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Energy Procedia 34 (2013) 282 – 290
Energy Procedia

10th Eco-Energy and Materials Science and Engineering Symposium (EMSES2012)

Opportunities and Challenges of Integrating Renewable Energy in Smart Grid System

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Abstract

Smart grid technology is the key for an efficient use of distributed energy resources. Noting the climate change becomes an important issue the whole world is currently facing, the ever increasing price of petroleum products and the reduction in cost of renewable energy power systems, opportunities for renewable energy systems to address electricity generation seems to be increasing. However, to achieve commercialization and widespread use, an efficient energy management strategy of system needs to be addressed. Recently, the concept of smart grid has been successfully applied to the electric power systems. This paper presents the study of integrating renewable energy in smart grid system. The introductory sections provide the role of renewable energy and distributed generation in smart grid system. Subsequent sections cover the concept of smart grid as well as benefits and barrier of smart grid renewable energy system. Pricing is a significant variable in success of renewable energy promotion. Thus, it is important to gain insight to renewable energy pricing by considering unique characteristics associated with renewable energy alternatives. A review of work done in renewable smart grid systems in recent years indicates the promising potential of such research characteristics in the future. This would be useful to developers and practitioners of renewable energy systems and to policy makers.

Selection and peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)

Keywords: Distributed generation; Renewable energy; Smart grid; Sustainable development ;

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Selection and peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)
doi:10.1016/j.egypro.2013.06.756

1. Introduction

Smart grid provides quality power that meet 21st century demand which cooperative generation and storage options that fulfills customer's needs considering the changes and the challenges. The key goal of smart grid is to promote active customer participation and decision making as well as to create the operation environment in which both utilities and electricity users influence each other. In smart grids, users can influence utilities by adding distributed generation sources such as photovoltaic (PV) modules or energy storage at the point of use, and reacting pricing signals. Utilities can improve reliability through the demand response programs, adding distributed generation or energy storage at substations, and providing automated control to the grid.

In recent years, utilization of renewable energy resources in smart grid system has been increasing. A significant number of programs have been implemented in various parts of the world – most of them are in the developed and developing countries. Some studies show that these technologies can provide reliable and comparatively low cost electricity service [1-3]. To feed the energy appetite of the world, renewable energy offer alternative options that enable consideration of the impact on the environment and other social and economic factors.

Renewable energy technologies (RETs) - hydropower, biomass, wind and solar photovoltaic - have been successfully demonstrated over the years. Currently, the total shares of all renewables for electricity production make up for about 19%, a vast majority (83%) of it being from hydroelectric power [4]. Power generation through the use of biomass offers a viable and long-term solution to grid electrification, however it is inefficient use, biomass resources presently supply only about 20% of what they could if converted by modern, more efficient, available technologies [5]. In recent years, interest in biomass as a modern energy source, especially for electricity generation has been growing worldwide. Wind power has emerged out as the world's fastest growing energy source [6]. The decentralized and locally available nature of wind energy makes it particularly attractive to grid electrification. Solar PV uses and applications have been justified and strongly recommended for grid electrification [7]. The current cost of PV devices, though lower than a decade ago, is still too high to provide power to compete the conventional electric supply. This paper aims to study the opportunities and challenges of integrating renewable energy in smart grid system. The concept of smart grid renewable energy system and its applications are presented.

2. Smart Grid Renewable Energy System

The electricity grid to accommodate higher percentage of renewable energy would need large quantities of conventional back up power and huge energy storage. These would be necessary to compensate for natural variations in the amount of power generated depending on the time of day, season and other factors such as the amount of sunlight or wind at any given time. Since today's electricity grid cannot handle this variability, the cost of adopting the renewable energy sources is much more expensive than it should be. This section addresses the definition, benefits and barriers of smart grid renewable energy, role of renewable energy and distributed generation in smart grid, PV smart grid system, and work done in smart grid system.

2.1. Definition of smart grid

Smart grid is defined as the electricity networks that intelligently integrates generators and consumers to efficiently deliver electricity which is sufficient capacity and coverage area accessible, safe, economic, reliable, efficient, and sustainable [8]. Smart grid development tends to be driven by one of the two principal visions for enhancing electric power interactions for both utilities and customers. The growing installations of renewable energy resources require a coordinated effort from the planning stage all the way down to the electronic devices used for power generation, distribution, storage and consumption [9].

