure rate [*24*].

To support the modernization of the energy sector, all owners of public concessions in distribution and transmission sectors and involved companies are forced according the Brazilian law to invest approximately 0,5 % of their income to R & D. The goal is to create a constant urge to improvement, which cannot arise naturally because of the lack of competitive pressure in a monopoly economy. Due these measures there is great number of researches on smart grids in almost all engineering institutes and universities in Brazil. The government plans to equip more than 65 million consumers with smart meters until 2020. Today, over 1 million smart meters in Brazil are already installed. It is expected that the policy framework for smart metering and integration of micro generation, which was

recently published by ANEEL, will cause the market for smart grid technology to grow extremely fast [*25*].

4.1. Communication in smart grids

In order to guarantee smart grids can work reliable, fast and effective, there is a great requirement on information and communication technology. Fig. 7 shows a schematic representation of a typical measurement system presented in a smart grid.

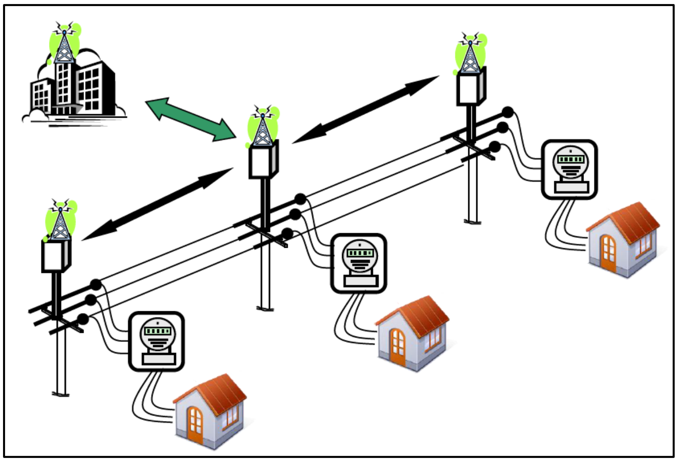

Fig. 7: Basic communication structure in smart grids [*23*]

The basic elements are the measuring center, the smart meter and an intervening communications infrastructure. Particularly important is the point of data concentration that collects consumer measurement data and sends them to the centralized control center. The concentrator also represents the nodal point for the distribution of information to the consumer. The bi-directional communication offers many new opportunities for the electrical grid. Due continuous information flow about the grid condition high power quality can be ensured. In addition, rapid fault detection and automatic recovery are greatly improved. The control ability can perform a quick load flow regulation and consumers can be integrated in the distribution system with their own small generators. The integration of a new flexible electricity price system also provides a great opportunity to influence the consumer behavior [*26*].

4.2. Communication technologies

It is therefore very important to discuss the optimal conditions in the field of hardware and software for communication. There already exist several methods that can be used for smart grids. The most important technologies, which play a role in Brazilian smart grid sector, will now be presented:

Powerline Communication

Power Line Communication (PLC) is one of the oldest known methods for communication in electrical networks. This technique uses data transmission frequencies which are fed into the existing power grids. Depending on the frequency band, transmission rates up to several Mbit per second can be achieved. This technique is used in load control of energy transfer for many years. The particular advantage of this method is that no new communication lines are needed; resulting in a strong cost reduction. Especially in rural sector PLC can be used to easily connect important data nodes and smart meters. It has already been shown that the signal transmission from low voltage into a higher voltage level by a transformer is possible [*27*]. Disadvantages in the use of PLC are mainly the environmental signal conditions, which have a high noise level. Furthermore, the signal quality may be affected by: the number of devices communicating on the same line, the length of the line and the network topology. For this reason, the PLC is not considered as the ultimate solution. The security question to protect the user data is not yet clear as well. In addition undesirable interference between different PLC data transmission standards can occur. A possible solution to this problem would be the introduction of coexisting standards, which are specialized and optimized for respective applications [*28*], [*29*].

