Critical Factors and ICT Contribution for Accelerating Smart Grid Realization

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ABSTRACT

For the realization of "Smart Grid", many and various demonstration projects have been conducted all over the world for several years. Although large economic crises and various energy problems occurred recently, approaches for Smart Grid still continue and it shows Smart Grid realization is expected to grow exponentially. However it looks the benefit of Smart Grid is unclear yet and related markets are not in rapid expansion. One of the reasons should be Smart Grid realization requires reform of the regional power supply systems and thus an enormous expense should be necessary. Such an enormous expense requires large scale investments in utility companies and also reflects to electricity price in consumer side. Another reason might be insufficient utilization of Information Communication Technology (ICT) in power supply systems, although ICT utilization should be essential in order to realize efficient management of detailed and enormous Smart Grid components such as power system equipment, networks and their management systems etc. Therefore, firstly this paper clarifies critical factors of Smart Grid realization through the research of demonstration projects focusing on benefit of Smart Grid. And then, effective research and development areas are proposed forcing on the utilization of ICT.

KEYWORDS

Smart Grid, Information Communication Technology (ICT), Renewable Energy Sources (RES), Distributed Generation (DG), Distribution System, Demand Side Management (DSM).

1 INTRODUCTION

Several years have passed since the term "Smart Grid" became widely used all over the world, and many pilot and/or demonstration Smart Grid projects have been conducted. In addition, some incentive plans or subsidy systems have been implemented to promote Smart Grid in many countries or regions.

However, it looks that only a few verified and commercially deployed Smart Grid technologies with clear benefits exist. The reason might be Smart Grid benefit is still unclear because Smart Grid realization requires restructuring of various existing power supply systems and their components, and these should need large scale expense, while many expectations by the Smart Grid realization such as improvement of power supply reliability, reduction of environmental burdens and expansion of the number of employees working for new energy related businesses etc., exist. One of the reasons might be major Smart Grid expected achievements such as advanced demand control and large installation of small sized renewable energy sources (RES) are mainly on technology improvements in demand side. Because most current Smart Grid technologies are based on existing technologies for large size and small number of equipment, and these would require high cost if such technologies would be deployed to small size and large number of equipment in demand side. In addition, many new technologies in demand side such as power selling using photovoltaic (PV) generation systems, power saving by energy management systems (EMS) and dynamic pricing & demand response (DR) programs are proposed, however it is difficult for most of them to recover their installation and operation costs at present. For example, power selling by RES generation is not profitable without subsidies, and various support programs are required to recover their service installation and operation cost only with their small cost reduction effect in most countries and regions.

In order to solve these challenges, high value production by the realization of Smart Grid and its quantification method should be essential.

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Moreover, it is necessary to clarify profitability of Smart Grid businesses, and many business organizations should join to various Smart Grid projects and make investment continuously. Although utilization of ICT should contribute not only for efficiency improvement of existing power system technologies but also value production using various and huge information which can be collected by the recent information technology evolution, actually ICT applied areas to Smart Grid are limited at present.

Therefore, this paper proposes critical factors and their corresponding actions which increase Smart Grid realization benefit especially focusing on the utilization of ICT through the consideration of expected benefit and its quantification method.

2 SMART GRID DEMONSTRATION PROJECTS AND THEIR REPORTS

Many and various Smart Grid projects have been conducted all over the world centering on US and EU countries, and their plans, results and effects have been reported in various publications. For major examples, US department of Energy (DOE) awarded 9 Smart Grid demonstration projects to promote Smart Grid in 2008 and Electric Power Research Institute (EPRI) conducted a framework development project to estimate benefits and costs of Smart Grid projects and introduced 10 steps which organized Smart Grid elements, functions, and benefits [1]. EPRI also has provided reports for these advanced projects' status continuously [2-5]. In addition, [6] considers Smart Grid benefits and costs by utility sectors such as transmission, distribution and customers, and Joint Research Centre (JRC) in EU and US DOE provided a joint report for assessment of Smart Grid benefits and costs [7]. In many of these reports, criteria and metrics to assess Smart Grid benefits and costs are provided. This paper discusses and provides critical factors and ICT contribution for accelerating Smart Grid realization using these various projects and their evaluation reports.

3 CLARIFICATION PROCEDURES OF CRITICAL FACTORS TO PROMOTE SMART GRID

In this section, effective procedures to decide critical factors to promote Smart Grid and their measures are proposed. As mention in the introduction, this paper assumes that possible reasons which prevent Smart Grid realization might be its necessity of enormous investment under the unclear benefit, and ICT utilization should create new additional values and contribute to clarify these values. Followings are proposed procedures to clarify critical factors to promote Smart Grid.

3.1 Clarification Approach of Critical Factors to Promote Smart Grid

Clarification approaches to clarify critical factors to promote Smart Grid are provided as follows.