2.2. Benefits and barrier of smart grid renewable energy

The benefits of smart grid renewable energy system are summarized as follows [10]:

- First, enabling renewable energy resources to accommodate higher penetration with cost effective while improving power quality and reliability.
- Second, integrating consumers as active players in the electricity system; savings, achieved by reducing peaks in demand and improving energy efficiency, as well as cutting greenhouse gas emissions.
- Finally, voltage regulation and load following enables reducing cost of operations based on marginal production costs.

The barrier to smart grid technology adoption is justifying the value preposition by the service provider and the customer, followed by regulatory constraints and technology standard that obstruct the smart grid technologies.

2.3. Role of renewable energy and distributed generation in smart grid

Around the world a change in electricity generation is desired in order to fight climate change and increase energy security. Consequently renewable energies and distributed generation are receiving support and their shares in electricity generation are rising. The increasing renewable generation in an inflexible system is the major challenge for developers and practitioners of smart grid system. The addition of distributed generation to the electrical distribution system has been the key driver in the evolution of distributed system, however distributed generation hardly receives market signals nor participates in system management for two reasons [11]. First, distributed generation is often from renewable sources and therefore prioritized under fixed feed-in tariffs and exempted from market prices. Second, generators in distribution networks are often too small and not equipped with technology and characteristics for system management purposes in balancing markets. Furthermore, one of the problems experienced is that the increasing renewable shares may cause congestion in distribution networks [9]. Other problems may include the intermittency of generation from renewable sources and the lack of dispatch ability [2,7].

Smart grid delivers electricity from suppliers to consumers using digital technology through control automation, continuous monitoring and optimization of distribution system, in order to save energy, reduce consumer cost and improve reliability [12]. Through cooperation, smart grid technology can provide the flexibility needed to integrate variable generation that is a characteristic of renewable resource such as wind or PV.

2.4. PV smart grid system

PV generates power in a manner that is fundamentally different than the way power has been generated in the past, and requires a power electronics interface to convert the native format of the generation so it becomes grid-compatible. PV energy is the most easily scalable type of renewable energy generation; it can be produced in amounts from a few kilowatts as the residential scale up to multiple megawatts at the utility scale. The intermittency of PV power stems from the diurnal and seasonal cycles of the sun and is deterministic. Its variability due to the fact that the instantaneous power generation depends on the level of incident solar radiation.

Due to the growing of electricity demand, increasing price of petroleum products (now about US$ 100 a barrel) and the reduction in PV systems costs over the last many years, the opportunities for PV smart grid system seem to be increasing.

2.5. Work done in smart grid renewable energy system

A survey of integrating renewable energy in smart grid system during the last decade is presented in Table 1. The table presents details of research characteristics, methodology used, objective and results obtained. Smart grid studies and research have mostly focused on conventional interconnected grid systems. Summary of work done in smart grid application for renewable energy distributed generation can be classified according to the research characteristics as follows: giving the concept of smart grid as well as pros and cons, technology adoption, optimal allocation of renewable energy in smart grid system, pricing and forecasting, and challenge of integrating renewable sources in smart grid system, etc.

Of the available RETs, photovoltaics have been promoted to extend the electric grid as technology matures and manufacturing production economies of scale emerge, however PV (particular residential PV) is poised to assume a more prominent role in the future electrical generation portfolio. Earlier studies on PV systems have been in terms of modeling, system sizing and its performance, while studies based on the balance electricity price for integrating PV in a smart grid system is limited. Tools are available for PV system design and sizing [13,14]. These are designed to address specific objectives, such as, design based on low life cycle cost or according to the expected function of the system. Earlier experiences also indicate that there are problems arising from the system sizing and PV contribution to the load [13]. Several obstacles have been identified related to the techniques on operation of the system [15]. One is due to nonlinear component characteristic [16] and choosing the proper operation strategy [17]. The balance electricity price for integrating PV in a smart grid system dealing with the reality of using PV smart grid systems is not available. In order to address these challenges, it is necessary to study the use of PV smart grid system for sustainable development.

The implementation of the smart grid concept and the deployment of smart grid technologies on power distribution systems are leading to the emergence of challenges to the way distribution systems are planned and operated. This trend is providing planners with abundant data at feeder, distribution transformer and customer level. The new methodologies and computation tools are required to make efficient use of the available data and allow for integrated resource planning and multi-objective optimization.