The use of PLC as a part of a hybrid solution for communication has already been carried out in China, France and Italy. There, the PLC was used as a communication tool to connect existing smart meters in households with a data collector. From this data collector then the GPRS standard is used for data transmission to the control center [*30*].

Cellular Network Communication

Other technologies for communication in a smart grid are Cellular Networks. Similar to the PLC, one of the biggest advantages is that these networks are already in place. Thus no major investments need to be made and costs are minimized. The available communication technologies are: 2G, 2.5G, 3G, WiMAX and LTE. A further advantage is that strong security standards have already been developed by the spread of mobile cell phone data transmission. A major task for the deployment of mobile networks in smart grids is the large amount of data obtained while operating. This can be a problem especially in rural areas where only slow transmission standards are available. But there are also new standards such as WiMAX and LTE with very high data transmission rates. However, the mobile networks share the environment with the large number of private user. This can sometimes lead to unpredictable peak loads on the networks and thus jeopardize the system stability. In general the low investment costs, high availability, high security and low maintenance costs make the use of mobile networks one of the most promising candidates in the data transmission of smart grids [*30*].

Wireless Mesh

The mesh network is built up of individual nodes that have the ability to communicate with each other. They operate with standardized IEEE 802.11 protocols and can have many benefits. Since all the routers are able to communicate with each other, the network has a high self-healing potential. If a single node fails, the connection can be reestablished via another active router so that the network is complete again. This signal transmission method is very effective and adaptable, particularly in urban areas, where a network of many routers can be available. Especially for domestic applications such as metering and energy management, this technology is well suited. Disadvantage for Wireless Mesh Networks are the limited capacity and the susceptibility. If the density of the routers is too low, the stability

and capacity of the network suffers considerably. Accordingly, a sufficient number of routers always must be available, which can cause significant costs. Since the information packets passing through each router, a strong security encryption is necessary. Furthermore, a frequent change of the connection path can cause faster network utilization [*30*], [*31*].

ZigBee

ZigBee is based on IEEE 802.15.4 industrial radio standard with a maximum range of 100 m. The technology is considered as the most promising candidate for communications technology in the Home Area Network (HAN) to connect smart devices and smart meters with each other. Thus it is possible to build up a comprehensive energy management system. The advantages of using the ZigBee standard are mainly: low power consumption, fast response and response time, high reliability, self-organizing network topology, high cross linking ability (65,000 nodes) and high safety standards. In China ZigBee networks are used for monitoring of ultra-high voltage power lines. With their help environmental parameters such as temperature, humidity and wind speed are collected. The biggest advantage in such rural areas is the very low energy consumption. However, in practice there are various problems in the use of ZigBee as a communication standard. By the use of license free IEEE 802.15.4 standard there are possible complications with other networks such as WiFi, Bluetooth and microwaves. Under these noisy conditions, the system stability of the network could be vulnerable, e.g. by interferences with 802.11/b/g standards. A further disadvantage is the limited amount of memory related to a low processing capacity [*30*], [*32*].

Digital Subscriber Lines

The use of Digital Subscriber Lines (DSL) in the communications sector is very common. The digital connection reaches very high transmission rates by the use of a wide frequency band. The copper-based wired infrastructure already exists in many parts of Brazil. This allows avoiding greater investment costs. Because of the high availability and transfer rate DSL communication is of great interest for transmitting data in a smart grid. However, some disadvantage need to be mentioned. There is an occasional non-availability which might be sufficient for private internet users but not acceptable for live monitoring in a smart grid. High maintenance costs of the cable-linked system, as well as unavailability in rural areas are more disadvantages of the system [*30*].

In summary it can be considered that the available communication technologies have different advantages and disadvantages for the use in a smart grid. There is nothing like a general solution and therefore the choice of technology must always be adapted to the given conditions.