(1) Analysis of Expected Benefits by the Realization of Smart Grid

Firstly this paper describes expected benefits by the realization of Smart Grid through survey analysis of Smart Grid demonstration projects in US. The analysis focuses on benefit of Smart Grid, because it is necessary to generate profits for both utility companies and consumers to realize Smart grid which requires enormous investment and cost. Then, technological measures to realize the Smart Grid benefits are extracted from demonstration projects, and then extracted measures are grouped. After that, actions in Smart Grid projects to provide benefits for these groups are considered and created.

(2) Consideration of ICT Contribution Areas for Smart Grid Benefits

Secondly, ICT contribution areas to these Smart Grid benefits and some actual realization measures are discussed. ICT contributions are evaluated by the difference between benefits with and without ICT application. Then, effective actions to promote Smart Grid realization significantly with expansion of ICT application are considered and created.

(3) Decision of Critical Factors for Accelerating Smart Grid Realization

From results of above mentioned two discussions, critical factors and detailed research and development required areas are discussed and concrete research topics accelerating Smart Grid would be provided.

3.2 Clarification Procedures of Critical Factors to Promote Smart Grid

Figure 1 shows clarification procedures of critical factors to promote Smart Grid which summarize above mentioned three steps.

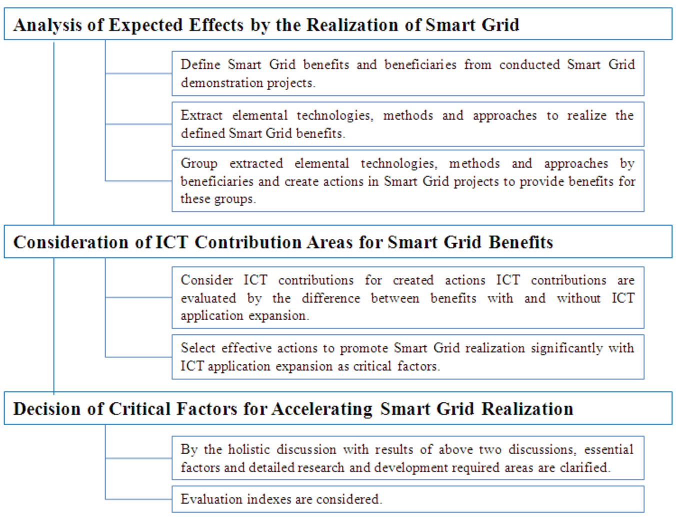

Figure 1. Clarification Procedures of Critical Factors to Promote Smart Grid

4 DISCUSSIONS OF CRITICAL FACTORS TO PROMOTE SMART GRID

In accordance with the procedures defined in section 3, critical factors and their countermeasures are considered in this section.

4.1 Definition of Smart Grid Benefits and Beneficiaries

Firstly, benefits and their beneficiaries by the Smart Grid realization are defined. Although various definitions exist with regard to Smart Grid benefits, this paper uses benefits and beneficiaries defined in [1] as the base definition because these benefits and beneficiaries are based on actual smart grid projects and the definition should have consensus among many smart grid project concerned parties. These defined benefits are categorized by "Economic", "Reliability and Power Quality", "Environment" and "Energy Security", and "Utility", "Consumer" and "Society" are used as beneficiaries in [1].

Table 1. Summary of Reorganized Smart Grid Benefits defined in [1]

Benefit Category	Benefits	Typical Beneficiary
Economic	Electricity cost savings	Consumer
	Reduced generation costs from improved asset utilization	Utility(G)
	Deferred Generation Capacity Investments	Utility(G)
	Reduced Ancillary Service Cost	Utility(G)
	Reduced transmission congestion costs	Utility(T)
	Deferred Transmission Capacity Investments	Utility(T)
	Deferred Distribution Capacity Investments	Utility(D)
	Reduced Transmission Equipment Failures	Utility(T)
	Reduced Distribution Equipment Failures	Utility(D)
	Reduced Transmission Equipment Operation & Maintenance Cost	Utility(T)
	Reduced Distribution Equipment Operation & Maintenance Cost	Utility(D)
	Reduced Transmission losses	Utility(T)
	Reduced Distribution losses	Utility(D)
	Theft reduction	Utility(R)
	Reduced Meter Reading Cost	Utility(R)
Reliability and Power Quality	Reduced cost of power interruptions	Utility(D)
	Reduced costs from better power quality	Consumer
	Reduced Sustained Outages and Major Outages	Consumer
Environment	Reduced damages as a result of lower GHG/carbon emissions Reduced damages as a result of lower SOx, NOx, and PM emissions	Society in general Utility(C)
Energy Security	Greater energy security from reduced oil consumption	Society in general Utility(C)
	Reduced widespread damage from wide scale blackouts	Society in general Consumer

Note: Gray colored cells are outside scope of this paper.

