RESEARCH ON POWER QUALITY MARKET SYSTEM

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ABSTRACT

Along with electricity market deregulation, management of power quality suffers more and more pressure from economic and social equity. It is necessary to establish Power Quality Market (PQM) to assure social equity and improve social integrated benefits. Based on the operation and deal characteristics of PQM, this paper explains the basic framework and functions of PQM system, and disassembles the PQM system into three kinds of market: electromagnetic pollution emission right trading market, power quality service market, power quality technology and information trading market. And those markets are explained in six primary market elements such as market participator, market object, market carrier, market price, market regulation and market supervising. Then the characteristics of PQM system are summarized. The organizations and functions of market supervising department are explained. Some emphasis and difficulty of technology that support PQM are proposed. Finally the keys of PQM existing, progressing and running effectively are discussed.

INTRODUCTION

Modern electrical loads incline to diversity and complexity. So many nonlinear, impulsive and unbalanced loads deteriorate Power Quality (PQ) of network. At the same time, lots of computer-based systems, robots and high-tech industries require the PQ to stay at high levels. Conflicts caused by PQ problems are aggravated dramatically. An important reason is that electromagnetic pollution has an external cost, which means some one emit electromagnetic pollution (conductive) into one Point of Common Connected (PCC), then all customers connected to this PCC will suffer economic losses from it. But now there is lack for incentives for decision-makers to settle this problem. Like other natural environment, electromagnetic environment is also a public property. PQ management suffers pressure from economy and the requirement for social equity. According to “environmental economics”, it is necessary to control electromagnetic pollution emitted by both electric utilities and customers [1]. Controlling electromagnetic pollution includes three parts: restricting pollution gross, optimal distribution of Emission Right (ER) and charging for pollution. Restricting pollution gross means to maintain PCC on an optimally polluted level where the sum of the losses caused by PQ disturbances, mitigation costs for PQ disturbances and improvement costs for higher PQ in the whole PCC is the least. By restricting pollution gross, customers have to curb their emissions to an acceptably low level. Otherwise, they

have to pay high price, which indicates ER has a value in trade. Optimal distribution of ER means to directly exert the electromagnetic environment to a great extent and indirectly attract optimal investment for mitigating PQ disturbances. Charging for pollution, based on the ER-quantity, infers to transfer external cost to interior, which means those with more ER should pay more while others with less ER should pay less. That is equitable and provides incentives for decision-makers to consider external cost of pollution. Optimal gross and distribution of ER both vary with the variations of loads and networks. Obviously, optimal gross and distribution of ER should be worked out through optimal programming methods. So the information concerning electric characteristics, economic losses caused by PQ disturbances, mitigation and efficiency improvement of electric utilities and customers needs to be accessible. In market environment, administrative means alone may not be too effective and may produce some side effects, such as corruption. As ER can be traded with value, optimization of electromagnetic pollution control should be actualized using market that assumes the responsibility to distribute resource optimally. So ER charging and trading market should be established as a carrier to actualize management, trading, pricing and charging for ER. As long as the market can display the real value of ER and guarantee its currency, all the three parts of electromagnetic pollution optimal control can be actualized, and total social benefit can be maximized as a result.

When customers choose electricity, the kind of primary commodity, their attention will be paid not only to the quantity of electricity, but also to its quality. In electricity market, the quality of electricity are guaranteed by ancillary services which are classified into six kinds based on their functions [2]: Automatic Generator Control (AGC), spinning reserve, non-spinning reserve, substitute reserve, reactive and voltage support, and blackout start. Obviously, these services are mainly served for the generation side. Can the ancillary services play an important role in power transmission and distribution? On the contrary, requirements in terms of PQ incline to intensity and diversity. The advent of conflicts relating to PQ in power transmission and distribution are very frequent and serious. Generally, as generators can provide voltage according with sine wave exactly, the main task of ancillary services in generation market is to keep high reliability and sufficient reactive power supply. Unfortunately, electricity in transmission and distribution systems is vulnerable to load changes in terms of amplitudes and waveforms. The functions of ancillary services in transmission and distribution systems include high reliability, enough reactive power supply, and making other PQ indices satisfy customers’ requirements. Furthermore, the ancillary
services in transmission and distribution systems should contain four parts, i.e. reliability service, support on reactive, voltage-amplitude service and waveform-service (both in steady and transient states). The ancillary services in transmission and distribution systems is named as PQ-services in order to be distinguished from their counterparts in generation market. As one of the important attributes of electricity in a perfectly competitive electricity market, PQ is quite able to influence the competition results among electric utilities. So, great importance should be attached to PQ-services.

