Efficiency Improvement of Renewable Integrated Power System: A Review

Priyanka[1] Deepak Kumar[2]
[1,2]Department of Electrical Engineering
[1,2]Om Institute of Technology and Management, Hisar - 125001, Haryana, India

Abstract— Electricity consumption will comprise an increasing share of global energy demand during the next two decades. In recent years, the increasing prices of fossil fuels and concerns about the environmental consequences of greenhouse gas emissions have renewed the interest in the development of alternative energy resources. In particular, the Fukushima Daiichi accident was a turning point in the call for alternative energy sources. Renewable energy is now considered a more desirable source of fuel than nuclear power due to the absence of risk and disasters. Considering that the major component of greenhouse gases is carbon dioxide, there is a global concern about reducing carbon emissions. In this regard, different policies could be applied to reducing carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations. Two main solutions may be implemented to reduce CO2 emissions and overcome the problem of climate change: replacing fossil fuels with renewable energy sources as much as possible and enhancing energy efficiency. In this paper, we discuss alternative technologies for enhancing renewable energy deployment and energy use efficiency.

Keywords: Energy Resources, Renewable Energy, Energy Use Efficiency, Generation Technology

I. Introduction

Considering that the major component of greenhouse gases (GHGs) is carbon dioxide, there is a global concern about reducing carbon emissions. In this regard, different policies could be applied to reduce carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations. In addition, supporting mechanisms, such as feed-in tariffs, renewable portfolio standards and tax policies, are employed by governments to develop renewable energy generation along with implementing energy use efficiency for saving energy [1].

Many countries have started to install facilities that use renewable energy sources for power generation. The importance of alternative energy sources comes together with climate change challenges associated with the excessive use of fossil fuels. There are three primary motivators that stimulate the growth of renewable energy technologies: energy security, economic impacts and carbon dioxide emission reduction. The term “alternative energy” refers to any form of energy other than the conventional sources of energy, including hydropower. In recent years the focus has been on renewable energy sources. The efficient speed controller is found to be an important requirement to run the motor for the brushless direct current (BLDC) motor. This requirement is considered as superior, as it may increase the operating speed and system efficiency. In the existing methods, proportional plus integral (PI) controller has been included because of its simple architecture. But the PI controller produces load disturbance, control complexity and some parametric (Proportional plus integral) variations. The purpose of this proposed controller is to overcome the problems produced by PI controller in BLDC motor[2].

IEA (2012d) refers to two significant global trends that should characterize the deployment of renewable technologies over the medium term [3]. First, as renewable electricity technologies scale up, from a total global supply of 1,454 gigawatts (GW) in 2011 to 2,167 GW in 2017, they should also spread out geographically. Second, the more recent years of high fossil fuel energy use has led renewable technologies to become increasingly competitive on a cost basis with their alternatives in a number of countries and circumstances. According to IEA calculations, wind is the most competitive type of renewable energy technology among the other options, if local conditions such as financing, CO_2 emission levels and fossil fuel prices prove favorable (OECD, 2010) [4].

When talking about clean technologies, there are two primary concepts of energy technologies: energy supply technologies, which refers to alternative sources of renewable energy (e.g., wind and solar power), and energy efficiency technologies, or those technologies which are hired to enhance energy use efficiency, (e.g., combined heat and power (CHP), virtual power plants (VPP) and smart meters). It should be noted that transforming the energy sector and replacing conventional energy with renewable energy is evolutionary associated with technological change and forming markets. Jacobsson and Bergek (2004) indicate that the transforming process for certain forms of renewable energy, such as wind and solar, will happen after 2020, even if the growth rate of consumption is strongly increasing over the next decade. Also, renewable energy markets are not easily formed due to cost disadvantages and the subsidizing of fossil fuels [5].

II. Renewable energy supply technologies

The renewable energy supply is continuously increasing. A large amount of investment has been made during recent years and the advancement of technology has enabled countries to produce renewable energy more cost effectively. It is forecasted that the number of countries producing above 100 megawatts (MW) of renewable energy will increase significantly figure 1.

2017 (IEA, 2012d). Due to some negative and irreversible externalities coming with conventional energy production, it is necessary to promote and develop renewable energy supply technologies[6]. These technologies may not be comparable with conventional fuels in terms of production cost, but they could be comparable if we consider their associated externalities, such as their environmental and social effects. Also, it should be noted that economies of scale could play a key role in reducing the unit production cost. Transmission and distribution costs, as well as technologies, do not differ much among the conventional and renewable energies. Below we present facts about the development of the main renewable energy supply technologies[7].