With regard to "Utility" as beneficiary, sub category such as G: Generation, T: Transmission, D: Distribution, R: Retail and C: Common are used in order to clarify targeted business organizations in this paper. Table 1 shows reorganized Smart Grid benefits and beneficiaries defined in [1] by above mentioned four categories, and some benefits are divided to define beneficiaries clearly. Although Table 1 shows many benefits to various beneficiaries expected by realizing Smart grid, this paper focuses on some major areas as the viewpoint of Smart Grid rapid promotion. One of the big differences in Smart Grid compared with current power supply systems is small-medium size distributed generations (DGs) exist in demand side (distribution area) and in economic, reliability and environmental aspects, optimal power delivery and consumption would be achieved by collaborated control between supply-side and demand-side. In order to realize these, various technology improvements are required in demand side.

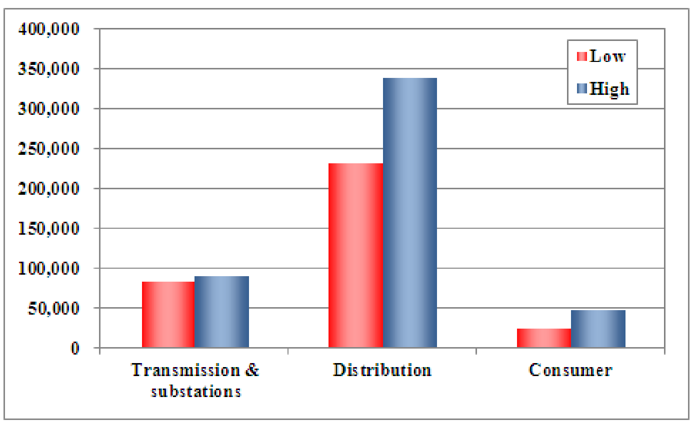

Figure 2. Total Smart Grid Cost [6]

Figure 2 shows total costs to enable a fully functioning smart gird showed in [6], and the report estimates 309-403 billion investment to distribution system area would have been provided for twenty years. This shows center area of Smart Grid investment is distribution system area (demand side). Therefore, benefits which beneficiaries are Utility (D) and Consumer and also benefits which contribute to demand side power source such as DG and batteries are focused on as major objects in this paper.

Because benefits which beneficiary is "Social" should be provided as philanthropy, business ethics and compliance for regulations etc., these are not adequate benefits considered by their profitability. Therefore, these benefits are out of scope of this paper. However, it would be essential to consider environment, safety and security related matters in the discussion of economic and reliability related benefits achievement.

4.2 Consideration of Technological Measures to Realize Defined Smart Grid Benefits

In this section, related technologies, methods and approaches to realize Smart Grid are considered for each selected Smart Grid benefits from major demonstration projects and related research reports and papers.

(1) Electricity Cost Savings

This benefit is that electricity price down or rebate receipt in consumers by behavior changes in themselves. It includes contract modification by load leveling, incentives from utility companies for consumer's peak cut, autonomous energy saving operation by smart appliances and cost reduction by changing various electricity price programs [8-10]. Followings are Smart Grid technological measures which realize this kind of benefit.

- Technologies for EMS in demand side such as Factory (FEMS), Building (BEMS) and Home (HEMS)
  - Visualization of electricity consumption, appliance and equipment control, demand forecast and simulation etc.
- Various electricity price programs including demand response (DR)
  - Time of Use (TOU), Real Time Pricing (RTP), Critical Peak Pricing (CPP), Peak time Rebate (PTR) etc.
- Smart Equipment, Smart Appliances

(2) Deferred Generation Capacity Investments

Although this benefit means deferred investment for large scale and centralized generation plants generally, the benefit is considered in this paper because it might be considered that some demand side control such as DR programs or DG installation etc., can contribute to deferment of investment for large scale generation plants [9]. Therefore, only demand side control methods by

DG and DR etc., are focused on as sources of this benefit.

- DG (RES) installation
- DR and DSM
- Peak reduction and energy saving by EMS

(3) Reduced Ancillary Service Cost

In this paper, ancillary service cost is defined as the cost which is paid by generation companies connecting their plants with power transmission or distribution systems for the power supply stability to the organization such as independent system operators (ISOs). In order to reduce ancillary service cost under the near future environment where large number of renewable energy source (RES) generators are installed, highly accurate forecast of generation capacity and electricity demand in a target area, and also real-time rapid control systems which use the forecasted information might contribute to effective management of distribution systems. Community EMS (CEMS), which provides electricity supply and demand control functions for a certain area, has been studied and developed in many countries and it is expected that CEMS provides advanced supply and demand control functions including efficient ancillary service provision.