Table 2 shows the mentioned communication technologies and their characteristics. The choice of the optimal technology always dependents on the field of application. For example, control and automation processes require only very low data rates of a few 100 kbit / s. In contrast, network monitoring needs very large amounts of data that must be transmitted almost in real time. For these applications networks are used, which have transfer rates over 1 Mbit / s and a maximum response time of 20 ms. The availability is also a major point of interest. While some less critical applications like demand management stand a reliability of 99 % per year need (3.65 d downtime per year) other applications such as synchronization between the elements need a much higher reliability of 99.9999 % (31 s of downtime per year) [*30*].

Table 2: Smart grid communication technologies [*30*]

Technology	Spectrum	Data Rate	Coverage Range	Application	Limitations
GSM	900-1800 MHz	Up to 14.4 kBit / s	1-10 km	AMI, Demand Response, HAN	Low date rates
GPRS	900-1800 MHz	Up to 170 kBit / s	1-10 km	AMI, Demand Response, HAN	Low data rates
3G	1.92-1.98 GHz 2.11-2.17 GHz	384 kBit / s- 2 MBit / s	1-10 km	AMI, Demand Response, HAN	Costly spectrum fees
WiMAX	2.5 GHz; 3.5 GHz; 5.8 GHz	Up to 75 Mbit / s	10-50 km (LOS) 1-5 km (NLOS)	AMI, Demand Response	Not widespread
PLC	1 - 30 MHz	2-3 Mbit / s	1-3 km	AMI, Fraud Detection	Harsh, noisy channel enviroment
ZigBee	2.4 GHz-868-915 MHz	250 kBit / s	30-100 m	AMI, HAN	Low data rates, short range

An example of how the technology hierarchy may look like in a Brazilian Smart Grid can be found in a report on smart grid structures in Brazil called "Relatório smart grid" published by ANEEL. The following solutions are proposed for the different tasks:

- Data reception and data delivery from electronic measuring points in the distribution network via PLC to the data concentrators
- Data concentrators connected via RF mesh radio technology with the central control center
- Data transmission to consumers metering devices via PLC
- Control of smart devices in HAN with the help of ZigBee networks
- Measuring systems in distribution system for comprehensive energy management; communication via DSL or WiMAX

When choosing the optimal communication technology the local conditions must always be considered, too. These include the existing communications infrastructure, geographical conditions, potential markets, the density of necessary control elements in the distribution network and the number of consumers. Since in Brazil local conditions show strong differences in the social sector as well as in the field of geography and economics, various approaches have to be investigated [*23*], [*33*].

4.3. Communication standard protocols

Furthermore, uniform communication standards must be found for the technologies and fields of application in a smart grid. The various standardization bodies such as ANSI (American Standards Institute) and IEC (International Electrotechnical Commission), IEEE (Institute of Electrical and Electronics Engineering) and ISO (International Organization for Standardization) have already published a set of standards for smart grid applications. Table **3** shows the most important standards and their applications.

Table 3: Smart grid communication protocol standards [*30*]

Type/Name of standard	Details	Application
IEC 61970/61969	Providing Common Information Model (CIM) in transmission and distribution domain	Energy Management System
IEC 61850	Flexible, future proofing, open standard for communication	Substation Automation
IEC 60870-6/TASE.2	Data exchange between utility control centers, utilities, power pools and regional centers	Inter-control Center Communications
IEC 62351 Parts 1-8	Defining cyber security for the communication protocols	Information Security Systems
IEEE P2030	A Guide for smart grid inter-operability of energy technology and IT operation with the electric power system	Customer side applications
IEEE P1901	High speed power line communication	In-home multimedia, utility and smart grid application
ITU-T G.9995/G9956	Contains the physical layer specification and the data link layer specification	Distribution Automation, AMI
Open ADR	Dynamic pricing, demand response	Price Responsive and Load Control
BACnet	Scalable system communications at customer side	Building automation
HomePlug	Powerline technology to connect the smart appliances to HAN	HAN
U-SNAP	Provides many communication protocols to connect HAN devices to smart meters	HAN
SAE J2293	Standard for the electrical energy transfer from electric utility to EV	Electric Vehicle Supply
ANSI C12.19	Flexible metering model for common data structure and meter communication	AMI
M-Bus	European standard and providing the requirements for remotely reading all kinds of utility meters	AMI
PRIME	Open, global standard for multi-vendor interoperability	AMI

