Classification of economic Approaches for Stability in Smart Grids

Corinne Keller, Daniel Manser, Sandro Vogler, Holger Wache
Institute for Information Systems, School of Business
University of Applied Sciences and Arts Northwestern Switzerland
Olten, Switzerland
{corinne.keller, daniel.manser, sandro.vogler}@students.fhnw.ch, holger.wache@fhnw.ch

***Abstract*—Several European countries are increasingly focusing on renewable energy in order to satisfy their demand. A core problem of these sources is their reliability, which means less continuously available energy is accessible. Smart grids are trying to cope with this problem by adding intelligence to the net, which tries to adjust the load according to the current produced amount of electrical energy. Many approaches try to tackle down this problem by technical means. This paper analyses existing economical approaches for smart grid environments and highlights the unique features and important properties of a broad selection of papers. Classification criteria are derived from existing literature. Afterwards, the most prominent papers are used to demonstrate how the classification scheme can be applied.**

***Index Terms*--Costs, Power generation economics, Power quality, Power system stability, Smart grids**

I. INTRODUCTION

A stable power supply (which incorporates the network) is essential for any developed national economy [1]. However, technical advances of renewable energy production such as wind or solar energy have created thousands of small, fluctuating energy producers to compete with the existing large providers, which affects the network stability [2]. Smart grids have been proposed to approach the challenge this situation creates, by using closely interlinked components able to communicate together in order to secure stability of the providing infrastructure [3].

Beside technical approaches to advance the power grid, the focus shifts more towards the customer. Hillemacher [4] states that caused by the change in the power supply system, an intelligent and decentralized leveling between consumption and generation becomes increasingly important due to the volatility of decentralized feeding. Such leveling can succeed only by involvement of all market actors [4].

Many smart grid related papers focus on technical aspects; as far as economic questions are concerned, no overview of proposed solutions, which integrates all market actors, could be found in scientific literature. In addition, no classification scheme for these approaches exists. Such classification can serve as a base for future pricing models, which inherently foster network stability.

This paper aims to identify criteria, which allow a classification of economical approaches for stabilizing power networks according to their different economic principles.

The research is split into two phases: a design phase and a classification phase. In the design phase, the classification scheme is developed. We recognized that smart grid economics are very similar to liberalized electricity markets. Therefore, we analyzed the electricity market with respect to smart grids and derived essential market aspects. The classification is created by aggregating existing classification of specific market aspects (see Section 2). For the classification phase, a literature research using scientific databases (IEEE Xplore, ABI Inform, Science Direct, Thompson Web of Science, Scopus and Business Source Premier), and the academic search engines of Google and Microsoft was performed. From the retrieved papers describing smart grid economic principles, the most often discussed papers in the community are selected. We applied the classification to them in order to verify the suitability of the proposed criteria (see Section 3).

II. CLASSIFICATION SCHEME

The electricity market differs from other markets and even from other energy markets due to some specifics of the good "electricity" [5], [6]. Besides electricity being crucial for developed economies, it is hardly substitutable, difficult to store and, although demand varies substantially in the course of a day and a year, production and consumption have to be balanced at every point in time in order not to provoke a blackout. [5]-[7]. As electricity is such an important good, many areas are government-controlled or government-subsidized. [8] furthermore states that the net is a natural monopoly, which necessarily needs governmental control. Continuity in power supply is not given per se, as e.g. renewable energy tends to destabilize the energy system due to weather phenomena. This complicates forecasts and has impacts on prices [9], [10].

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In Europe, electricity is traded across countries [6], but there is no common market as such. Further, several actors are involved: Producers, network operators (distribution and transmission networks) and consumers [11]. [6] adds the brokers as actor, and [12] introduces the prosumer as a consumer, which also generates or stores some power. Moreover, the markets consist of several levels, depending on the time horizon of electricity planning and the involved actors. E.g. in Germany the market is divided in bilateral "over-the-counter" transactions and transactions at the European Energy Exchange (EEX) [13]. All these factors have to be incorporated into the classification criteria.