- CEMS
  - High accuracy forecast of generation capacity and electricity demand
  - Real-time rapid control system
  - Ancillary service provision

(4) Deferred Distribution Capacity Investments

Electricity demand peak reduction is necessary as a method for deferment of distribution equipment investment. In order to achieve that, similar measurements in (1) and (2) are required. In other word, actions for load reduction in demand side lead to deferment of distribution asset investment, and private DG installations would make same effect. Therefore, these load reduction effects might lead to price reduction or incentives provision by electricity suppliers.

(5) Reduced Distribution Equipment Failures

By the detailed status monitoring of distribution systems, power flow with abnormal current and/or voltage injected into distribution equipment can be preventable. Also, by the collection of detailed status data from equipment in distribution systems, signs of equipment failure can be detected. Followings are technological measures to realize them.

- CEMS
  - High accuracy forecast of generation capacity and electricity demand
  - Optimal system control algorithms and simulations using electricity generation and load forecast.
- Asset and Equipment State Monitoring
  - For reliable operation and rapid failure detection
  - For improved asset maintenance methods such as equipment condition based maintenance.

(6) Reduced Distribution Equipment Operation & Maintenance Cost

Expansion of autonomous control areas contributes to operation and maintenance cost reduction. Also, equipment status monitoring makes condition based maintenance (CBM) possible from conventional time based maintenance (TBM), and CBM can reduce some inspection works which are not necessary from a viewpoint of asset health. This change is beneficial operation not only for the aspect of work volume reduction but also of human errors reduction. Followings should be technological measures to realize above these functions.

- Autonomous wide area asset monitoring
- Autonomous asset control
- Asset maintenance methodologies such as CBM, TBM etc.

(7) Reduced Distribution Losses

In the conventional power supply model that electric power generated by large-scale centralized power plants is transmitted and distributed to demand areas, one of significant problems is power loss which is caused by impedance of power transmission and distribution lines. Because power loss depends on the distance from a power plant to demand points, adequate DG and other equipment installation and system reconfiguration in demand side would be key points in order to reduce power loss [11-14]. Therefore, followings should be technological measures.

- Installation and optimal allocation of DGs.
- Distribution system reconfiguration
- Reactive power and voltage control (Static Var Compensator (SVC) or Step Voltage Regulator (SVR) installation and optimal allocation)

(8) Theft Reduction

Power theft reduction would be achieved by detecting abnormal usage through continuous power consumption monitoring. Generally, theft reduction is one of important benefits of advanced metering infrastructure (AMI).

- AMI (Smart Meter, communication network (last miles network) and data collection and management system (Meter Data Management System (MDMS))

(9) Reduced Meter Reading Cost

As well as (8), this is one of important benefits of AMI installation. Historically meter reading is operated by metering staffs every month or every year etc. By AMI, efficient, frequent and accurate metering would be achieved.

- AMI

(10) Reduced Cost of Power Interruptions

Cost of power interruptions is the expense for countermeasures of power interruptions required in utility companies. In order to reduce the cost, reduction of outage, rapid detection and islanding of outage sections are required and also rapid restoration from outage by using autonomous control, remote control and alternatives should be necessary. Followings should be required technological measures.

- Wide area distribution system and equipment monitoring
- Detection of outage section
- Autonomous control, remote control (Islanding and restoration)
- Collaborative operation with alternatives such as DGs and power storages including electric vehicles.

(11) Reduced Costs from Better Power Quality

This benefit means cost reduction for damages in demand side from momentary outage, voltage sag and swelling or harmonics. In order to reduce the cost, some hardware devices such as stationary power battery for short term outages and adaptive protection circuits are required.

(12) Reduced Sustained Outages and Major Outages

Sustained outages and major outages make significant damages to actions in electricity consumers and it is necessary to avoid. Basically, same actions in (10) are required and also electricity consumers should corporate peak cuts and peak shifts to avoid wide-area outages or major power interruptions considering consumers' profitability.

4.3 Grouping the Technological Measures and Creating Actions in Smart Grid Projects

In this section, extracted technological measures are grouped by their similarity and actions in actual Smart Grid projects are considered for each group.

a) Selection of Critical Benefits Which Need Further Discussion

Before the grouping, focusing technologies are selected considering the purpose of this research. Countermeasures for (8) "Theft reduction" and (9) "Reduced Meter Reading Cost" would be achieved by frequent electricity consumption data collection and autonomous data collection using AMI. AMI is one of base infrastructure for Smart Grid and it also takes important roles from the viewpoint of ICT utilization. However AMI for general purposes such as theft reduction and reduced meter reading cost would be out of scope in this paper because some countries and regions have already installed smart meters for these purposes. (Utilization of data collected by AMI for other purposes is scope of this paper.) In addition, countermeasures for (12) Reduced Sustained Outages and Major Outages would be mainly hardware related and it has little relationship with benefits expansion by ICT application increase.