Different communication protocols and standards have progressed far in Brazil partially. The main focus for the optimal standard protocol in Brazil is on choosing open standards to avoid legal problems and not be dependent on a single manufacturer for communications technologies. In particular, the IEC 61850 standard is already used in a wide range of applications. Especially in the area of monitoring transformer stations these free protocols are already frequently used. Other tasks are automatic load balancing, fault detection and circuit breaker control. For communication between the control centers IEC 60870-6 protocol (ICCP) is already used by large companies such as Eletrobras and Eletrosul. The operation of a Common Information Model (CIM) for an independent integration of IT systems is defined by the standards IEC 61968 and IEC 61970. In addition, the CIM requires an appropriate level of safety. In Brazil the IEC 62351 catches on, even if it is not very widespread yet. These standard protocols have been proposed in the U.S. Nation Institute of Standards and Technology. In Brazil, these proposals will be adopted so far [*23*].

5. Smart grid pilot projects in Brazil

Given the large market potential and anticipated regulatory foundations several companies and cities initiated pilot projects for integration of smart grids in the power distribution system. The range of these projects starts from various simulations to entire cities with an integrated smart grid. Table 4 gives an overview of the major projects Brazil, which are currently performed by some holders of distribution concessions.

Table 4: Smart grid pilot projects in Brazil [*26*]

Name	Location	Company
Buzios Cidade Inteligente	Armação dos Búzios - Rio de Janeiro	Ampla/Endesa
Projeto Smart Grid	Rio de Janeiro	Light
Cidades do Futuro	Sete Lagoas – Minas Gerais	Cemig
Projeto Parintins	Rio de Janeiro	Eletrobras Amazonas Energia
Projeto de Smart Grid	Barueri - São Paulo	AES Eletropaulo
InovCity	Aparecida - São Paulo	EDP Bandeirante
Aquiraz Smart City	Aquiraz - Ceará	Coelce/Endesa
Fazenda Rio Grande	Fazenda Rio Grande - Paraná	Copel

In this section, three other pilot projects are presented, which deal with the integration of different communication methods for smart grids in Brazil. The project in Curitiba and Niterói shows the experimental urban implementation and the project of Fernando de Norohna shows the experimental rural implementation. Thus the two main Brazilian applications will be investigated. In addition, a project dealing with the integration of micro grids and distributed generation is presented.

5.1. Fernando de Norohna – CELPE

The project is part of the R & D plan of ANEEL which is supposed to represent the feasibility of smart grid in Brazil. It was initiated on the Brazilian island of Fernando de Noronha by the distribution network operator CELPE (Companhia Energetica de Pernambuco). The main objectives of the project are:

- Building a smart grid infrastructure (smart metering, network automation, telecommunications, integration of micro-generation and power measurement)
- Establishment of a network of electric cars as electric buffer
- Assessment of the feasibility (reducing losses, increasing system stability, dynamic pricing, demand side management)
- Assessment of the ecological sustainability of Smart Grids

Particularly the use of communication technology plays an important role in this project. The results must fulfill technical, commercial and environmental requirements. The high temperatures and high salinity require high reliability of the used technology. Especially the GPRS antennas can be subject to performance degradation due corrosion on the surface. The dense vegetation also makes it necessary to use very high radio antennas to prevent a reduction of the signal strength.