Ancillary service market is established to actualize trade, management and pricing for ancillary services, where the services can be more easily accessible to all customers with as low prices as possible. Hitherto, the establishment, trade rules and market-clearing for ancillary service market have been discussed and debated by many scholars. However, all of their attention focuses only on generation side [3]. As PQ-services are important components of ancillary services, so a market actualize their trading, management and pricing should be established. PQ-service market can improve PQ-service and lower its cost as well.

Systems such as ER charging and trading market and PQ-service market can be built up to reduce social comprehensive loss caused by PQ problems. The former is a preventive and cure system against electromagnetic pollution. After electromagnetic environment is treated as a kind of resource and ER enters markets, the electromagnetic environment can be well exploited and PQ disturbances can be mitigated effectively and professionally. PQ service system is a PQ improvement system. After PQ improvement becomes an element of markets, it can maximize benefit created by limited investment and can distribute electric energy with high PQ rationally. The two markets that constitute the main body of Power Quality Market (PQM) complement and promote each other. Solution to PQ problems needs not only engineering technology, but also knowledge in social economy and resource optimization.

Perfect PQM facilitates the formation of pricing system, and lays the foundation for the government's macroeconomic control and optimal resource distribution. Furthermore, it has the function of value estimation, providing incentives, punishing and awarding. So, the conflicts brought about by PQ can be dealt with through establishing a perfect PQM, which includes six basic elements, such as market participators, market objectives, market carriers, market pricing, market regulation and market supervision. Starting from these six elements, this paper offers a comprehensive analysis of PQM.

THE BASIC FRAMEWORK OF PQM SYSTEM

Electromagnetic Pollution ER Charging and Trading Market

Charging for electromagnetic pollution is an important means to guarantee social equity. Individuals should pay for such kinds of electromagnetic pollution as harmonics, unbalanced current, surge current, irregular and flicker current and reactive power current. Charging for electromagnetic pollution has two purposes. The first is to control all kinds of electromagnetic pollution of PCC through economic stimulation. Furthermore ER can be distributed optimally and mitigation investment can be directed at best uses. So the total social loss (including loss caused by PQ disturbances and cost of mitigating PQ disturbances) can be minimized [4]. The second is to actualize social equity. Even if the PCC is at the optimal polluted level, there is still loss caused by PQ disturbances. That loss is shared in all customers inequitably because of external cost of electromagnetic pollution. In order to reflect social equity, charging electromagnetic pollution represents the principle "charging for any electromagnetic pollution". The fund charged from a certain PCC can compensate for some damaged consumers, and the remainder can be used to lessen power prices in this PCC. References [5]-[6] discuss the methods of pricing for harmonics and reactive power current as pollution, and propose marginal price models for their injections. But pricing methods according to other three polluting currents are under research.

In order to control ER gross and charging for ER quantitatively, charging policy as "emission permit" needs to be adopted. Firstly, Market participators must apply quantity of ER from PQ Supervision Department (PQSD) if they want to emit pollution into PCC. Secondly, The expenditure they should pay is calculated according to their quantity that ER permits, and they will be punished if they over-emit pollution. Thirdly, ER can be traded among market participators. Free ER trade contributes to making best use of electromagnetic environment and mitigation investment. Treading can occur among any individuals in the same distribution system, and different transmission or distribution entities. But those in different distribution systems can't trade with each other. The trade objects are ERs according to the mentioned five kinds of electromagnetic pollution, whose detection, classification, recognition, location and measurement have been discussed in [7]. Definitely, these efforts will contribute to electromagnetic pollution control, but the results haven't yet been so feasible for any practical applications. Unluckily, quantitative researches on measurement are very limited yet.