Therefore, benefit (12) is also outside the scope of this paper.

b) Categorization of Critical Technologies, Methods and Approaches in Selected Critical Benefits

Table 2. Actions for Critical Factors in Actual Smart Grid Projects and Their Objectives

Critical Factors Technological Countermeasurs	**Actions in Smart Grid Projects**	**Objectives**
(1) Optimal Power Supply - Distributed Generation (DG) - Optimal VAR ctrl. (SVR, SVC Installation) - Network Reconfiguration - Autonomous Control	- Optimal DG installation. - Optimal SVR, SVC installation - Optimal Distribution network reconfiguration - Generator operation and maintenance optimization (Asset mgt. Asset life cycle cost management)	- Peak power cut/shift - Power loss reduction - Total generation cost reduction - RES capacity expansion - Stable voltage/current - Ancillary service cost reduction - Operation and maintenance Cost reduction - Life time cost reduction
(2) Optimal Power Utilization - Demand side efficient energy management (Visualization, device control, demand forecast,) - Various electricity price program including DR - Smart equipment and Smart appliance (Autonomous Control)	- EMS (BEMS, FEMS and HEMS) - Demand Response and Various Electricity Price System - Smart Equipment and Appliance Autonomous Control -	- Electricity saving - Electricity peak cut - Electricity cost saving - CO2 Emission Amount Reduction - Optimal Electricity Price Program -
(3) Optimal power supply and demand - Wide Area Energy Management - Wide Area System, Asset and device Status Management - Outage Area Specification - Distribution Automation (Automatic control and remote control) - Supply and Demand forecasting and adjusting (DG, Battery, Power storage including EV, Stationary Power storages, UPS - DR	- EMS (CEMS, Wide Area EMS) - Outage management - Asset Condition Monitoring, - Outage Management - Distribution Automation - EV integration - System Control - Aggregator Services (BEMS, DR MEMS etc.)	- Real-time Supply and Demand balancing - Outage indexes minimization - Operation and Maintenance Cost Reduction - Deferred Asset Investment - Deferred Inspection Interval - Efficient management for Small and Many loads and power supply asset such as dispersed generators and electricity storages.

Because all countermeasures are related to improved power supply, power consumption or control between power supply and consumption in a certain region or area, extracted technological measures are categorized by "optimal power supply", "optimal power utilization" and "optimal power supply and demand control" in this paper. Therefore, these three major categories are defined as critical areas to promote Smart Grid penetration in this paper. Table 2 shows actions for critical factors in actual Smart Grid projects and their objectives which are needed to be achieved.

5 ANALYSES OF ICT CONTRIBUTION AREAS TO ACCELERATE SMART GRID REALIZATION

In this section, ICT contribution for challenges in each critical factors and technological measures selected and categorized in previous section is considered.

5.1 ICT Contribution Areas

Here, how ICT contributes to realize Smart Grid is discussed.

(1) ICT Value Provision Model

Figure 3 shows the value provision model of ICT which illustrates relationship between Smart Grid realization elements and Smart Grid benefit by the viewpoint of ICT. ICT should play several important roles in every element in order to provide Smart Grid benefit from data generation to value proposition as follows.

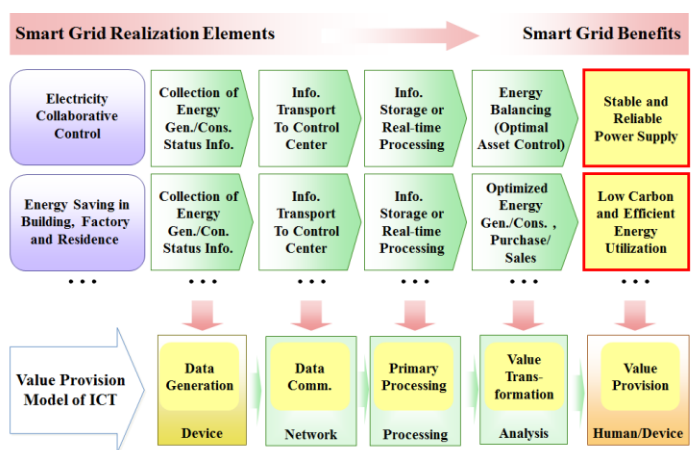

Figure 3. Value Provision Model of ICT

From the diagram, followings are technologies which especially require ICT contribution.

- **Advanced network technology** which communicates data between meters or sensors in demand side and data center systems in two ways
- **Advanced data collection technology** for big and frequently generating data from a large number of smart meters and sensors.
- **On-memory based rapid data processing technology** for real-time data utilization.
- **Advanced data storage technology** for rapid big data analyses for efficient data processing.
- **Value transformation technology** which creates new values and benefits for end users or control devices.