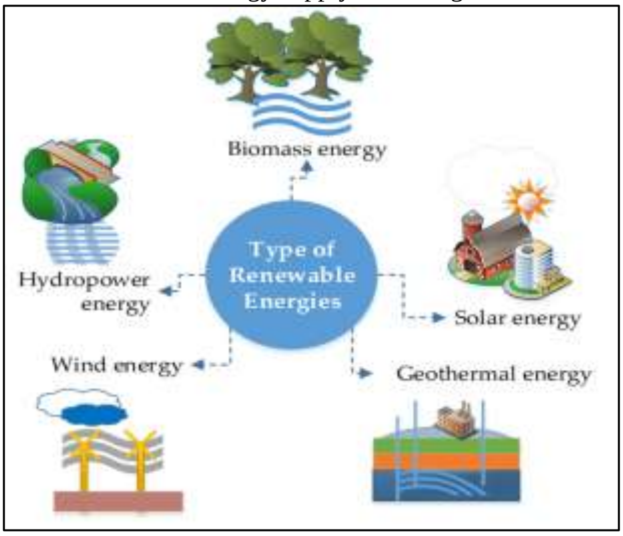

Fig. 1: Type of renewable energy

A. Hydro power

Hydro power is currently the largest renewable energy source for power generation around the world. Hydro electricity generation has had a strong increase over the past 50 years. It was 340 terawatt-hour (TWh) in 1950 and covered about one-third of the global electricity demand. It increased to 1,500 TWh in 1975 and further to 2,994 in 2005. We can compare this to the global consumption of 15,000 TWh of electricity with a global production of 18,306 TWh in 2005 (Ngô and Natowitz, 2009). Currently, hydro power development is difficult due to a large initial fixed investment cost and environmental concerns. Additionally, hydro power has caused problems for local residents associated with the need to relocate large populations, as well as the construction of dams is permanent with a sunk cost of utilities which cannot be removed. The environment is also influenced by hydro power construction because of large engineering works. On the other hand, hydro power is attractive due to a preexisting supply of water for agriculture, household and industrial use, and hydro power is clean and enables the storage of both water and energy. Also, the stored energy can be used for the application of both base-load and peak time power generation[8].

The largest capacity hydro power plant in the world is the Itaipu Dam installed on the Paraná River and developed jointly by Brazil and Paraguay. The initial capacity was 12.6 GW in 1984, but this has since been increased to 14 GW in 2006 (Ngô and Natowitz, 2009). Many argue that hydro plant construction projects could improve local economies. For example, the US employed thousands of workers to complete the Hoover Dam project, which was constructed during the depression in 1930s (Tester, 2005). Hydro power plays a key role for some countries, such as Norway and Sweden. Based on BP statistics (2012), hydro electricity demand in Norway (122 TWh) constituted almost 64% of the primary energy consumption in 2011, compared to shares of 26% and 8% for oil and natural gas, respectively. Similarly, around 30% of energy consumption in Sweden has been supplied by hydro power (66.5 TWh). China, Brazil and Canada are the top three hydro electricity producers worldwide, with 694.0, 429.6 and 376.5 TWh generated, respectively. Figure (1) shows the general trend of worldwide hydro electricity consumption from 1965 to 2011.

B. Wind power

The installed capacity of wind power has increased from 4.8 MW in 1995 to more than 239 GW in 2011. Today, each wind turbine could generate as much electricity as a conventional power plant. Wind energy has made its most significant contributions in China, the US and Germany, where the cumulative installed capacities are 62, 47 and 29 GW, respectively. The trend shows that wind capacity installation has increased continuously throughout the last two decades. IEA estimates that the global capacity will increase from 238 GW in 2011 to almost 1,100 GW by 2035, of which 80% will be derived from onshore wind turbines (IEA, 2012e). According to this report, offshore wind capacity is expected to grow fairly quickly from 4 GW in 2011 to 175 GW by 2035 as a result of public support. This target will be achieved if the required investment is made based on the design plan[9].