Table 1. Summary of work done in smart grid application for renewable energy distributed generation

Research characteristics	Methodology used	Objective/Results obtained	Author name/year
* Present a concept as well as pros and cons of smart grid for renewable energy distributed generation	* Discuss smart grid applications and its potential study in the future	* Survey and summarize the smart grid application for renewable energy distributed generation	Koykul W., 2011 [8] Geviano A., Weber W. and Dirmeier C., 2012 [9]
* Technology adoption	* Design and sizing of the hybrid energy system * Testing a system in laboratory scale to choose the proper operation strategy	* Monitoring real time data to evaluate the system situation in current status and making a decision for future power analysis	Kohsri S. and Plangklang B., 2011 [18] Ayompe L.M., Duffy A., McCormack S.J., and Conlon M., 2010 [33]
* Optimal allocation of renewable energy sources in smart grid system	* Consider the system loss and voltage stability as the objective function, and develop algorithm for optimal placement and sizing of the system's components	* Propose the strategy to finds out the optimal location of distributed generation (DG) units and the optimal reactive power injection in order to improve both, the voltage stability of the system and the DG penetration level	Alonso M., Amaris H. and Alvarez-Ortega C., 2012 [2] Phuangpornpitak N., Tia S., Prommee W. and Phuangpornpitak W., 2010 [19] Phuangpornpitak N., Tia S. and Prommee W., 2012 [20]
* Renewable energy pricing and forecasting	* Consider the factors which impact renewable energy investment decisions, i.e. economic, technical, social, political factors and obstacles	* Aim to integrate ideas of renewable energy pricing by considering unique characteristics associated with renewable energy alternatives * The predicted day-ahead prices match the real day-ahead prices closely. The estimated values of the lost load (VOLL) could help the power marketers to design optimal load leveling contracts and price tariffs for their customers.	Iskin I., Daim T., Kayakutlu G. and Altuntas M., 2012 [21] Kian A. and Keyhani A., 2001 [22] Filho J.C.R., Affonso C.M., and Oliveira R.C.L., 2002 [23]
* Challenges of integrating renewable energy in smart grid system	* Consider the research questions need to be addressed for future research	* Sizing aspects and financial feasibility issues for adding renewable energy, especially PV smart grid system to meet the demand load * Development of a suitable and effective model that includes technical and financial aspects of PV smart grid system to supply electricity	Phuangpornpitak N. and Tia S., 2012 (This study)

3. Renewable Energy Pricing

Pricing is a significant variable in success of renewable energy promotion. The pricing models for renewable energy are based on the same fundamental as the fossil fuels, but incorporating the unique characteristic of the renewable source [21]. The application of smart grid technology promises to provide benefit to electricity consumers by better utilizing electric system assets to securely satisfy consumer energy demands at a lower monetary and environmental cost. In determining the electricity tariff structure, the criteria have been taken into consideration are marginal cost, load pattern, social criteria as well as the revenue requirement of the power utilities.

3.1. Marginal cost

Marginal costs mean the incremental costs resulting from the most appropriate adjustment of the power generation and distribution systems to meet the continuously increasing demand per unit. The electricity tariff calculation that is based on the marginal costs will reflect the actual costs of power generation and distribution. Marginal costs in the power sector can be divided into four levels, i.e. generation, transmission, distribution and retailing.

3.2. Load pattern

Due to the changing load pattern, in early 1997 the Time of Use (TOU) rate was introduced. The TOU rate was offered as an alternative rate for the existing Time of Day (TOD) customers and as a compulsory rate for new power consumers. Under the TOU rate, the tariffs would be expensive during the peak period and would be cheaper during the off-peak. The current load pattern has altered from what it used to be, i.e. the load curve during Saturday, Sunday and official holidays shows lower demand than that during Monday - Friday. The peak period of the system is during 09.00 - 22.00 hrs from Monday to Friday and the off-peak is during 22.00 - 09.00 hrs from Monday to Friday and the whole day on Saturday, Sunday and public holidays.

3.3. Revenue requirement of the power utilities

The power utilities will undertake an estimate of their financial status and make an estimate of the average electricity tariff that would yield the financial status pursuant to the established criteria. The revenue in each year will be called the revenue requirement. In order to estimate the financial status, explicit assumptions are essential, particularly assumptions on fuel prices, inflation rates or consumer price index, efficiency improvement of the transmission system, distribution system and retail business.

3.4. Social criteria

The key political and social requirements for the electricity tariff determination are as follows:

- Uniform tariffs should be applied nationwide for each individual customer category;
- Subsidization for residential consumers should remain, particularly for small residential consumers whose consumption is low; and
- The structure of electricity tariffs for other consumer categories should be designed to best reflect the marginal costs.

4. Smart Grid Development in Thailand

Energy is considered as an important mechanism in a country for the development, but in the current situation, the energy consumption and the price is increasing. All these reasons directly effect the progressive development of Thailand [18]. Therefore integrating renewable energy sources to smart grid systems are imperative to implement for future use.