The goal of this classification is to provide the means to assess papers describing economic approaches for smart gird environments. Using the classification, it is possible to quickly assess the differences between the papers. The classification criteria described here allow identifying the characterizing facts of economic approaches or models for smart grid environments. In Section 3, we use these criteria to classify the papers and are thus able to show the criteria are able to distinguish the papers according to the way they approach the problem.

As previously stated, feasible taxonomies were taken from existing literature in order to classify the selected papers. However, no holistic classification of economic approaches could be found in the researched sources that has the required depth and does apply to the specific situations of the electricity – and thus smart grid – market.

The developed criteria catalogue has been built in a hierarchical way, starting with a general classification of economic approaches and subsequently, each top-level criterion has been refined using sources, which present a classification scheme for this specific branch, i.e. the electricity market. The most general level to build the classification upon has been derived from the definition in [14]: A *market* is formed when *buyers/sellers* that trough interactions determine the *price* of a *product(s)*. These four criteria are refined in the following:

A. Market

To describe a market's properties further, the classification described by [15] was used. Although [15] focuses on technical approaches, it proposes a useful market segmentation which considers a variety of criteria, such as degree of competition, time scoping, how uncertainty is represented, and consideration of transmission network, interperiod links, as well as whether it takes transmission constraints into account, the power producers and the underlying market model. This classification is used as a starting point and is adapted to the smart grid situation.

1) Competition

The microeconomics theory knows several manifestations regarding the criteria of the market structure. According to [14], the following forms can be distinguished: *monopoly* (a market with only one seller for many buyers), *monopsony* (a market with only one buyer and many sellers), *bilateral monopoly* (only one seller and one buyer), *monopolistic competition* (differentiated products, many firms, low restrictions for new firms) and *oligopoly* (few firms, restrictions for new firms) as well as *competitive markets* and *cartels*. The term *competitive market* describes a market model with perfect competition and assumes the following: price taking of the participants, product homogeneity as well as free entry and exit [14].

2) Marketplace

According to [6], electricity is traded on different levels. Very common is the *over-the-counter* trading (bilateral trading). Additionally, there are *energy exchanges* such as the EEX European Energy Exchange. Several technical approaches propose to exchange energy in micro-grids (e.g. [16]. At the stock exchange both *spot-market* deals (short-term: in Europe defined as until 36 hours before the transaction [11]) and *futures* are traded.

B. Product

To describe the properties of the product, namely energy, the lifecycle of the product is looked upon, i.e. going from production, over transport to consumption.

1) Production

[17] distinguishes between the following three types of generation systems: *Micro-generation* is defined as small on-side electricity generation technology that is suitable to provide full or partial power for a home or business and produces up to 5kW. It may also export a little back into the electricity network. *Mini-Scale generation* produces energy in the range of 5-20kW so that a large household, business or small farm could offset a large portion of its power bill and may export back into the network. *Commercial-scale distributed generation* is defined as a generation plant that is usually used to sell electricity to a retailer, another purchaser, or into the wholesale market, they produce more than 20kW.

2) Transport

The power grid is subdivided into four voltage levels: *Extra-high tension (EHT)*, *high voltage*, *medium voltage* and *low voltage*. The EHT network transports power over long distances. At high and medium voltage networks, industrial consumers are connected, whereas residential customers are connected to the low voltage network [13]. A classification approach using voltage levels was chosen, since it is more versatile and has a finer granularity than a classification using types of networks (such as transmission net).

3) Consumption

On the consumption side of the power network "Demand Side Management" (DSM; also Energy demand management) is one of the most important instruments to ensure the stability of the network. DSM is a portfolio of measurements to reduce demand and improve the energy system at the side of consumption. [18] categorized it into the following four categories:

Energy efficiency includes all permanent changes to equipment, for example exchanging an inefficient ventilation system with a better one. *Time of Use* tries to shift demand to different periods by using higher tariffs to penalize using in certain time periods. *Demand Response* refers to several programs that can be used to encourage customers to make short term energy savings, examples for this include direct load control, where a third party entity outside of the home decides how customer loads will be controlled [19]. Lastly, *Spinning reserve* refers to the extra generating capacity that is available from generators that are already running in the power grid. It can be distinguished between primary control (active power output directly depends on frequency) and secondary control (restoring frequency and grid state with additional active power).

