Development of Smart Grids in Brazil: a multi-level perspective analysis

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ABSTRACT

The development of smart grids is a complex, multidimensional process, which contemplates the emergence of new technologies, their dissemination and social acceptance, and also a difficult market-creation phase. Such process is therefore better understood through an interdisciplinary approach. In recent years, the approach of the multilevel perspective (MLP) has gained acceptance as an explanatory dynamic methodology of technological transitions; it is based on the concepts of socio-technological regimes, niches and “landscapes”. The purpose of this paper is to analyze the smart grids in Brazil based on the theoretical framework multi-level perspective. The analysis of the status quo and perspectives of development of smart grids in Brazil requires prior knowledge of the motivations and challenges involved. The Brazilian landscape in which smart grids are embedded points to efficiency gains, to the promotion of a more reliable system, and to higher quality as key drivers for the transition, in a context of significant growth in demand. But, it is noteworthy that the current regulatory framework does not encourage investment in network modernization (development of smart grids). Thus, existing smart grid projects in Brazil are currently restricted to early-stage research and development projects, particularly pilot projects.

KEYWORDS: smart grid, smart meter, regulation, projects, policies, multi-level perspective

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1 - INTRODUCTION

The development of smart grid consists of a central element in the dynamics of transformation of the electricity sector in order to meet the growing demand for electricity with safety, quality and sustainability. Although such networks are not an end in themselves, they create necessary conditions for the electrical systems to become more distributed without compromising the security of supply and at the same time, where consumers have a more active behaviour in the management of demand for energy. However, the techno-economic characteristics of the electricity sector (capital-intensive, undifferentiated product, regulated tariffs, inelastic demand, need for instant balance between supply and demand, etc.) do not induce the innovation process to occur endogenously. Therefore, there is a need to adopt public policies to promote investments in the development and the diffusion of innovation such as smart grids.

In Brazil, the development of intelligent networks is still at a very early stage, with incentives restricted to financing pilot projects. In other words, Brazil presents ad hoc initiatives, coupled with insufficient and thus ineffective policies for the implementation of smart grids. Besides the need to improve the quality of service, the need to reduce non-technical losses is a great motivation for investments in smart grids for many distributors. The purpose of this article is precisely to examine the smart grids development prospects in Brazil, considering the characteristics of the existing system and the pressures exerted on it. At the same time, it examines the niches where one can develop and implement smart grid solutions in Brazil.

The development of smart grids is not merely a technological innovation. It is a technological transition, because a new technology will substitute for the incumbent one. It is therefore necessary to examine all the multidimensional variables present in this evolutionary process such as the organizational environment, the institutions involved and especially the interests of different stakeholders in the process. Our study applies the multilevel perspective (MLP) (Geels, 2005a; 2005b; 2012; Markard and Truffer, 2008) to the Brazilian case, which is an adequate approach to analyse the dynamics of technological transitions.

2 – SMART GRIDS AND TECHNOLOGY TRANSITION OF POWER SECTOR

The development of smart grids is complex which contemplates the emergence of new technologies, their dissemination and social acceptance, and also a difficult market-creation phase. Such process is therefore better understood through an interdisciplinary approach. Therefore, it is adequate to use the analytical framework of technological transition on the analysis of smart grids. This approach enables the identification of a set of challenges for policy makers. Strictly speaking, the framework is concerned not with the potential of a new technology itself, but with how this potentiality can be materialized and realized against the advantages of the incumbent technology (Jacobsson and Bergek, 2004).

The following features allow one to analyse the development of smart grids as a process of technological transition:

i. The technologies associated with smart grids can be analysed as an emerging technological system, with the set of emerging technologies associated with smart grids challenging incumbent technologies;

ii. The international literature on smart grids recognizes that this is a long term project, with several full implementation goals by the year 2030. It is therefore a project of slow implementation;

iii. Already there are networks and coalitions of interest around the technologies of smart grids;

iv. Cases of imminent success in relation to smart grid projects are strongly associated with the institutional framework created to develop and disseminate technology.

Although the Technological Systems consists of a very consistent approach to examine the interaction between actors, networks and institutions within the scope of the dynamics of innovation, it is important to emphasize that this approach does not provide a clear distinction between incremental innovations and radical innovations (Markard and Truffer, 2008). Therefore, there is a limitation on this theoretical framework for dealing with technological transitions, i.e. the change from one system to another.