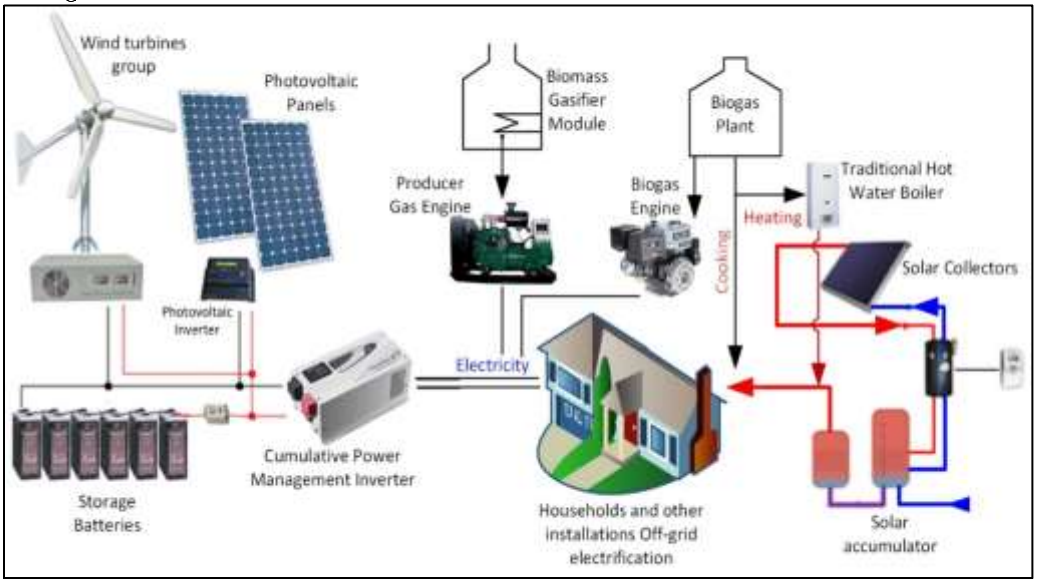

Fig. 2: Integrated renewable power system

C. Solar Power

During the two last decades, the economic feasibility of solar power for residential, commercial and industrial consumption has been investigated by researchers. Industrial countries like Japan and Germany are looking for alternative sources of energy such as solar power due to the limited availability of natural primary energy sources[10]. In early 1990s, Japan started to take advantage of large-scale electricity generation by solar photovoltaic (PV), and was soon followed by Germany. Currently, both countries have taken the lead in the manufacture and production of solar power technologies. More recently, China has developed an extensive solar power capacity due to cheap labor and government subsidies, in turn, decreasing the cost of solar power generation[11].

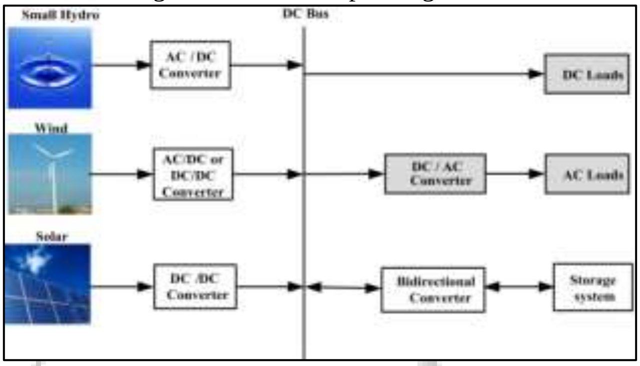

Fig. 3: Renewable energy system

Alongside the cost reduction in power generated through conventional solar PV technologies, the advancement, and increase in efficiency, of concentrated solar power technologies in the US has further reduced the cost of electricity in the solar power industry (Gevorkian, 2012). On the other hand, there are also negative effects caused by solar technologies, such as impacts on buildings' aesthetics, routine and accidental releases of chemicals, land use, etc[13]. (Tsoutsos et al., 2005). The solar photovoltaic market has experienced extraordinary growth over the last five years. The market has increased from 9,564 MW in 2007 to 69,371 MW in 2011. Figure 3.5 shows the trend since 1996 to 2011 based on the BP (2012) report.

III. ENERGY EFFICIENCY TECHNOLOGIES

As previously mentioned, there are two main solutions to reducing CO_2 emissions and to overcoming the climate change problem: replacing fossil fuels with renewable energy sources as much as possible and through enhancing energy efficiency[14]. We discussed the state of the art methods for technical and economic feasibility of expanding the use renewable energy sources and the possibility of substitution in the first part of this review. In this part that follows, we discuss energy efficiency technologies. Energy efficiency for an electricity network could be considered in different stages, such as the power generation, transmission, distribution and consumption. The different technologies that are currently available include electric vehicles (EV), combined heat and power (CHP), virtual power plants (VPP) and smart grids, each of which are discussed below [15].