4) *Price*

Price responsiveness is a key element of smart grids. It describes the economic concept of elasticity: When the price for electrical energy rises, the consumers are more willing to shift their need to a time with lower demand (and thus lower prices) [5]. The need for price responsiveness is based on the fact that electrical energy cannot be stored efficiently [5]. In terms of price, we are looking at the different pricing models that are used when the final sale from the retailer to the consumer takes place.

a) *Pricing Models*

[20] defines the following criteria: *Fixed Tariffs*, where consumers face a flat price, which result in an overconsumption during peak hours and an under-consumption in off peak hours. With *Inclined Block Rates* on the other hand, the consumer pays a different tariff for each bracket of consumption. *Seasonal Rates* set different rates for different times of the year so that customers face higher rates in peak months of the year; it is therefore very similar to TOU tariffs. *Critical Peak Pricing (CPP)* is a dynamic pricing model in which consumers are previously notified of the peak hours and will have to pay higher charges during the peak hours after they reach a certain threshold. *Peak Time Rebate (PTR)* is similar to CPP, but instead of facing higher prices during peak hours customers receive a discount for consumption during off-peak hours. In *Real Time Pricing (RTP),* the customer price is based on the underlying spot market price.

5) *Actors*

The below described actors can participate in the power market. The distinction between the different actors is based on [13]: The *consumer* is the actor, which obtains power for the operation of devices. The group of *consumers* is very heterogeneous. Normally, residential customers and industrial customers are distinguished. Additional to the work [13], [21] as well as [12] introduce the term "*prosumer*" as a special kind of customer that namely as produces renewable energy. The *suppliers* on the other hand are companies that operate own power plants or deal with power. Here, various states of integration are possible. The *producer*s are only the operators of power plants. The transportation of electricity requires different voltage levels and a complex network. Depending on their function, a distinction is drawn between *distribution network operators* and *transmission network operators*. [6] add to the actors the role of *energy broker*. Similar to that but on another level are also the energy service providers, which have a potential to overtake several services for the many small *producers*, such as bundling and optimizations of decentralized producers [4]. An approach is classified as focused on a specific actor, if this actor takes a dominant or important role in the model.

III. APPLYING CLASSIFICATION

In this Section, the most prominent papers are classified according to the proposed scheme. An overview is presented in Table 1. Empty cells in the table indicate the respective paper does not make statements about the particular criteria or that the criteria is not applicable.

A model to reduce peak load by offering rebates (*Peak time rebates*) is proposed in [22]. As the rebates are offered to consumers, the targeted transport is the *low voltage* system. This approach is a typical example for *demand response management.*

Also, [23] operates in a *competitive market*, where the brokers can sell and buy electricity. A difference can be found in the *energy exchange* (the market), where *spot and future transactions* can take place. The approach uses time-slots but considers them to be very short (10 - 15 minutes), which is why we classify them as *real time pricing*. A unique property of this approach is the fact the distribution utility charges for not using local resources, causing a similar effect as [22], but by using a penalty instead of a coupon.

In [24], a market with periodic market clearing is proposed, which implies a kind of *energy exchange*. Their study researches the impact of price signal delays, which is only relevant in a *real-time* based market environment.

A simulation assuming a a *bilateral monopoly* in a micro grid environment is presented in [25]. The grid is able to get power from a local renewable energy source (*micro-generation*). They generalize the original static pricing to a dynamic pricing model, which is why this approach's pricing model is classified as *real-time*.

Another simulation, using *real-time* pricing is described in [26]. The energy consumption controller helps to maximize the welfare of all the participants and align their *demand response* to the optimal consumption levels.

The intelligent energy management framework of [27] operates in a *competitive market*. The aggregators coordinate automatically the demand by shifting demand (*TOU*) and direct load control (*demand response*). Together with *real-time pricing* and smart charging, benefits for both consumer and suppliers are realized.