Since the technological transition is the change in a larger system, it is noticeable that it is not confined to the technological sphere and one must consider the presence of lock-in around the existing system. This lock-in is derived from the advantages and / or economic interests of the firms established on the basis of current technological paradigm: core competences on related technologies, built infrastructure, organizational arrangements established standards and consumer preferences (Geels, 2005a).

In summary, the roots of lock in in the electricity industry transcends the supply chain industry where the technology is used. Therefore, the examination of Technological Transition cannot be restricted to comparing alternative technologies in terms of technical efficiency because nothing guarantees that a demonstrably superior technology will be able to overcome initial socio-economic barriers and diffuse in the market. Thus, the process of “locking out” that will ultimately enable the technological transition necessarily involves the consideration of economic, organizational, institutional and cultural variables. Among the possibilities that can trigger lock out, Cowan and Hulten (1996) highlight a possible crisis in the current technological system, adoption of new regulatory guidelines, a technological breakthrough, changes in consumer preferences, the existence of niche markets and the results of scientific research.

3 – ANALYTICAL FRAMEWORK: THE MULTI-LEVEL PERSPECTIVE

In recent years, the approach of multilevel perspective has been gaining space as an explanatory dynamic methodology of technology transition based on the concepts of socio-technical regimes, niches and “landscapes”. Briefly, this theoretical framework considers that technological transitions are not a linear process; they occur due to the interaction between the changes in the micro-level of the niches and the meso-level of socio-technological regimes, which are embedded in a macro level called “landscape”. Based on this approach, authors have proposed policies and helped to define business strategies (Markard and Truffer, 2008).

Such an approach allows working with different levels of system stability. The socio-technical regime is characterized by a high degree of stability, whereby actors and institutions reproduce and maintain the existing system. Thus, it is apparent that innovations that arise at the regime level tend to have an incremental character, as the presence of lock in mechanisms and path dependence lead to changes along the established technological trajectory. It therefore at the niche level that the disruptive innovations tend to appear, as at this level practices and institutions are not yet stabilized. In short, niches are protected areas (market segments where demand has specific characteristics, demonstration projects, research and development laboratories, etc.) in which actors seek the development of promising innovations, which can be incorporated into the regime, or even replace the existing regime in the long run. Within a niche, processes of learning about a new technology take place, together with the alignment of expectations and building of a network. Such processes lead to the involvement of more actors, which enables the expansion of these niches. Finally, above regimes and niches, there is the socio-technical "landscape", comprising elements on which niche and regime actors have little influence and those that change only slowly, such as wars, economic crises, culture and demographical trends (Geels, 2005a).

The various dimensions interact in a dynamic where innovations arise in niches, while slow changes happen at the landscape level, both of which exerting pressure on the existing socio-technical regime. The destabilisation of the regime creates opportunities for the dissemination of innovations originated in niches. In this sense, the Multilevel Perspective considers that the transition process is not the result of linear and unidirectional causal relationships. According to this approach, there are interrelated processes cutting across different levels and comprising multiple (social, economic, political, technical, etc.) dimensions that build up and influence one another; it is therefore possible to speak of "circular causality" in the transition process.

The MLP has been applied the analysis of transition processes taking place at the energy sector,considering the importance of lock-in effect on this industry and pressure from other socio-economic developments. For example, Solomon and Krishna (2011) emphasize the importance of this methodology to examine energy transition processes in general, while Strunz (2014) uses it to analyse the German energy transition, and Mah et al. (2012) address the development of smart grid in South Korea.

4 – SMART GRIDS IN BRAZIL

The analysis of the status quo and perspectives of development of smart grids in Brazil requires prior knowledge of the motivations and challenges involved. This analysis should include not only issues related to the energy sector, but also consider Brazilian socio-economic variables. For example, one must consider the reduced Brazilian per-capita income because it makes implementation costs one of the most relevant obstacle when compared to the reality of developed countries, because costs can hardly be passed on to consumers. The purpose of this section is to analyse the development of smart grids in Brazil with the aid of the multi-level perspective.

4.1 – Landscape

Even considering the increase in income per capita projected over the next twenty years, Brazil will be no more than a country whose income is at average levels internationally. Therefore, the decision of allocation of scarce resources becomes even more complex due to the need to meet several competing demands. This results in difficulties in the definition of priority capital expenditures by the public and private sectors. In contrast, the ability of consumers to pay for the provision of public services is limited, which justifies, for example, the search for low tariffs as one of the priority guidelines in the Brazilian power sector. In addition, the low level of income of a considerable part of the population leads to high levels of non-technical energy losses, especially in regions where the enforcement and inspection is weak and, thus, illegal connections are made (stealing electricity).

