Promising concepts and technologies for future power delivery systems

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PROMISING CONCEPTS AND TECHNOLOGIES FOR FUTURE POWER DELIVERY SYSTEMS

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ABSTRACT

The transition from a conventional delivery system to a suitable robust distribution system is emerging to adapt with different possible scenarios of future development. This paper gives a particular vision of future grid with its main requirements. An investigation of suitable concepts and technologies which draw out attentions at the present has been carried out. They are discussed regarding mentioned requirements of sustainability, efficiency, flexibility and intelligence. Active Network is then introduced as the backbone of the future power delivery system. Besides, Multi-Agent System (MAS) is described as a potential technology to cope with anticipated challenges of future grid operation. The research described is under the framework of the Electricity Infrastructure of the Future (EIT) project carried out by cooperation of TU/e, KEMA and ECN (www.futurepowersystems.nl).

Keywords: Electricity infrastructure, future power delivery system, Active Network, Multi-Agent System.

1 INTRODUCTION

Since large-scale implementation of distributed generation (DG) started, the power delivery system has been changed gradually from the downstream unidirectional scheme to an equally bidirectional scheme. This 'vertical-to-horizontal' transition will lead to a number of challenges in system control, operation, and management. However, the transition supported by liberalization market will create new opportunities for the improvement of network services in term of power quality and reliability. The existing distribution system designed in a passive and less intelligent way is insufficient to adapt to future circumstances. Therefore, designing a suitable robust system is emerging to overcome those challenges and take advantage of all opportunities.

The power delivery system of the future is now being considered in many researches. These works, however, mostly just point out the vision of the future network with different scenarios. Given that detailed descriptions are still missing due to the uncertainties of future scenarios, this paper intends to provide a narrow but deeper view in the future network. Firstly, the power delivery system of the future will be described particularly with its required functions by addressing certain assumptions. And then, promising concepts and technologies compatible with the described network will be explored.

2 FUTURE POWER DELIVERY SYSTEM

Under the scope of this paper, the future power delivery system will be depicted with several assumptions. Its

main requirements for designing and operating will be pointed out.

2.1 Description

A power delivery system in traditional terms includes transmission and distribution network. However, it is anticipated for the future that the most innovation part of the power delivery system belongs to the distribution network [1]. Therefore, this paper mainly concerns with the distribution network although the title of a power delivery system has been used.

The longer the time span from present to future is, the more uncertain the scenarios are. In most of previous works, scenarios of future network development and distributed generation penetration are discussed in period of 2010 - 2020. Regarding mature development of known concepts and technologies this paper focuses on network situation from 2015 to 2020.

Foot et. al [2] has predicted that the DG capacity in 2010 will represent between 8% and 20% of total installed generating capacity in Europe. The SUSTELNET project shows other results of distributed generation penetration in 2020 through four different scenarios. The share of DG capacity will grow over 30% in the highest DG penetration level case [3]. Especially, the DG capacity in Denmark and Germany will rise over 40% of power consumption. In the UK, detailed forecast data for 2020 obtained lately points out that the highest DG penetration rate in environmental awakening scenarios is around 27% of electricity production [4].

Table I Summary of DG penetration forecasts

Countries	DG capacity as percentage of total capacity	
	2010	2020
Denmark	29	40
Germany	20	43
Italy	16.8	19
Netherlands	9	27
UK	17.3	27
Average	18.4	31.2

Power quality and reliability (PQR) requirements are increasing along with the development of digital society [1]. Currently, the availability of the average electricity grid has been in a range of 99.9% to 99.999%. For instance, U.S.'s reliability target is about 99.99% while one of the most reliable grids, the Dutch grid's reliability is around 99.996% [5;6]. Figure 1 illustrates a PQR level approach based on investment in the public grid. By 2015, the digital society will need at least "six nines" (99.9999%) or more to ensure continuous power supply for more critical customers. Consequently, reliability point is pushed farther to the right in Figure 1 with more expensive investment. It is in fact impossible to archive ultra high PQR level through the public grid. Differentiating the reliability for a variety of customer group has been proposed as a way out of this issue [6]. Future network design therefore should be enable the function of unbundled PQR services for various customers.