A. Electric Vehicles

Electric vehicles (EV, including the battery, fuel cell, and hybrid types) have the potential to be considered viable options for both electricity storage and power generation. Considering that the transportation sector is one of the main sources of emissions, improving fuel efficiency enables us to achieve the largest fuel savings and CO_2 reduction in the short term. Thus, the increased usage of EVs and increasing their share of the vehicle fleet can play a key role in the long term. IEA (2012c) forecasted an increased share of plug-in hybrid electric vehicles (PHEV) over the next two decades, with a total increase of up to 50% by 2050. “In long-term, smart grid technology may enable EVs to be used as distributed storage devices, feeding electricity stored in their batteries back to the system when needed (vehicle to grid), to help provide peak-shaving capability [16].

Examined the impact of the large scale use of electric vehicles in southern California and concluded that Southern California Edison (a power company in the area) was able to accommodate a large number of EVs with their existing capacity, particularly if the charging system was managed by smart control. Ford argued that EVs can improve load management, enhance efficiency and save energy. He also calculated that EVs are able to reduce emissions at a value of around 9,000 USD per vehicle. Calculated the present value costs for an EV owner and the benefits to utilities. Based on the results, all three vehicle/battery combinations are cost-effective power sources during the peak time for the short-term. He argued that if a part of the transportation section is utilized by electric vehicles with connections to the electricity network, there will be less demand for base-load generation. In addition, the use of intermittent renewable energy sources becomes more applicable due to a lack of concern about the time-of-day match between demand and supply[17].

Kempton and Tomic (2005) investigated the systems and procedures required to use energy in vehicles, as well as the implementation of vehicle to grid (V2G) technology. The most important role of V2G could be its support to renewable energy in the emerging power markets through managing load and supply fluctuations. They argued that after initially tapping EVs for their high value, market saturation and cost reduction, V2G fleets could be used as storage capacity for renewable energy power generation. Tomic and Kempton (2007) examined the economic feasibility of battery-electric vehicles to supply power for a particular market in the US.

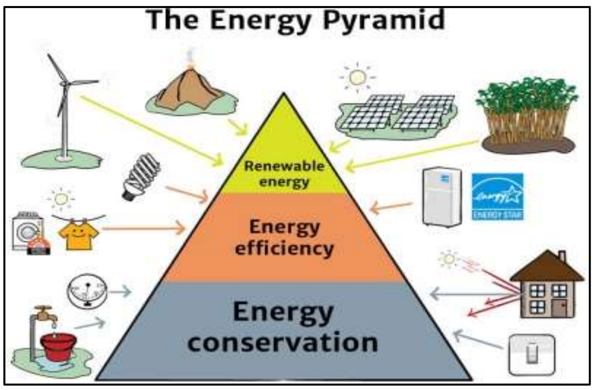

Fig. 4: Energy efficiency

Investigated the systems and procedures required to use energy in vehicles, as well as the implementation of vehicle to grid (V2G) technology[18]. The most important role of V2G could be its support to renewable energy in the emerging power markets through managing load and supply fluctuations. They argued that after initially tapping EVs for their high value, market saturation and cost reduction, V2G fleets could be used as storage capacity for renewable energy power generation. Examined the economic feasibility of battery-electric vehicles to supply power for a particular market in the US. The results show that V2G electricity is able to provide a significant income flow, contributing to the feasibility of grid connected vehicles and furthering support for adoption. Evaluated the integration of renewable energy into the transport and electricity sectors by V2G. They applied a model to analyze energy integration for electricity, transport and heating. V2G technology has been found to provide storage for the matching time of generation and time of load. Adding EVs and V2G technology to power networks enables the system to be integrated with wind electricity without extra power generation and also makes a significant reduction in CO_2 emissions[19].