In terms of the structure of the economy, although the tertiary sector is predominant in the Brazilian economy and the agricultural sector is also significant, there are many industries characterized by a high energy consumption. As a result, the energy intensity of the Brazilian economy is not low and ensuring energy supply at reasonable prices is of relevance to the competitiveness of domestic industry.

In recent years, there has been much discussion of the process of "earlier deindustrialization" of the Brazilian economy (Carvalho and Kupfer, 2011; da Silva, 2014). This process is characterized by a reduction in the share of the industrial sector in the Brazilian economy, at an early stage of socioeconomic development, characterized by a relatively low level of per-capita income. Given that the Brazilian industry tax costs are often mentioned as one of the main reasons for this phenomenon, it is understandable that the prices of electricity are seen as an added obstacle for the industry.

At the same time, Brazil needs to increase the added value of the national economy through the development of sectors more intensive in technology and knowledge. This strategy aims to make Brazil a developer of technologies in different areas rather than its traditional role of importer of technologies and, consequently, generate income, jobs and foreign exchange. As illustration, the Greater Brazil Plan established, among its goals, an increase in expenditure on research and development as a proportion of GDP, a higher percentage of knowledge-intensive industry, and qualification of human resources.

In this context, we emphasize the importance of developing smart grids, as an economic structure with higher technological density will allow the existence of an electricity network with real-time monitoring of energy flows. In addition, if stimulus are given to the local development of the equipment industry, investments in smart grids may become a value-added mechanism for transforming the Brazilian economy.

The corollary of the maintenance of the Brazilian industrialization process, as well as development focused on sectors with higher added value and more efficient use of energy resources is a reduction in energy intensity of the Brazilian economy. However, considering the still low per-capita level of power consumption in the Brazil, in absolute terms the consumption tends to grow over the coming decades. In particular, demand for electricity should show significant increases.

Besides the demand for electricity is increasing, the requirements of consumers in terms of quality and sustainability of goods and services is also increasing. This consumer behaviour change is associated with diffusion of the knowledge society and a more effective participation in the economy. As a result, the power sector will be subject to increasing pressures on the reliability and quality of supply.

Given the higher demand of society for the sustainability of socioeconomic activities, the need to preserve natural resources and the mitigation of environmental impacts will become increasingly imperative. In fact, since the 1988 Constitution there is a more rigid Brazilian environmental legislation, especially in terms of implementation of projects in the Amazon biome. In turn, in light of the level of climate change mitigation efforts comprised by the Paris Agreement, Brazil will assume formal commitments to reduce its emissions of greenhouse gases. As a result, it is expected that some emissions limitation effort will be imposed on the Brazilian energy sector.

In summary, we can say that the Brazilian landscape in which smart grids are circumscribed indicate potential efficiency gains, the promotion of a more reliable system and higher quality as key drivers in a context of significant growth in demand. The environmental driver is smaller when compared to dynamic seen in countries with electrical systems characterized by the predominance of generation from fossil sources. In the case of regions with high non-technical losses, addressing this issue is also an important motivation. Furthermore, one needs to consider adherence between the development of smart grids and the goal of providing the Brazilian economic structure of greater technological density. On the other hand, limitations on capital availability to the investments and the necessity of offer energy at affordable prices consist of barriers for smart grid development in Brazil.

4.2 – Socio-Technical Regime

In 2014, the Brazilian electricity consumption was approximately 531 TWh, being approximately 2630 kWh per capita. Therefore, it is a level of consumption still relatively modest compared to developed countries. This consumption has been met by a 624 TWh production and thus there was a loss in the order of 14,9% (MME e EPE, 2015a). Although Brazil is a country with an interconnected system of intercontinental dimensions, these losses are not explained only at the technical level because also include non-technical losses (theft) of energy.

At the level of electricity generation, Brazil’s system is predominantly hydroelectric. To handle the seasonality of inflows, the hydric park was built historically associated with storage reservoirs with the function to regularize the supply of energy throughout the whole year. In addition, it has a robust transmission system in order to interconnect different regions and to exploit synergies derived from the differences between these inflows regions. In turn, the function of the traditional thermal power stations must be backup system.

Is highlighted that, even with the water crisis that started in late 2012 and the consequent need to dispatch a large amount of thermal power plants on the system’s basis continuously, the hydro park continues to account for over two thirds of electric power generation. However, the profile of the hydro park is changing and, to a large extent, the current water supply crisis is already consequence of this paradigm shift.