An important prerequisite for constituting relevant ER trade rules is how to make rational the procedure of issuing ER to each electromagnetic pollution source that will have decisive impact on social equity and tendency of mitigation investment. There are two reasonable methods for ER distribution. In the first method, ER is issued freely and fees are collected timely. In the second method, initial ER is auctioned out. Every participator fairly possesses the rights to cause electromagnetic pollution. Based on the former methods, ER should be issued proportional to the amount of the holder’s active power. The customers with excess ER can sell that to other customers or hand it back to PQSD. The quantity of ER to distribution utility should be decided by the PQ level that is provided. Thus the equity of ER distribution can be guaranteed and ER can be exercised to full. This method features its easiness for...
practice and convenience for controlling total ER via adjusting ER price. But, the disadvantage of the method lies in its inability to confirm optimal gross ER and rational unit ER price. ER is auctioned like ordinary merchandise in the second method, which offsets drawbacks of the first method. As auction is a typical game process, game theory can be applied as an important means in market economy [8]-[9]. It helps to figure out what decisions should be taken when players’ action directly influences each other. It, also, keeps the equilibrium of these decisions. Using the game theory, such action as preliminary calculation, initial distribution and trade of ER can be described as different game processes respectively, which ensures that the study on market policy and market players’ action should accord with actual cases. Uniform-price sealed auction is appropriate for ER distribution [10]. After processing the comprehensive information of all the players, PQSD can work out optimal gross ER of PCC close to the most economical polluted level. During the auction, the emission cost according to ER will be offset, so those who get ER can emit pollution freely within their permissions. But this method is so complicated that it hard to be adopted. Considering the length of this paper, it will not be explained in detail. The author has explained how to work out optimal gross and price for ER based on game theory in another paper. Given the number of the customers and the load capacity in PCC are variable, the optimal ER gross is unsteady. In order to guarantee optimization of ER gross and prevent monopolization in PQM, ER should be redistributed every other period of time, whose length should be decided by the characteristics of the loads in PCC. So ER’s validity depends on time.

ER trade is the most general and important trade in PQM. The execution of trade regulation is closely concerned with PQSD. In order to maintain power grid (including distribution system) on the optimally polluted level, and actualize encouragement and punishment with equity, PQSD must be independent of any transmission or distribution utilities. It assumes the duty to establish regulatory systems for ER trade market, to set up accounts for all kinds of ER, to register and transfer excess ER, to supervise trade of excess ER, to issue ER trade information periodically, to track and supervise the implementation of trade contracts and emission quantity. If some customers who possess ER do not deteriorate PQ any longer as a result of being banned, closedown or bankruptcy, the PQSD that distributed ER to them should withdraw the ER, and distribute the ER through public auction. ER can be traded freely in PQM, and its price is formed through participant’s negotiation. Because electromagnetic pollution is influenced greatly by networks topological structure and relevant parameters, ER’s validity relies on space. If two individuals want to trade ER with each other, the assignee should consign PQSD to evaluate the feasibility of trade. Then they can complete the trade formally.

Through ER distribution and trade, the players who have high mitigation expense and high revenue will get ER with high unit price, and mitigation investment tends to those players with low mitigation expense. So electromagnetic environment and mitigation investment can be made best use. After ER trade, all individuals can run under the limit of ER permit. If some individuals go beyond their limits, they will be punished by PQSD.