Smart Grid realization should be promoted if above these ICT advantages could be effectively applied to critical Smart Grid elements selected in the previous section. Although all these ICT related technologies are essential for the realization of Smart Grid, this paper focuses "Value transformation technology" because this is the collaboration required area between electrical technologies and ICT while other four elemental technologies are achieved by mainly information processing and network technologies.

(2) ICT Contribution Areas for Value Provision

By the engineering innovations related to sensor technology, many measuring devices including Smart Meters should be installed in many and various areas, and various enormous data could be collected through information networks. As new value added areas utilizing various information, following areas should be promising considering ICT utilization advantages.

a) Specific and Total Optimization

In most of utilizing measures and technologies for power supply, historical and experimental knowledge has been utilized. These are small risk and safe but might not be optimal. Although application of optimization approaches is still very limited because of various constraints such as small number inaccurate data, low computer performance and intractability of problems needed to solve. Recent ICT innovation is removing some of such constraints and a current small PC has the same performance as a mainframe computer several years ago. Therefore, optimization using ICT have possibilities for changing profitability of power suppliers' and consumers' business.

b) Interoperability and Collaborative Operation

While the conventional power supply model is one way model from large-scale centralized power plants to demand area, advanced power supply model in Smart Grid should be two-way model which can execute more effective collaborative operation between supply and demand sides. In order to realize the new two-way model, detailed and frequent both sides information utilization is necessary and real-time processing should be required. By the improvement in this area, regional power utilization optimization including local power production for local consumption and power interchange within the region could be realized.

c) Integrated and Automatic Control

ICT has contributed to automation of human works recently and lead to better productivity. Next step should be ICT contribution to equipment automatic control utilizing information and wide-area network. With regard to equipment automatic control, it has been difficult to use wide-area network because of its lack of response time and network reliability so far. However recent ICT innovation is steadily realizing equipment control collaboration with equipment automatic control functions.

5.2 ICT Contribution Topics for Critical elemental technologies to Realize Smart Grid

Here, possible topics of ICT contribution for elemental technologies for the realization of smart Grid categorized in section 3 are discussed considering ICT advantages; Optimization, Automation and Interoperability.

(1) Optimal Power Supply

In this category, main research topic is optimal installation of distributed equipment for efficient and reliable power supply such as DG. The major purposes of this topic are cost and power loss reduction by locating generators near demand, RES increase and quick recovery from a disaster.

(2) Optimal Power Utilization

In this category, major research topics should be to provide effective consumer EMS for optimal energy utilization and to develop effective price programs for optimal utility's operation. Both effective EMS and price programs provision, customers' equipment automatic control should be essential.

(3) Optimal Power Supply and Demand Control

In this category, the most critical challenge is to maintain reliability of the future advanced power supply system, including electricity supply and demand balancing, voltage and current management, and outage management in a target system using both supply and demand side information.

Table 3. ICT Contribution Topics for Critical Technological Measures to Realize Smart Grid

Category	ICT Contribution Topics
Optimal Power Supply	**Optimal installation of assets for efficient power supply such as distributed generation etc.** - Optimal allocation of DG, SVR and SVC. - Benefit and Cost evaluation of RES
Optimal Power Utilization	**Benefit realization of demand control measures such as efficiency energy consumption (Consumer EMS) and various price program** - Benefit and Cost evaluation of consumer EMS - Benefit and Cost evaluation of utilities price programs including DR
Optimal Power Supply and Demand Control	**Effective methods to maintain power supply reliability in a targeted area** - Information fully utilized generation and demand forecast - Development of optimal operation schedule and autonomous update utilizing real-time measured data

From the above consideration, Table 3 describes ICT contribution topics for critical technological measures to realize Smart Grid. The paper defines that Smart Grid elemental technologies in "Optimal Power Supply", "Optimal Power Utilization" and "Optimal Power Supply and Demand" should be keys to Smart Grid realization and ICT application expansion to these activities should accelerate Smart Grid realization.

6 KEY TECHNICAL RESEARCH TOPICS FOR REALIZING SMART GIRD AND DIRECTIONS OF THEIR SOLUTIONS

Lastly, key technical research topics including concrete challenges for selected ICT contribution topics defined in the previous section are described and research directions and expectations are proposed.