Given that the remaining hydropower potential is located in the Amazon region, which is characterized by soft topography, and there are restrictions imposed by the environmental sphere, the plants that are being built, as planned, do not have storage reservoirs. Therefore, the regulating capacity of the hydroelectric supply is clearly downwards and therefore the hydroelectric energy supply will become increasingly seasonal.

We observe thus the need to diversify the Brazilian energy matrix, especially when considering that the expected growth in demand for electricity between 2014 and 2024 is 260 TWh (MME e EPE, 2015b). Thus, prospects are of a considerable increase in non-hydro renewables in the period, which is consistent with the finding that the exploitation of Brazil's potential for renewable energy is a relevant and aligned strategy with the promotion of a low carbon economy. In this sense, besides the inclusion in the network of surplus electricity produced in sugarcane plants from the residual processing of sugar cane biomass, in recent years there has been significant investments in the construction of wind farms. As a result, the installed capacity of wind power generation amounted to approximately 8.5 GW at the end of 2015.

Although wind power is seasonally complementary to the hydrological regime, it is an intermittent source that poses challenges for system operation, especially in terms of peak demand service. Even if the participation of wind generation is still small, these effects can already be noticed. This difficulty tends to be accentuated with the inclusion of solar generation, specifically photovoltaic solar energy over the next few years. Given that the diffusion of photovoltaic generation will occur mainly in the consumer units connected to the low voltage network (according to Resolution 482/2012 and its later revisions), the issue of intermittency will also need to be managed directly by the electricity distribution companies.

In order to ensure security of supply, hiring controllable power plants presents itself as a relevant strategy. Generally speaking, the strategy consists in the realization of investments in thermoelectric plants to operate in the base of the system, as well as in thermoelectric plants equipped with dispatch to meet peak demand. At the same time, it recognizes the importance of carrying reinforcements on the network in order to make it more robust.

However, one must emphasize that the flexibility of demand can take on great importance in the system management. While the entire set of measures in the scope of demand side management is important in terms of an integrated view of energy planning, the focus here is specifically on demand response measures that alleviate the system's peak demand. At the level of large consumers, there is the existence of rates of time-of-use type (TOU). This tariff structure shows a time signal that aims to distinguish the peak hours compared to other times. In fact, studies indicate that industrial consumers effectively respond to this tariff signalling.

More recently, the white tariff mode destined for low voltage consumers was created, whose membership are optional. This tariff structure is also the TOU kind and seeks to distinguish the price of energy in terms schedules on weekdays, i.e. the peak hours between 18 and 21 hours; an intermediate time comprising the hours immediately before and after the peak hours; off the peak comprising the remaining schedules. However, the effectiveness of the white tariff requires the existence of smart meters. But, currently, the vast majority of consumers continue to have their energy consumption measured by electromechanical meters. Although Resolution 502/2012 has set March 2014 as the deadline for the installation of smart meters in the consumer units who join the white tariff, this issue is not yet equated due to the limited supply of smart meters in the market and uncertainty about technical standards. In this context, it is understandable why in February 2014 ANEEL chose to postpone the schedule originally envisaged for implementation of the white rate.

The existence of intelligent tariff models is a central rationale for the dissemination of smart meters. But there are other reasons, which range from inciting more efficient behaviour in the use of equipment, to handling two-way flows of energy and monitoring the load. Furthermore, the need to combat non-technical losses in some regions emphasizes the importance of implementing smart meters. While these meters alone will not reduce losses, they permit to accurately identify loss location and therefore they make it possible to adopt effective measures for combatting fraud.

However, it should be stressed that the development of a smart metering system and not only the roll out of smart meters is required. This highlights the the importance of communications infrastructure. Given the precariousness of the Brazilian telecommunications network, it is common that distribution companies have to develop their own networks. As a result, the cost of smart metering systems ends up being a burden and this makes it difficult to implement them, with the potential impact on tariffs.

Consequently, given that smart grids are not limited to smart metering, we need to consider other of its aspects in terms of relevance to the Brazilian electrical system and the plausibility of effective implementation. Therefore, it is first necessary to consider the status quo of the current grid. In this regard, the generation facilities and transmission system operators in Brazil are characterized by the presence of automated systems equipped with digital technology and controlled by virtual centers. Thus, it is possible to monitor in real time the operating conditions. In contrast to the high voltage domain, distribution companies have networks characterized by an automation level still quite limited. The operation of the distribution network continues to be performed based on conventional technologies and practices (Galo *et al.*, 2014).