Figure 1 PQR of public grid [5]

2.2 Main requirements

Taking into account a large-scale deployment of DGs and an enhanced PQR expectation in the future, a robust active distribution network is needed to adapt the existing passive and less intelligent one. Designing the future grid should be based on main requirements according future circumstances.

Firstly, the network needs to be efficient and flexible to cope with arising problems in operation such as bidirectional power flow, voltage rise, short-circuit

current increase, or stability increase. The structure of the network should be designed in an adjustable and scalable way for varying needs.

Another required characteristic of the network is intelligence in order to self-adjust and to be adaptable in autonomous operation. Hence, the balancing between supply and demand could be controlled precisely in both normal and disturbance states.

Last but the most important factor is the sustainable criterion that requires concepts and technologies for future grids in social accepted range.

3 PROMISING CONCEPTS

As current concepts might not be appropriate for functions of the power delivery system in the future, new concepts have been proposed recently. This section gives known concepts which applications draw much attention in recent times.

3.1 MicroGrid - Autonomous Network

The MicroGrid has been known as a possible solution to increase penetration of distributed energy resources (DER) in Low Voltage (LV) distribution systems. By integrating DERs together with storage devices and controllable loads, the MicroGrid can possibly operate both islanded and interconnected to the public grid [7]. However, behaviour in island mode caused by losing connection with the MV grid is of its major concerns.

In medium voltage network with more complexity and larger size, the concept of Autonomous Network (AN) has been introduced as a manner of network management [8]. Although also providing a self-controlled network, the AN concept is different from the MicroGrid while its concern is to optimize the performance during normal operation. Provoost et. al is working on controlled power exchange, voltage profile as well as stability issues of AN [9].

Other work concerning AN is on an Autonomous Demand Area Power System (ADAPS) which is proposed to obtain effective use of energy from DGs for both customers and suppliers [10]. Two main devices are introduced in this system including a Loop Power Controller (LPC) and a Supply and Demand Interface (S&D Interface). The LPC device is used to flexibly control power flows (fault current possible), and to avoid power congestion and voltage problems. The S&D Interface is based on an advanced communication network to deal with balance between supply and demand sides.

3.2 Active Network

Van Overbeeke and Roberts have proposed the vision of "Active Networks" as facilitators for DG [11]. The solution is based on three main points including

interconnection, local control areas (cells), and system services as specified attributes of a connection. While the first point is to provide more than one power flow path, manage congestion by re-routing power and isolate faulted areas effectively, the third point supports system services and charges to individual customers. However the most revolution change is proposed in the second point, the local control areas or “cells”. Hence, one more control level will be installed for each cell component to manage and to control system inside and across the cell boundaries. It could be deployed with different typical actuators such as voltage and reactive power controllers, FACTS devices, remotely controllable loads and generators.

In other works, the terms of Distribution Automation and Active Network Management (ANM) has been mentioned for distribution systems having control and communication network. While the first one is developed in US as the solution to improve system reliability, the second one is a headline title in UK with main focus on facilitation of distributed and renewable generation [12]. Although technologies in both concepts are essentially equivalent, ANM is in some way more suitable to adapt with the sustainable criterion in the future. Current activities of Active Network Management (ANM) are to solve major technical issues of voltage control, power flows, and fault level [12].

Decentralized Autonomous Network Management is a typical example enabling ANM concepts [13]. Thus, the proposed control approach ensures the power flows in all the circuits in staying within their capacity limits based on Multi-Agent System (MAS) technology. More possible functionalities for ANM are included such as demand side management, network reconfiguration, and network restoration.