6.1 Optimal Equipment Installation for Efficient Power Supply

With regard to installation of DG, SVR, SVC etc., for stable power supply, poor selection of location and size of equipment installation would lead to higher power loss compared with no equipment installation. Therefore, challenges and proposed countermeasures to identify the optimal location and size of distribution equipment are described firstly, and also challenges related to RES installation is described and direction for their solutions are discussed because major DG type should be RES in future distribution systems.

a) Optimal Allocation of DG, SVR and SVC

Generally optimal DG and other power system equipment allocation problems in power distribution system require to solve non-linear discrete optimization problem called "Discrete Optimal Power Flow (OPF) Problem" under various constraints such as power flow laws, voltage upper and lower limits, etc. However, Discrete OPF has individual intractability for the solution and thus various metaheuristics approaches had been applied to these optimization problems for optimal DG allocation and some studies proposed an analytical method [11, 12] using the real power loss expression known as "exact loss" formula [13]. Although such metaheuristics and analytical approaches are effective methodologies to solve such intractable problems, it is difficult to ensure whether the solution is optimal and also difficult to understand the qualitative characteristics of DG and other equipment allocation impact. Therefore, an approach using an exact solution such as enumerative method should be considered because it has many advantages such as consideration of complex constraints, applicability for multi-objective problems and qualitative analysis capability for whole solutions. Although the enumerative method has the critical challenge which combinational explosion tends to occur, recent rapid advancement of computer capability expands its computable combinatorial numbers exponentially and the number of combination can be reduced by the adoption of adequate constraints or conditions. Therefore, utilization of enumerative method for problems related to future distribution systems should be expected.

b) Benefit and Cost Evaluation of RES

Large scale RES installation is expected in the recent DG installation. However, it is difficult to recover their installation and operation cost only with surplus power sales and cost reduction from effective power utilization, and this tendency would be more likely to be in small size consumers such as small companies and households. Therefore, apparent benefits or incentives for consumers should be necessary in order to promote RES penetration, and RES installation benefits for utility companies such as peak cut and shift, CO2 reduction and power loss reduction, should be passed on DG owners and consumers to expand consumers' benefits.

On the other hand, it is necessary to take into account the difficulty of RES installation forecasting in these discussions, because capacity of RES depends on weather conditions and owners of RES are not utility companies but mainly electricity consumers. Therefore, approaches using stochastic valuables might be effective and some stochastic approaches were proposed [14, 15].

6.2 Benefit Realization of Demand Control Measures

Consumer's benefit from various types of consumer side EMSs such as BEMS, HEMS and FEMS and price programs implemented for the purpose of optimal energy consumption should be mostly energy cost reduction. With regard to major difference between the purposes of EMS and price program, EMS is provided for energy utilization efficiency in consumer side. Therefore, EMS is used to optimize consumer's electricity consumption and total energy cost is reduced as the result of the optimization. On the other hand, price programs by utility companies are provided to lead their customers' electricity consumption behaviors to utility's operation optimization and some part of utility's benefits from the optimization are passed on their customers. Therefore, approaches for the evaluation methods are described as follows.

a) Benefit and Cost Evaluation of Consumer EMS

Because consumer's interest in this area is mostly on possibility of energy cost reduction, expansion of customer EMS would be promoted if customer's benefit would be apparent by combination of high accuracy benefit simulation and autonomous consumer's equipment control. Although major source for this benefit should be efficiency improvement in consumer's electricity consumption, it is necessary to understand that waste reduction has limitation. At the first year, a consumer might reduce their energy consumption cost dramatically by the installation of EMS. However, additional cost reduction in following years should be difficult because apparent wastes should have been removed by the last year. In addition, cost reduction size depends on customer's energy consumption size generally, so it is difficult for small size companies and for households to cover their EMS installation cost by only energy cost reduction.

ICT contribution for EMS is to provide various cost simulation and autonomous control methods based on consumer's optimal operation schedule. In simulation and autonomous control methods, it is effective for decision makers to obtain a multi-objective optimization method such as "cost" – "system stability" and "cost" – "RES capacity" etc., because companies need to make decisions considering such trade-off multi-objectives. Also, it should be useful if the relation between energy consumption and business profitability would be clarified because optimal energy consumption to maximize its profitability should be calculated.

b) Benefit and Cost Evaluation of Utilities Price Programs Including DR

Various price programs are provided for the purpose of efficient power supply by peak cut and shift using electricity price elasticity. However careful discussion should be required whether benefit from these price programs is reasonable for their preparation cost and consumers' inconvenience caused by electricity consumption behavior changes. Especially in small and medium enterprise and residential consumers, price elasticity should be relatively small because of their small total electricity consumption and thus more incentives or additional benefit might be necessary. Although DR is one of expected methods to provide additional benefit for consumers, it is necessary to understand that business models in DR programs require utility companies to generate revenue from the reduction of electricity sales amount, while they generally generate revenue from electricity sales. Therefore, a special electricity market environment and management rules are required in order to generate benefit for both DR program providers and consumers. In addition, service infrastructure preparation cost should be taken into account because electricity price change considering actual supply and demand would require real-time data collection and processing system and two way communication system between utility companies and their customers. Because these price programs should be provided as one of utility's services, infrastructure cost such as AMI components (smart meters, communication networks, data collection systems and customer side devices such as In-home display (IHD)) need to be prepared by utility companies generally.