Thailand has recently announced a number of activities to increase the role of smart grid. In 2011, the Provincial Electricity Authority (PEA) initiates the smart grid roadmap project which has a goal of applying advanced technologies to optimize the operation of the power system to serve people through Thailand [24]. WADE (2012) noted that the potential improvements of smart grid in Thailand are increasing renewable to be incorporated by the utilities; revising the tariff mechanism to accommodate and encourage implementation of smart grid systems; and creation of a competitive retail market for development of services, for example, TOU pricing and demand response, etc [25].

Pipattanasomporn et al. (2009) proposed the design and implementation of a multi-agent system that provides intelligence to a distributed smart grid [26]. Ayompe et al. (2010) noted that the concept of smart meters provide precise information on electricity consumed as well as the time of use [27]. They are intelligent communication devices with digital real time power measurement. They offers the opportunity for operation and meter reading as well as potential for real time pricing, new tariff option and demand side management.

Solar electricity provides non-depleting, site-dependent and environmental-friendly alternative energy option [28,29]. Although, solar energy is enormous and clean, it is not always economical in comparison to conventional fossil fuel based electricity. PV modules have the advantage of minimum maintenance and easy expansion (upsizing) to meet the growing energy needs. This modularity allows users to tailor PV system to the desired situation. The main disadvantages are the high cost and the need for the application/load to match with sunshine dependent output of PV. However, technological breakthroughs (yielding cost reduction of PV, improved efficiency, etc.) may change the scenario.

Due to the increasing price of petroleum products and the reduction in PV systems costs over the last many years, the opportunities for PV system to address smart energy system seems to be increasing. Menke (2012) noted that the challenge for smart grid development in Thailand including PV can cover at least daily load profile which is mainly air conditioning driven [30]. The monitoring of PV plant performance becomes the key issue since electricity from PV is dependent on solar radiation.

5. Conclusion

The power system operators and planners still face the challenge of integrating renewable energy sources into power system grids. Renewable energy system is an innovative option for electricity generation, especially the solar PV system as it is a clean energy resource. Recognizing the advantages of PV system, many such systems have been installed worldwide in recent years. To achieve the commercialization and widespread use, a number of issues need to be addressed. These issues are related to the design and sizing of the system, the suitable and effective model that includes technical and financial aspects of PV smart grid to supply electricity, and the balance electricity price for integrating PV in a smart grid system. Earlier studies showed that the balance electricity price for integrating PV in a smart grid system dealing with the reality of using PV smart grid systems are limited. Therefore, there is a need to develop a PV smart grid system model that incorporates technical and financial aspects. This would be useful to evaluate the balance electricity price for integrating PV in a smart grid system.

Acknowledgements

The authors are grateful to the Office of the Higher Education Commission, the Thailand Research Fund and the Kasetsart University Research and Development Institute for the scholarship support in conducting this study. They also convey their sincere thanks to the Center of Advanced Studies in Industrial Technology, Faculty of Engineering, Kasetsart University. Thanks are due to the Faculty of Science and Engineering, Kasetsart University, Chalermphrakiat Sakonnakhon Province Campus, and the Research and Development Institute of Chalermphrakiat Sakonnakhon Province Campus for their kindness and generous assistance.

References

[1] Cosentino V, Favuzza S, Graditi G, Ippolito MG, Massaro F, Riva Sanseverino E, Zizzo G. Smart renewable generation for an islanded system. Technical and economic issues of future scenarios. Energy 2012;39 (1):196-204.

[2] Alonso M, Amaris H, Alvarez-Ortega C. Integration of renewable energy sources in smart grids by means of evolutionary optimization algorithms. Expert Systems with Applications 2012;39 (5):5513-22.

[3] Al-Ali AR, El-Hag A, Bahadiri M, Harbaji M, Ali El Haj Y. Smart Home Renewable Energy Management System. Energy Procedia 2012;12:120-6.

[4] Alain Liébard, Nahon C. Worldwide electricity production from renewable energy sources. 2011.

[5] Bhattacharya SC, Abdul Salam P, Runqing H, Somashekar HI, Racelis DA, Rathnasiri PG, Yingyuad R. An assessment of the potential for non-plantation biomass resources in selected Asian countries for 2010. Biomass and Bioenergy 2005;29 (3):153-66.

[6] Phuangpornpitak N, Tia S. Feasibility Study of Wind Farms Under the Thai Very Small Scale Renewable Energy Power Producer (VSPP) Program. Energy Procedia 2011;9:159-70.