3.3 Smart Grid

The Smart Grid is an orientation of intelligent technologies utilization that draws many attentions from large research centres such as EPRI (IntelliGrid), Nature Resources Canada (Integration of Decentralized Energy Resources Program) and European Union (SmartGrids) [14]. Actually, it is an overall picture of the future network that utilises new concepts included MicroGrid, Virtual Power Plant or Virtual Utility together. Core technologies implemented in a Smart Grid take account of distributed intelligent devices, communication network, advanced simulation software, and power electronic applications.

The Smart Grid operates with both central and distributed generation. Based on a Virtual Power Plant or Virtual Utility concept, clusters of DGs can be aggregated to operate as a large central power plant. Therefore, bidirectional power flow is a main characteristic of the grid. In addition, grid components have to be connected to a communication network.

3.4 FRIENDS

The concept of “Flexible, Reliable and Intelligent Electrical eNergy Delivery System (FRIENDS)” has been known as a potential approach to resolve not only current issues caused by introduction of DG but also potential problems under the deregulated environment [15]. The most innovative part of this concept is the Quality Control Center (QCC) established as an interface between the distribution system and the customers. The QCCs include static-type switches, several kinds of DG, and storages. They work under computer-based operation and coordinate with each other by the communication network.

FRIENDS, therefore can offer various levels of quality of supply for its customers. Flexible reconfiguration in emergency operation deployed by fast static-type switches is another advantage of the concept. Besides, it is possible to autonomous control actions such as voltage regulation or reactive power control.

4 PROMISING TECHNOLOGIES

In order to enable above concepts in the future, suitable network technologies need to be introduced. In this section, state of the art of technologies for future systems is investigated briefly. Among of these technologies, the Multi-Agent System (MAS) is presented in more detail as of author’s favourite.

4.1 Power Electronic Applications

The application of electronic devices from transmission level to distribution level is a current direction. DC coupling on medium voltage, based on back-to-back HVDC concept with IGBT technology is a typical example [16]. Advantages of this application include interconnecting sub-networks without short-circuit current increase, controlling Var separately, and supplying power to an isolated network with possibility a different voltage level, frequency and phase angle.

Flexible AC Transmission System (FACTS) technology plays an essential role in modern power system control. Its utilization in distribution system is expected to increase efficient and flexible capability of the network. Custom Power is introduced with a focus on critical loads to enhance the quality of voltage supply. Some electronic devices involved in this aspect are Distributed Static Compensator (DSTATCOM), Dynamic Voltage Restore (DVR), and Solid-State Transfer Switch (SSTS). In the same direction of installing FACTS next to load side, DGFacts systems lead to integrated application of such devices to optimally improve the stability and Quality of Supply of different network parts [17]. In other direction of application, FACTS is applied to establish an interface between DG and the network.

4.2 Information and Communication Technologies (ICT)

The function of ICT is anticipated as more important in electricity infrastructure in the future. It could be considered as the key technology to enable any new concept mentioned in previous section. Typical example of ICT applications in distribution system control and operation are presented in the EU-CRISP Project [18]. This has given ICT capabilities in protection, reconfiguration, and internet-based control.

4.3 Multi-Agent System (MAS)

Multi-Agent Systems have been mentioned recently as a potential technology for many fields of power system applications. In [19], a basic definition of the MAS concept and its approaches for power application have been presented. The simplest level of MAS is the “agent” that is defined as an entity (software or hardware) able to work autonomously in some environment. The intelligent agent extended from the agent concept is not only able to react to changes in its environment but is also able to interact with other intelligent agents. The MAS concept is from a combination of more than one intelligent agent and other agents.

Belonging to the area of computational intelligence, MAS can offer a certain degree of intelligent behaviour in autonomous systems [20]. Different applications of MAS in power system include disturbance diagnosis, restoration, protection, and voltage control. For instance, power flow management in active network is implemented based on MAS [13]. Another example is power balancing through an electronic market based on local agents, then so called “PowerMatcher” [18].