Based on a comprehensive requirement analysis, a plan for the installation of the communication network was created. The architecture shown in Table 5 includes three levels that use various communication technologies for operation. The backbone network, which is characterized by a high data transfer rate, is provided by fiber optic cables and WiMax connections. The backhaul system, which is the minor connection to the central system, is implemented by different technologies depending on the field of application. The access level uses ZigBee, GPRS and PLC as communication technology.

Table 5: Communication technologies in smart grid project of Fernando de Norohna [*34*]

Level	**Technology**
Backbone	Fiber optic cables, WiMAX
Backhaul	Fiber optic cables, WiMAX, WiFi, GPRS
Access	ZigBee, GPRS, PLC

In order to compare the technologies, different scenarios were created. In scenario 1, the communication system is completely based on fiber optic cables. Scenario 2 relies on a total commitment of radio technology. Scenario 3 represents a hybrid solution between fiber optic cable and radio systems. It was shown that Scenario 3 achieved the best cost/benefit solution. However, the project must continue to investigate the ecological impacts. The results can be used to define requirements for future scenarios. The project is currently in the initial phase [*34*].

5.2. Niterói and Curitiba – Ampla Energia

This project is created with the assistance of ANEEL to investigate a feasibility study for the integration of smart grids in the urban sector. As reference cities Niterói and Curitiba were chosen. In Niterói the distribution system was equipped with intelligent network technology for measuring and monitoring the condition of the grid and in Curitiba a comprehensive street lighting monitoring network was built. The focuses of the project are on increasing the power quality, improving grid stability, proving the installation feasibility in an existing overhead line distribution system and reducing the maintenance costs. The selection of communication methods and technologies aims on open standards to prevent high costs spreads by licensed products.

A meshed network with a very low energy consumption, which communicates on the free IEEE 802.11 standard, was chosen as the communication method. Due the ability of the routers to communicate with each other, the network can work without having a coordination server. It is appropriate to use these networks in the urban sector, as a high cross-linking density can be expected. This also leads to high system stability, since in case of failure of single nodes the communication can be reestablished through alternative nodes. Fig. 8 shows an example of communication within a distribution system using meshed networks.

The network provides monitoring applications, switches, voltage regulators, monitoring lights or transformers and power quality measurement. To allow simultaneous control of applications, multiple protocol layers have to be used in the network. For this task, the ZigBee standard is considered as a good solution and added to the MAC layer of the IEEE 802.15.4 standard. For communication between the smart meters ABNT (NBR 14522), which is a standard published by the Associação Brasileira de Normas Técnicas was chosen. The controlling and monitoring devices use the widespread standard DNP 3.0. At the choice

of hardware it was taken into consideration to guarantee full compatibility with the IEEE 802.15.4 standard and implementation ability of additional protocol layers. All routers also have super capacitors that provide the electronics with electrical energy up to 8 hours after a power failure. Special attention was given to the selection of small price hardware with open source integrated circuits.

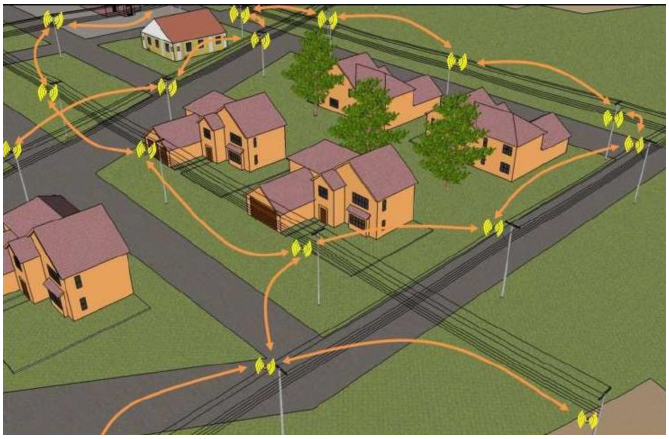

Fig. 8: Example for a meshed network [35]

Various field test measurements were carried out. For coordination of the router network a management system was developed and integrated, which verifies the availability and the response time for every node. Fig. 9 shows the voltage measurement of a router in a region with a high proportion of the tertiary sector of the city of Niterói.