PQ-Service Market

PQ-service market is another kind of sub PQM based on custom power technology, where customers can purchase PQ-service that satisfies any of their PQ demands. Custom power technology was put forward by American Dr. N.G. Hingorani in 1988 [11]. It can produce customized electric power that meets customers’ demands for high reliability and high quality in virtue of large-sized power electronic technology and automation of distribution system. Electric utilities or other individuals can actualize appointed PQ for a customer or a customer group using custom power devices. Custom power technology can make electric power without interruptions, with exact voltage and low harmonic components. So end consumers can be immune to the negative influences of any fluctuant or non-linear loads. Custom power is not only a new technology for power supply, but also a new service idea that electric power should be supplied according to customers’ demand. PQ-service market can separate basic electric energy supply and PQ-service effectively. Customer can compare PQ-service with other actualizing modes and can choose suitable electric energy freely. Based on the customers’ choices, electric utilities can estimate transmission investment and PQ-service investment separately, instead of traditional confusing them with distribution investment.

Hitherto, many scholars have carried out considerable researches on custom power technology, proposed lots of new methods and developed a variety of devices [12], some of which have been put into practice [13]. These methods and devices provide significant momentum for PQ-service in technology. In different electricity market modes, custom power has different actualizing modes including pool of custom power [14], PQ control center [15], and PQ-service company [1]. Electric company of France (EDF) has been providing electric energy with multi-quality, named emerald, silver and gold separately, which have diverse unit prices. Furthermore, EDF is applying itself to advance their service based on “Emerald Contract” [16] and ancillary services. This operation mode will positively be more and more popular, and achieve benefit socially and economically in the future.

The emergence of PQ-service is an inevitable result of electricity market operation. Custom power is similar to defining a special power supply contract. Besides including supply address, capacity of load, power supply method, measurement of electric power, electricity rate and settlement method of electricity fees in traditional contracts, custom power also definitely clarifies PQ level and compensation for PQ violations. PQSD must establish particular laws to ensure the realization of this kind of contract. The price of custom power is complicated and important as well. It has decisive effects on PQ-service market development. The economic estimation on PQ and the pricing for electric energy considering PQ was
discussed in [17] and [18] respectively, and the management and pricing for reliability was studied in [19]-[20]. As an overview, researches on pricing PQ-service are far from mature, and there is lots of work to do. In another paper, the author has introduced quality insurance method into pricing for PQ-service, which is to add PQ insurance to basic electric energy price. Maximal Unqualified Rate (MUR) and Maximal Violation Times (MVT) are introduced as two important indicators of basic electric energy. Unit compensation price is directly proportional to unit insurance, whose amount can be chosen discretionarily. This method not only can separate prices of basic electric energy and PQ-service naturally, but also can price for custom power easily. PQ-accidents can be compensated rationally according to the insurance contract chosen by customers. As PQ is individualized according to consumers’ preferences, the burden for PQSD to determine the most economical PQ level for the system is shifted. The chosen PQ-service by electric consumers serves as economic signals in the form of insurance contracts, which provides incentives for electric utilities to improve efficiency of PQ-service and to guarantee acceptable PQ for every consumer. Also, the economic signals facilitate electric utilities’ making of efficient investment decisions. Insurance allocates economic risks caused by PQ-disturbances to electric utilities (which control power systems), instead of consumers (who have little or no control ability).

In general, traditional electric power supply does not consider load characteristics and PQ demands. Sometimes the PQ that is supplied and the compensation for violations are unreasonable. Fortunately, the emergence of PQ-service market with flexible power supply contributes to the settlement of this harassment. It emphasizes the idea of consumerism and is tailored to all consumers. Using optimal distribution function of market, consumers who are sensitive to and concerned with PQ economically can accept high unit price for high-quality electric energy, and those insensitive to PQ can enjoy lower unit price. With the above proposal, PQ-service market can make best use of PQ-improving devices and supply electric power with high quality to the consumers.

**Other Issues**

In order to guarantee PQM operating normally, besides sub-markets introduced above, some ancillary markets like PQ technology and information market, financial markets and commodity markets are indispensable for further study.

**CHARACTERISTICS OF PQM**

Emerging out of electricity market, PQM is not supposed to go against the common rules in market. ER charging and trading market and PQ-service market should become important components of transmission and distribution market. Any market systems must be uniform, open, competitive and well ordered, which are essential characteristics of market system. Besides what has been mentioned above, PQM has other characteristics distinct from other markets.