In a number of platforms for MAS, the Java Agent Development Framework (JADE) is popular in power engineering applications. Agent communication languages are set by the Foundation for Intelligent Physical Agents (FIPA) international standard.

5 COMPATIBILITY FOR THE FUTURE SYSTEM

In this section, possible capacities of mentioned concepts for adapting the main requirements of the future grid will be discussed. Then, a structure suitable for the future grid will be proposed with the necessary technologies.

According to concepts’ descriptions, the sustainability is dominant when the concepts concern about the facilitation of DER and RES integration. It is also possible to approach the efficient state because installing DGs near load decreases the power losses basically.

Since focusing on island operation during faults and various network disturbances, MicroGrid has not paid much attention to flexible operation. However, other concepts are able to transmit power flexibly by electronic devices (FRIENDS, Autonomous Network) or interconnection (Active Network).

Although autonomous operation is essential in most of the concepts, intelligent control is only possible to be involved in Active Network and Smart Grid due to its complicated implementation in low voltage level. Some researches in Autonomous Network are now going to improve its intelligent capability but this is still at an early stage.

Figure 2 presents different levels that promising concepts are able to match with the future network requirements.

Figure 2 Adaptation of promising concepts with the future network requirements

Regarding above assessment, Active Networks and Smart Grids are able to meet sufficiently the main requirements of the future grid. While Smart Grid concerns about broad issues of the whole system that need much engineering efforts, large investment for new technologies, and government’s incentive policies, Active Network seems to be more suitable for scope of this work. On one hand, Active Network can be adapted with the main requirements of the future network. On the other hand, Active Network has great economic advantage because necessary modifications for concept implementation belong mostly to virtual parts such as control and communication. Therefore, Active Network should be proposed as a backbone for the future grid.

Although other concepts do not have adequate ability, they will still be utilized in certain parts of the network. Hence, future grid based on Active Network needs to be able to integrate with other sub-networks formed by Autonomous Network, FRIENDS, or MicroGrid. Figure 3 shows the possible configuration of the future network with an adjustable structure.

With the integrated configuration of Active Network and other concepts, the future grid would become more complex with differences between sub-networks in decentralization and centralization, or between island

and interconnection. These challenges for system operation, control, and management are not simple to overcome by existing technologies.

Figure 3 Integration for future grid

In order to cope with above challenges, it is proposed to apply MAS as a new control technology. In fact, MAS has been utilized in several promising concepts such as MicroGrid and FRIEND [20; 21]. These successful applications have shown its capability to implement for the rest of the system. With support of Information Technology (IT), MAS is expected to enable efficiency, flexibility and intelligence of the future network.

Possible structure of MAS application in the future network might be realized as in Figure 4. In the high level, transport system formed by Active Network is presented as central agent that combines three different functional agents. They are based on definitions in [21] that include control agents for controlling physical units directly, management agent for managing and taking decisions, and ancillary agent for supporting network services.

Figure 4 Possible structure of MAS technology

In the lower level, certain subsystems formed by AN, FRIENDS, or MicroGrid concepts are presented by

local agents respectively. Other parts of the system has been divided and controlled locally by cells. Each cell is also presented by one local agent. Similar to central agent, local agent includes three different functional agents.

Further work will go in more detailed designing of different agents. Simulation will be setup by an interface between Matlab/Simulink (electrical network) and JADE (agent platform). The performance is expected to obtain optimized operation of the network.

6 CONCLUSION

Considering expectations for the future, the power delivery system must be sustainable, efficient, flexible and intelligent. Through literature review, suitable concepts and technologies for the network were selected and discussed. An adjustable structure that can integrate different subsystems is necessary for uncertainties of the future network. Regarding possible challenges given by new structure, the study has emphasized the important role of MAS technology to cope with complex situations.

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