Analyzed three scenarios to evaluate the impacts of increasing ethanol 85, hydrogen, and electricity powered vehicles into the passenger transportation fleet starting in 2010, and reaching 100% of the new vehicle market by 2050. The results show that CO_2 emissions will be reduced by 153 Mt from the use of electric vehicles to 156 Mt from the use of hydrogen fuel cell vehicles by the year 2050. It is also forecasted that ethanol driving cars will be cellulose based by 2050, generating a significant reduction in CO_2 emission, but still producing an unsustainable amount of crop residues[20].

B. Combined Heat and Power

Cogeneration, or combined heat and power (CHP), is the use of heat and electric power together. It is expected to have a substantial gain in efficiency over each source separately. Most power distribution companies supply only electricity, not hot water or steam. Considering that almost 30-40% of a country's total energy load is used for heating, CHP is an efficient use of fuel when a portion of the energy is discarded as waste heat. It captures some or all of the waste energy as a by-product for heating. In Reykjavik and New York, end users are able to purchase both electricity and thermal energy from a utility company [21]. An example of cogeneration is the CHP unit in Avedore, Denmark which is a multifuel plant. Calculated that increasing the CHP capacity of the United States to 20% by 2030 would lead to a reduction of 5.3 Quads (Quadrillion British Thermal Units) of energy consumption and 848 MMT of carbon dioxide emissions. Based on their findings, the United States would save more than 1.9 Quads of fuel consumption and 248 million metric tons of carbon dioxide emissions by employing CHP. According to the WEO (2012) report, the average efficiency of power plants is 41% worldwide, with almost 60% of the primary energy being converted to waste heat [22]. CHP could transform a significant part of the waste heat into a positive economic value for industrial processes or heating in residual and commercial buildings. It is estimated that new CHP units could improve energy efficiency to a level greater than 85%.

Investigated the application of combined cooling heat and power (CCHP) for supermarkets in the UK and compared it to the energy savings/capital cost of conventional technology. The results show that CCHP is able to provide a significant amount of primary energy while reducing CO_2 emissions compared to conventional schemes, but it is also believe to be competitive with more efficient technologies in long term. They argued that new technologies, such as fuel cells, could provide improvements in energy efficiency for CCHP in refrigeration[23].

Examined cost effective operating strategies of three alternatives micro-CHP technologies (Sterling engine, gas engine and solid oxide fuel cell-based (SOFC) system) for residential application in the UK. They evaluated the economic and environmental attributes on the abovementioned technologies for heat-led, electricity-led and least-cost operating strategies. The results showed that the SOFC-based system had the maximum operating cost and the largest CO_2 emission reduction following the least-cost operating strategy. You Examined the electricity export capability of aggregated micro-CHP units as a virtual power plant (VPP) through participation in the electricity wholesale market. They found that the export capability of micro-CHP systems strongly depends on technical parameters, associated energy price, and the demand profile. Based on applied model, it is surmised that the marginal price for a micro-CHP system is higher than the spot price for most of the year [24].

C. Virtual Power Plant

A Virtual Power Plant (VPP) is a cluster of distributed energy resources, such as micro-CHP, wind turbines, and solar photovoltaic panels, which are controlled and managed by a central control unit. The term distributed energy resources (DER) can be used for fossil or renewable energy fuels. A DER system has been defined in order to overcome energy waste problems due to long distances and transmission losses. Therefore, DERs are generally located close to the distribution networks. The concept of VPP is used for DER integration. According to the Europe FENIX project, there are two types of VPPs, the Commercial VPP (CVPP) and the Technical VPP (TVPP). DERs can simultaneously be part of both a CVPP and a TVPP. A commercial VPP is defined as a portfolio that could be used by a DER to participate in electricity markets. CVPPs can represent a DER from any geographic place in an electricity network. A technical VPP enables operators to facilitate DER energy capacity and optimize the power balance in the system with the minimum cost [25].

The share of distributed generation (DG) in an electricity network is increasing in importance and VPP is considered to be an emerging technology that enhances energy efficiency. Analyzed the technical and economic feasibility of operating a VPP with micro- CHP units. They explained that, due to Germany's plan to abandon nuclear power plants until 2020, a part of the new capacity should be comprised of renewable energy sources and CHP utility, which are considered DG units. VPP is an alternative to the management of these units, as of the absence control needs provides an advantage for renewable energy technology. Based their findings, the power generated by an individual owner is too small to supply, with the amount of the power output needing to be 30 MW or higher based on existing regulation. A VPP operator can integrate a large number of DERs and provide 30 MW through aggregating 6,000 micro-CHP units, each with a power output of 5 kW. They estimated that every unit is charged 300 Euros for connection into the integrated system. Applied a model to manage a VPP made up of a large number of customers with controlled home appliances in order to optimize load reduction over a certain time schedule[26].