Constrained by the grid, PQM will form the structure with several hierarchies and specific region based on relatively independent distribution networks. Because of the economy of scale of distribution networks, competition in PQM highlights monopolization. Although market objects in PQM are comparatively few, and most trades are related to the transfer of participants’ right, but the trade prices may fluctuate violently, so market manipulation must be monitored and prohibited. When electric utilities and electric consumers become equal participators in the market, PQSD will decide their award, punishment or compensation based on their actual action. According to these characteristics of PQM, PQSD plays an irreplaceable role.

**SUPERVISIONS TO PQM**

In order to guarantee equity, justness, publicity and efficiency in PQM, PQSD must be set up in administrative regions. It takes the responsibility to supervise and deal with affairs relating to PQ at different levels of electric networks according to related laws and regulations. The responsibility can be specified as follows:

i) To research and propose rules or suggestions about PQ, and to supervise PQM.

ii) To participate in the planning of electric power industry, to draw up PQM development planning and district PQM establishment.

iii) To supervise and manage PQM operation, to maintain PQM order, and to guarantee fairly competition.

iv) To participate in enacting PQ standards for all levels electric networks and district, to supervise the execution of PQ standards, to distribute and manage “emission permit”.

v) To provide suggestions of price adjustment according to PQM situation, to supervise and examine the price relating to PQM, and to supervise and manage the charging standards of PQ-service.

vi) To investigate violation of electric utilities and power customers according to laws, and to deal with disputes in PQM.

vii) To collect and issue PQM information.

viii) To charge for ER.

ix) To provide suggestion for reformation, and to participate in carrying out electricity market reformation.

**FUTURE RESEARCHES ON PQM**

Custom power technology developing rapidly, the cost of PQ control will reduce gradually. As the cost of manpower rises constantly, the cost of PQM operation will increase continuously. If the social benefit gained by PQM cannot balance the operation cost, PQM will be a meaningless identity. So, to a great extent, the existence of PQM depends on how to decrease PQM operation cost. It is the mutual choice between electric utilities and power customers that propels the advance of electricity market. But PQM is based on monopolized competition, and
electric power industry belongs to special industry that is important for the whole society. So how to guarantee market participators’ choice is the key to PQM development.

As an organization authorized by the government, PQSD has the right to impose requirements on and intervene to market participators. Meanwhile, it is eligible to charge for electromagnetic pollution, which accords with PQM characteristics. PQSD exercises great influences on normal operation of PQM. So how to establish modern supervision ideas, to form powerful organizing ability rapidly, to make PQSD professional, open, self-governed and rule-based is the key to PQM normal operation.

CONCLUSIONS

Conflicts caused by PQ are deepening increasingly. PQ management has to withstand pressures from economy and social equity requirement. As such, it is very necessary to establish PQM. PQM system described in the paper consists of four components: ER charging and trading market, PQ-service market, PQ technology & information market and PQSD. ER-trading market and PQ-service market should become the important components of transmission and distribution market. PQSD should be set up in definite administrative regions, to supervise and deal with affairs relating to PQ in all levels of electric networks according to laws and regulations. Also, the running mechanism of PQM is explained, such as “emission permit” charging policy, searching for optimal gross and distribution of ER, ER trade method and so on. Charging for ER quantitatively can ensure social equity. Optimal gross and distribution of ER can be worked out through free ER trade, and the best use of high quality electric energy can be made through free PQ-service trade, thus social integrated benefit can be maximized. This paper also summarizes some technologies supporting PQM, such as electromagnetic pollution detection, classification, recognition, location and measurement, pricing for PQ-service, modes of actualizing PQ-service and so on.

As PQM is a new issue, how to decrease its operation cost, how to guarantee market participators’ choice, and how to establish modern supervision ideas and powerful organizing ability are very important to its existence, development and operation.

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