[7] Alagoz BB, Kaygusuz A, Karabiber A. A user-mode distributed energy management architecture for smart grid applications. Energy 2012;44 (1):167-77.

[8] Koykul W. Current status and action plan of utility sector on smart grid and smart community in Thailand. Thailand - Japan Workshop on Smart Community in Thailand: Provincial Electricity Authority, Thailand, 2011.

[9] Gaviano A, Weber K, Dirmeier C. Challenges and Integration of PV and Wind Energy Facilities from a Smart Grid Point of View. Energy Procedia 2012;25:118-25.

[10] Clastres C. Smart grids: Another step towards competition, energy security and climate change objectives. Energy Policy 2011;39 (9):5399-408.

[11] Christine B, Gert B, Nele F. Smart Pricing to Reduce Network Investment in Smart Distribution Grids - Experience in Germany: Elsevier Inc., 2012.

[12] IEEE. Smart Grid: Reinventing the Electric Power System. IEEE Power and Energy Magazine for Electric Power Professionals. USA: IEEE Power and Energy Society, 2011.

[13] Fragaki A, Markvart T. Stand-alone PV system design: Results using a new sizing approach. Renewable Energy 2008;33 (1):162-7.

[14] Posadillo R, Lopez Luque R. Approaches for developing a sizing method for stand-alone PV systems with variable demand. Renewable Energy 2008;33 (5):1037-48.

[15] Dakkak M, Hatori K, Ise T. The concept of distribution flexible network PV system. Renewable Energy 2006;31 (12):1916-33.

[16] Hua S, Zhou Q, Kong D, Ma J. Application of valve-regulated lead-acid batteries for storage of solar electricity in stand-alone photovoltaic systems in the northwest areas of China. Journal of Power Sources 2006;158 (2):1178-85.

[17] Dakkak M, Hirata A, Muhida R, Kawasaki Z. Operation strategy of residential centralized photovoltaic system in remote areas. Renewable Energy 2003;28 (7):997-1012.

[18] Kohsri S, Plangklang B. Energy Management and Control System for Smart Renewable Energy Remote Power Generation. Energy Procedia 2011;9:198-206.

[19] Phuangpornpitak N, S. Tia, W. Prommee, and W. Phuangpornpitak. A Study of Particle Swarm Technique for Renewable Energy Power Systems. PEA-AIT International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010). Chiang Mai, Thailand, 2010.

[20] Phuangpornpitak N, Tia S, Prommee W. Optimal Photovoltaic Placement by Self-Organizing Hierarchical Binary Particle Swarm Optimization with Solar Irradiance Capability in Thailand. Submitted to an International Journal of Renewable and Sustainable Energy Reviews 2012.

[21] Iskin I, Daim T, Kayakutlu G, Altuntas M. Exploring renewable energy pricing with analytic network process - Comparing a developed and a developing economy. Energy Economics 2012;34 (4):882-91.

[22] Kian A, Keyhani A. Stochastic price modeling of electricity in deregulated energy markets. 34th Hawaii International Conference on System Sciences. Hawaii, USA, 2001.

[23] Filho JCR, Affonso CM, Oliveira RCL. Pricing analysis in the Brazilian energy market: a decision tree approach. IEEE Power Tech Conference. Bucharest, Romania, 2002.

[24] APEC. Using Smart Grids to Enhance Use of Energy-Efficiency and Renewable Energy Technologies. APEC Energy Working Group, 2011.

[25] WADE. Smart/Intelligent Grid Development and Deployment in Thailand (Smart Thai). World Alliance for Decentralized Energy, 2012.

[26] Pipattanasomporn M, Feroze H, Rahman S. Multi-Agent Systems in a Distributed Smart Grid: Design and Implementation. IEEE PES 2009 Power Systems Conference and Exposition. Seattle, Washington, USA, 2009. pp. 1-8.

[27] Ayompe LM, Duffy A, McCormack SJ, Conlon M. Validated real-time energy models for small-scale grid-connected PV-systems. Energy 2010;35 (10):4086-91.

[28] Taele BM, Gopinathan KK, Mokhuts'oane L. The potential of renewable energy technologies for rural development in Lesotho. Renewable Energy 2007;32 (4):609-22.

[29] Nguyen KQ. Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. Energy Policy 2007;35 (4):2579-89.

[30] Menke C. The future of PV in Germany and prospective for Thailand. Renewable Energy Project Development Programme (PDP) South-East Asia 20 years of grid connected PV systems: Lessons learnt from Germany why quality matters. Bangkok, Thailand, 2012.