Another field test experiment was investigated in Curitiba. The street light network in a residential area was automated and measurements of current and voltage were performed at each point.

In this project the feasibility of a communication network using mesh networks could be shown. It is planned to increase the number of installed routers up to 400 units. In addition, a further project is being considered, which would be located in rural areas [35].

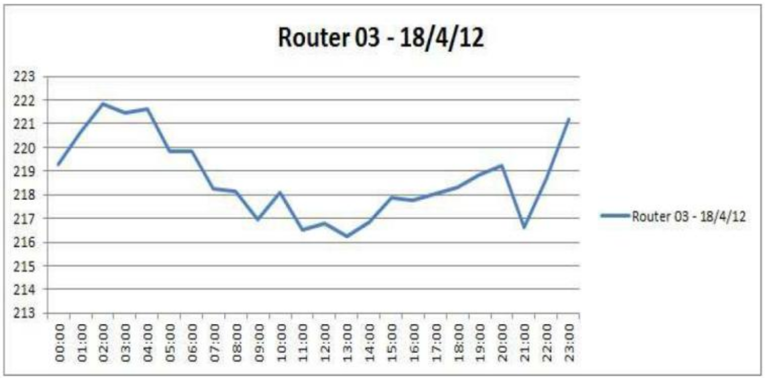

Fig. 9: Voltage measuring in a commercial area of Niterói [35]

5.3. Micro Grid of Sustainable Energy – CELESC

Under the direction of the distribution network operator CELESC another project for the integration of smart grids in Brazil is currently carried out in Florianópolis and Blumenau in the state of Santa Catarina. The focus in Florianópolis is on the implementation of micro grids and distributed generation into the existing distribution network, as well as researches in demand response. As a result, the share of regenerative energy in the electrical grid can be increased and peak loads can be balanced especially in the summer.

More than 10 000 control devices and over 7000 smart meters and measurement units were installed in Florianópolis and Blumenau. The goal is to increase the power quality and reduce the losses with the use auf an effective demand management system. The communication between the measuring points and the central control station is done with the help of power line communication using the existing distribution grid. The measurement devices are connected via transponders with the control center. Then, the transmitted data is sent to a central data collection station where they will be evaluated. The system performance includes the possibilities of smart meter reading, remote connection/disconnection, automatic restart after cutoff, grid monitoring and automatic restart after power failure.

Furthermore, there is a comprehensive test area currently being built in Sapiens Park in Florianópolis, which investigates the design and feasibility of micro grid networks using renewable energy sources and their integration into the existing distribution network. The goal is to show that micro grids consisting of decentralized micro power generators can make a major contribution to the stability of the electrical network [*36*].

6. Conclusion

The present paper is a structured presentation of the Brazilian energy and communication sectors, as well as the current state of development of smart grid in Brazil with focus on the communication technology. The integration of a comprehensive intelligent infrastructure will be an important goal of the Brazilian government. Brazil has the potential to be key market for smart grid technologies. The role of individual communication technologies in the context of a future smart energy network is still open. For this instance the Brazilian government is trying to adapt the experience made by the USA in smart grid technology. The social, topographical and economic diversities, which may take different proportions in all of Brazil, pose a great challenge for the optimal integration of a communication infrastructure in the electric network. The communication methods presented in this paper must be optimally selected for an effective use based on local indicators. Focus should be on reliability, availability, performance as well as on aspect of economics and data security. There is no doubt that this can’t be done by just one single solution. The integration of smart grids will require different technologies, which are adapted to their suitable operating conditions and work as hybrid solutions. The projects, which are currently investigated in selected regions of Brazil, will give further information on the feasibility of different approaches in the near future.

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