Therefore, ICT contribution for the price program area should include clarification of electricity elasticity, cost simulation for various electricity price programs and autonomous control methods based on both utility company's optimal operation and consumer's incentives. Also it should be necessary to consider expansion of the benefit passed on consumers from utilities should be increased same as EMS.

6.3 Effective Methods to Realize Power Supply Reliability in a Targeted Area

As mentioned in above, it is expected that various demand side new technologies should be implemented for the realization of future effective power supply systems. In Smart Grid realization, solutions by collaborative operation between supply and demand sides would be expected in addition to solutions by individual technologies improvement.

a) Information Fully Utilized Distribution Systems Stabilization Support

It is expected that large number of RES generations such as PV systems would be connected into distribution systems and this might cause some problems such as voltage sag and rise, which influence distribution system stability. Although existing distribution automation systems and bulk installation of batteries are discussed for these problems generally, such measures require large scale investment. Therefore ICT contribution should be to enlarge distribution system stabilization and also to reduce investment for expensive hardware installation by the utilization of ICT. Assuming AMI would be completely installed in the near future, it should be possible to recognize real-time distribution system status such as voltage and current etc. These distribution system status data can be used for the detection of equipment failure symptoms and real-time fault detection etc. In addition, it would be possible to forecast power supply amount including DG capacity and demand in the target area accurately, and optimal schedule for distribution equipment based on the forecast can be developed.

b) Development of Optimal Operation Schedule and Autonomous Update Utilizing Real-time Measured Data

Optimal operation would be possible if real-time collection data from AMI etc., can be utilized for real-time schedule updating for each equipment. Although it is necessary to develop more advanced technologies in various ICT areas such as censers, networks, data collection and storage systems, and data processing systems, ultimate goal of Smart Grid should be realize such optimal and autonomous power supply systems.

Table 4. Objective Functions, Discussion Methods and Criteria for ICT Contribution Topics

Optimal Equipment Installation for Efficient Power Supply		
	Objective Function	- Loss Minimization - Cost Minimization
	Discussion Topics	- Effective optimization approach - Consideration of practical allocation scenarios and constraints. - Qualitative characteristics realization for DG and other regulating asset allocation impact - Benefit Transformation approach from utility to Consumer and its quantification method - Power loss reduction effect quantification - Deferred generation and distribution capacity investment by DG - Stochastic approach for uncertain RES installation
	Criteria	- Loss Reduction Rate - Total Cost Reduction Rate
Benefit Realization of Demand Control Measures		
	Objective Function	- Energy Related Cost Minimization - CO2 Emission Minimization - Benefit Maximization
	Discussion Topics	- Multi objective optimization method - Additional revenue generated by increasing energy consumption by 1 unit. - Benefit Transformation approach from utility companies to consumers and its quantification method - Benefit quantification of EMS installation - Quantification of electricity price elasticity - Benefit quantification of utility's price programs installation - Incentive quantification of consumer's price programs use. - Constraints and conditions for electricity market and rules for the profitability of electricity price programs
	Criteria	- Expected Benefit - Total Energy Related Cost Reduction Rate - CO2 Emission Amount
Maintain Power Supply Reliability in a Targeted Area		
	Objective Function	- RES Capacity Maximization - CO2 Emission Minimization - Area Total Benefit Maximization
	Discussion Method	- RES maximization or CO2 emission minimization approach maintaining the stabilization of distribution systems by the utilization of ICT. - Distribution systems stabilization approach for many unstable RES installed environment by the utilization of ICT - Benefit maximization approach considering total cost, RES capacity, CO2 emission and distribution system stability. - Benefit Transformation approach from utility to Consumer and its quantification method
	Criteria	- Outage related indices (SAIFI, SAIDI, CAIFI, CAIDI and MAIFI) - RES Capacity Rate - Total Power Loss Reduction Rate

Table 4 shows objective function, discussion topics and criteria of ICT contribution areas for the accelerating Smart Grid realization discussed in this section. In order to realize such information fully utilized energy management methods, large size information infrastructure is required. The infrastructure would be established by integration of many industries business networks such as Internet, telecommunication network, transportation network and so on. These infrastructures have possibility to utilize for various purposes and should be used for them to increase their values as shared infrastructures.

7 CONCLUSIONS

In this paper, Smart Grid benefits and their related technologies which can accelerate Smart Grid realization by the effective utilization of ICT was discussed assuming that possible reasons which prevents Smart Grid realization might be its necessity of enormous investment under its unclear benefit, and ICT utilization should create new additional values and contribute to clarify these values. Discussion results showed that several areas and actions which had high possibility to accelerate Smart Grid realization by the effective utilization of ICT and three areas were selected as future expected business areas in power supply and demand systems and some effective development topics were provided.

As the future work, it is required to quantify benefits of critical factors in these three areas. These quantifications should be provided as versatile tools which can be applied to various conditions and environments in actual projects.

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