A *competitive market,* where arbitrage agents are able to exchange energy freely, is assumed in [16]. The decentralized micro energy grids generate and need power and heat, which is managed by electronic agents. Furthermore, open book call markets support the negotiation of the energy allocation. The market-based approach for efficient matching of supply and demand (*TOU*) is complemented by technical balancing approaches (*spinning reserves*).

TABLE I. OVERVIEW OF CLASSIFIED PAPERS

Author	**Criteria Group**						
	Market		**Product**			**Price**	**Actors**
	Competition	***Marketplace***	***Production***	***Transport***	***Consumption - Demand Side Management***	***Pricing Models***	***Focused Actor***
Zhong, Le Xie & Xia [22]	Competitive markets		Commercial-scale distributed generation	Low voltage	Demand response	Peak Time Rebate	Supplier-focused approach
Ketter, Collins & Reddy [23]	Competitive markets	Energy exchange (spot and future)				Real Time Pricing	Broker-focused approach
Nutaro & Protopopescu [24]		Energy exchange				Real Time Pricing	
Chiu, Sun & Poor [25]	Bilateral monopoly		Micro generation			Fixed tariffs	
Samadi et al. [26]	Competitive markets				Demand response	Real time pricing	
Adika & Wang [27]	Competitive markets				Time of use, Demand response	Real Time Pricing	
Block, Neumann & Weinhardt [16]	Competitive markets	Energy exchange	Micro generation		Time of use, Spinning reserve		Prosumer-focused approach
Chen et al. [28]	Oligopoly, Competitive markets	Energy exchange		Low voltage	Demand response	Real Time Pricing	Consumer-focused approach
Feng et al. [29]					Time of use		Consumer-focused approach, Distribution-focused approach
HomChaudhuri & Kumar [20]		Energy exchange	Micro generation, Mini-scale generation	Low voltage			
Eger, Gerdes & Rusitschka [31]	Competitive markets						Consumer-focused approach, Broker-focused approach

The resulting equilibria and *demand response* schemes for both a *competitive market* and an *oligopoly* is characterized in [28]. The demand response within the smart grid can be described as an *energy exchange*. They also consider a situation where customers are subjected to *real-time* spot prices. Therefore, this paper also includes the price model *real time pricing* to a certain extent. The document focuses entirely on *demand response* and presents a *consumer-focused approach*. The paper is focusing on local *Low voltage* transport.

The authors of [29] focus entirely on *Time of Use Pricing* as a form of *Demand Side Management*. They model functions for both the user and the company distributing the energy and can therefore be classified as both a *consumer-focused* and *distribution-focused approach*.

The problem, which arises in a Smart Grid due to Micro generation and Mini-scale generation, is, in parts, considered in [30]. The described market-based auction model for grid resource management can be classified as *energy exchange*. The approach is focusing on a Smart Grid; therefore, the mode of transport is *Low voltage*.

A *competitive market* is presumed in [31]. The proposed mechanism fits neither the form of an energy exchange or over-the-counter market, but could be classified as “any-to-any” which is not described in literature used for the classification scheme. In addition, focusing on the trading between consumer and producer, the concept of energy *brokering* is also introduced into the described mechanism. This paper can be classified as *Consumer-focused*, and *Broker-focused*.

IV. CONCLUSIONS

In this work, we present a classification scheme for the power market based on how they foster network stability. Economic approaches were investigated which try to achieve network stability characterize them based on what they try to optimize. We found a large variety of mechanisms on different levels due to the heterogeneity of the electricity market. The scheme was derived from literature, bringing together various aspects identified. The classification tries to find a balance between being very specific and at the same time general enough to be applicable for the various economic approaches. It could be shown that the provided criteria are suitable to classify the selected papers in a reasonable manner, so they can be distinguished according to their economic principles.

We found that some criteria can be applied to almost all papers, since the corresponding aspect is well described (e.g. competition or pricing model). Other criteria, such as transport are often not covered or not applicable to the model. This, however also means this aspect is currently not well addressed in literature.

As our work gives an overview of existing approaches how to ensure network stability, these concepts have now to be discussed further and to be adapted on the country-specific conditions. With help of the presented classification, it becomes easier to focus on particular aspects of pricing schemes, which supports the development of new economic models that focus explicitly on network stability.

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