Examined an architecture and communication pattern for employing a large number of electric vehicles to be integrated into a VPP system. They argued that EVs have a strong potential to be a component of the electricity network if the fleet of vehicles is managed appropriately. It is indicated that intelligence is required to optimize the charging of EV batteries in order to manage the integration of EVs into the electricity network. You proposed a market-based VPP model constituted with DER units which have access to electricity markets. Based on the model, general bidding and price signals are considered two operation scenarios performed by one market-based virtual power plant. Developed a mathematical optimization model for the management of CHPs. Considering the main task of a VPP is to increase generated electricity by DG units, the operation of individual generators should be optimized. Next, their contribution to output of VPP is calculated. They applied this model for a local heating system populated by 5 CHP units, and their results indicate a 10% increase in benefits compared to a general CHP system.

IV. Energy Storage Applications

There is a wide range of EES applications for power systems. EES can be integrated at different levels of electrical systems: at generation level, at transmission level, at distribution level, and at customer level. On occasions there is a need at generation plants for a black start, which is a process of restoration of a power plant to normal operation without relying on the transmission grid support. Also, generation bridging support can be provided using EES, until a conventional generator starts up or restarts, so EES has the ability to firm generators load or give a ramping support, picking up fast load variations and allowing a given generator to level its production to the technical limits.

In power distribution systems EES may also find suitable applications counterbalancing contingency effects in order to reduce impacts of the loss of major grid components, as well as in emergency situations after a loss of major grid components. On the customer side, energy management applications of EES systems is another important function, which aims at the reduction of the invoice by securing the continuity of supply at pick hours at accessible price However, there are some limiting factors, since most EES technologies are only used for specific applications, and may be completely unsuitable for other applications. Thus, in the next decade R&D effort should be directed towards extending the EES applications range, using a hybrid approach to complement their deficiencies and create a versatile EES system with multifunctional capabilities. Such hybridization would be similar to a well-known combination of flywheel storage with battery storage, employed not as a substitute, but as a complement, improving the batteries performance and their life [27].

There are many applications for EES. For some applications EES has already been commercially deployed and it will continue to be used for these applications in the future. Furthermore, some new applications for EES are emerging, such as support for the expansion of renewable energy generation, the smart grid, smart micro grid, smart houses and electric vehicles. The importance of EES in the society of the future is widely recognized, and some studies on the future market potential for EES have already been carried out. While these studies vary in target time range, target area, applications considered and so on. The study indicates that value and market size for each application can vary with circumstances in the future, and that one EES installation may be used for multiple applications simultaneously, which increases the benefits. One factor affecting the future market is the scale of new installation of renewable energies.

V. Future Recommendations

Renewable energy resources being environmental friendly and enhance system reliability and stability, are widely deployed in power grid. RERs pose many problems at modeling, planning, integration and control level. The key issue is how to model the renewable energy resource. The fuel resource such as wind and solar radiations being highly unpredictable require probabilistic model, forecasting and scheduling methods. Since Wind and solar are highly unpredictable therefore both can be available during off peak load hours. During this time period the installed potential can be wasted. To undo this wastage energy storage systems have to be installed. The extra power will be stored in these systems and will be provided to the load during peak hours. So storage systems need to be improved. Effective electronic interface improves the performance of RERs. An effort is required to develop electronic interfaces controlled by intelligent controllers to integrate RERs in power grid. When solar energy resources are included in power system, the cumulative inertia of power system reduces, thereby reducing the system stability. Effective controllers need to be designed to save the power system stability. Solar cells have energy conversion and heating problems. Therefore research work has to be carried out to upgrade existing solar cell technology.

VI. Conclusions

This review of Efficiency Improvement of Renewable Integrated Power System has provided detailed and useful information that can be used in the decision making of different stakeholders in the rapidly developing market. Each technology has both advantages and disadvantages that vary by location, availability, the technological capability of producers, financial limitations and environmental considerations. Each municipality, region or country has different initial conditions that determine the energy mix that can be produced at the lowest cost while minimizing the harm done to the environment. Thus, there is no single solution to every energy need and problem, but rather an optimal location specific solution among a set of possible renewable solutions.

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