Furthermore it is important to emphasize that the Brazilian distribution network has obsolete assets. Therefore, it becomes understandable why, in addition to the high level of losses, there is a low quality of electricity supply. This poor quality is measured by the high number of interruptions during the year and the duration of these interruptions, the latter metric directly derived from difficulties / system limitations in correcting faults and carrying out the re-establishment (Di Santo et al., 2015).

The modernization of the distribution infrastructure, particularly the development of smart grids is central to the improvement of quality of service, contributing to the achievement of objectives such as increasing system efficiency level and reducing of non-technical losses. However, they are not checked effective efforts in this direction. To a large extent, the difficulty arises from the current regulatory model because it does not encourage companies to opt for more efficient technology: it does not recognize the investment and/or the investment cannot be paid appropriately with the current rules, especially when they concern technology characterized by a cost structure of higher OPEX relative to CAPEX. The issue of investment in telecommunications networks and information technology has thus become problematic.

4.3 – Niche-innovations

With the aim of developing smart grids in Brazil, there is some important niche initiatives. The legislative framework is being reformed: bills are still pending in Congress, such as 608/2001, 84/2012 and 3337/2012 which deal with the large-scale dissemination of smart grids. In parallel, there is the work of the inter-ministerial group under the command of ABDI (a quasi-governmental organization devoted to industrial development) that seeks to identify the entire production chain of smart grids and propose public policies that include the development of a national industry. In the context of regulatory guidelines, besides the already mentioned Resolution 482/2012 and 502/2012, there are resolutions 375/2009 and 395/2009 which deal respectively with the use of the distribution network to carry analog and digital signals (for example, internet) and the implementation of georeferenced information of the distribution network system.

However, it must be emphasized that the most effective initiatives for smart grid development are still restricted to research and development projects, in particular through pilot projects implemented by some electricity distribution companies. Commonly, these projects are intended to test on a sample of market technologies and measures inherent to smart grids, among which, metering systems and smart tariffs, network automation (including self-healing), micro, electric mobility and smart home.

As an illustration, there is the InovCity project developed by EDP / Bandeirantes in the city of Aparecida (state of São Paulo), which is analogous to the project implemented by EDP in the city of Évora in Portugal. The city of Aparecida represents 1% of the consumer market of EDP / Bandeirantes and the project covers a universe of 15,000 consumers. The project includes the installation of smart meters, energy efficiency measures, network automation, distributed generation, public lighting provided with efficiency, public awareness actions on the rational use of energy and electric mobility.

In turn, AES / Eletropaulo has the largest smart grid project in Brazil in the cities of Barueri and Vargem Grande Paulista (both in São Paulo). Given that Barueri is part of the metropolitan region of São Paulo, this is a suitable city for experiments to be replicated in urban and industrial areas. In short, the project will meet 52,000 consumers in Barueri and will include smart metering and automation of the network in order to reduce commercial losses, improve quality of supply and make the system more efficient. In contrast, Vargem Grande Paulista is an essentially rural area where the concessionaire seeks to develop solutions for such regions, especially in terms of self healing.

With some variations, similar projects to the EDP / Bandeirantes and AES / Eletropaulo are being developed by Ampla in the city Buzios (state of Rio de Janeiro), by Cemig in the city of Sete Lagoas (Minas Gerais) and by COPEL in the metropolitan region of Curitiba (paraná). Generally speaking, the projects seek to not only find ways to make the system more efficient and with lower operating costs, as define a model to be replicated on a larger scale.

The development of smart grids is occurring primarily on the basis of pilot projects, because the current regulatory framework does not encourage the modernization of the network, there are specific niches where the reduction of operating costs can justify larger investments. This is the case of Light in Rio de Janeiro that has already installed 400,000 smart meters in order to reduce commercial losses and, consequently, improve its operating result.

5 – CONCLUSIONS

Growing demand for electricity and the predominance of renewables in the energy matrix make smart grids motivations in Brazil a little different from those observed in developed countries. Although the easing of demand has increasing importance due to the disseminating intermittent sources, investments in smart grids are justified primarily by the need to improve the poor quality of supply, make the system more efficient and enable the reduction of non-technical losses.

But, it is noteworthy that the current regulatory framework does not encourage investment in network modernization. Thus, existing smart metering projects turn out to be too restricted to research and development projects, particularly pilot projects. Therefore, it emphasizes the necessity of regulatory changes that encourage innovation and regulation of new business. In addition, the formation of public policies providing, for example, targets for rolling out smart meters, or standard quality requirements of the telecommunications infrastructure.

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