Infrastructure for Sustainable Renewable Energy in India: A Case Study of Solar PV Installation

S. A. Khaparde, Senior Member, IEEE, and Arunavo Mukerjee, Member, IEEE

Abstract—The renewable energy sources are going to become the long-term solution for future energy. Adequate infrastructure development is of crucial importance to harness power from them. This paper accumulates state-of-the-art issues and feasible solutions associated with large scale deployment of the renewable energy technologies. Various alternatives presented here are likely to change the look of the future power system. The role of existing technologies, automation, and communication for sustainable development is explained here. A case study of solar photovoltaic installation is presented to show efforts of India in sustainable energy development.

Index Terms—Distributed energy resource, energy storage devices, information and communication technology, MicroGrid, renewable energy, sustainable development.

I. INTRODUCTION

LIMITED fossil fuel resources have directed the mankind to find alternative ways to satisfy the future energy needs and optimizing the utilization of the existing resources. The renewable energy technologies, in this regard, are likely to be the potential solution for future energy requirements. They not only provide energy, but also help in reducing effect of the green house gases (GHG). Various renewable energy sources such as wind, photovoltaic cell (PV cell), hydro, biomass, biofuel, etc., are going to play an important role in sustainable energy development. Worldwide survey of 132 nations indicated that, the nations ranked high on sustainable development, tend to have higher usage of the renewable energy [1].

The central idea presented in this paper emphasizes on the infrastructure development to achieve sustainable energy scenario in the energy deficient countries like India. The need of an intelligent grid has been recognized here to accommodate distributed energy resources (DERs) and renewable energy technologies on large scale. Different issues related to the deployment of renewable energy resources and possible enabling technologies are discussed here. A case study in the Indian scenario is presented as an effort of India towards sustainable energy development.

The organization of the paper is as follows. Section II explains various issues related to the development of sustainable energy using renewable energy technologies. Different alternatives based on upcoming technologies to tap the renewable energy potential is detailed in section III. Section IV briefs the activities of various organizations like European Union and United Nations. Efforts and achievements of India in sustainable energy development is explored in section V. A case study of the renewable energy development using solar photovoltaic installation is also presented in the same section. Section VI concludes the paper.

II. KEY ISSUES FOR SUSTAINABLE ENERGY DEVELOPMENT USING THE RENEWABLE RESOURCES

Possible uncertainty of the fossil fuel based resources in coming decades and market price hikes of the fuel have renewed interest into the green power generation. However, the ways of utilizing these resources face lots of new challenges in planning, implementation, and management. Various issues in harnessing power from the renewable energy resources involve technology selection, investment, generation control, power quality and reliability issues, government policies, etc. These issues are broadly categorized and explained here.

A. Technology selection

The process of technology selection relies upon various technical as well as commercial indices. These indices can be represented in the form of a matrix known as sustainability matrix. The technology with maximum total index can be referred as the most suitable technology. One such sustainability matrix showing the cost of sustainable electricity generation is presented in [2]. Based on [3] and the discussion with the Maharashtra Energy Development Agency (MEDA) personnel, a sustainability matrix for various renewable technologies in Indian scenario is prepared as shown in table I. The weight allocation to each index, however, is a subjective matter, and the list of the attributes presented is not exhaustive. Still, the table is sufficient indicative of the overall evaluation. From the table it can be observed that wind and biomass power generation look promising.

B. Investment

Per kW investment on the renewable energy technologies is much higher as compared to a conventional coal-fired power plant. Except hydro and wind power generation, other technologies are not market proven. Hence, they put some risk on the investment. In addition to the capital investment, the auxiliaries like reactive power support, black-start capability, storage capacity, etc., to maintain reliability and power quality of the supply, eventually increase the cost of energy to the consumers.
The hydro, biomass, etc., can be dispatched because the prime mover input can be controlled. Hence, they are suitable to supply the base and/or peak load. The other renewable energy resources like wind and PV cell are weather dependent, i.e., they cannot be despatched. Therefore, their applications generally do not suit to supply continuous load. Intermittency of power generation raises reliability and power quality issues. For instance, bagasse is available during 4 – 5 months in a year. The availability of supply from such generators can be improved by operating them on alternative fuel.

D. Grid integration

The renewable energy, although clean and green, may not lead to a reliable power supply solution. Intermittency of the wind and solar insolation makes them unsuitable for most of the commercial and industrial applications. Alternatively, such resources can be operated in conjunction with the utility grid. The grid-connected operation leads to another set of issues related to voltage stability, reactive power demand, etc. These issues depend upon characteristics of the local network, and differ from country to country. Hence, the country-specific standards and recommended practices should be developed for each type of energy resource.

E. Fuel requirement

Fuel requirement of a class of renewable technologies based on biogas, biomass and biofuel need investment upon the infrastructure to supply the fuel continuously. The infrastructure involves transportation facilities, fuel storage, etc. Availability of these resources in the close vicinity of the plant is highly desirable to reduce the fuel cost.

F. Environmental issues and role of new technologies

Hydro, wind, and PV cell are pollution free power generating technologies. The other technologies like biomass, bagasse etc. pollute the environment in a manner same as a coal-fired power plant. Improved technology in DERs (e.g. lean-burn technology) can reduce the emissions to permissible level. New power generation technologies like stirling engine, combined heat and power (CHP), co-generation, etc., can improve the energy extraction from the renewable resources.

G. Regulatory policy and demand side management

The energy policy of each year should propel the growth of renewable energy sources. Subsidies and other incentives can be planned to encourage the investors in this field. For example, rebate in tax is an encouraging factor for development of renewable energy resources by the private investors. Similarly demand side management can mitigate the effect of intermittency of the resources. Support from customer side will make the operation and control of the resources easier.

III. ENABLING TECHNOLOGIES

To build an intelligent and sustainable power system for future, it is essential to bring the low-cost technologies to the market. They are necessary to bridge the gap between local networks, and to create a modern infrastructure with capabilities of integrating the DERs. The last section dealt with various issues and challenges related to the renewable energy development. This section describes the possible solutions to overcome few of the hurdles. The enabling technologies for secure energy scenario in the future are as follows.

A. Standards development

The standards provide common portfolio for variety of generation technologies. Absence of the standards slowdowns
the proliferation of renewable energy technologies. For example, the substation automation standards IEC 61850 is the new standard for communications in substations. It defines process bus and substation bus communications allowing the development of new distributed applications for protection, control and automation. IEEE 1547 is the grid integration standard for DERs. Large scale deployment of renewable resources should be supported by international standards, and adopted worldwide.

B. Energy storage technologies

The energy storage devices play an important role in enhancing energy production from the renewable energy technologies like wind and PV cell. The supply inconsistency due to intermittency of weather conditions can be mitigated up to some extent by providing backup from the energy storage devices. Various energy storage technologies include battery, flywheel, ultra-capacitor, superconducting magnetic energy storage (SMES), pumped hydro, compressed air energy storage (CAES), and hydrogen energy storage. Among these, the battery technology is the most developed, and is well established for a variety of applications. The other forms of energy storage are either still in the prototype stage of development or are not suitable for mass production [4].

Since electricity production from the renewable resources depends upon weather conditions, use of storage devices will enhance energy extraction. For instance, many wind plants produce much of their energy when it is not needed, and solar plants produce electricity based on daylight variations. The storage of renewable energy would allow to dispatch the renewable plants.

C. MicroGrid

The renewable energy technologies when operated in stand-alone mode fail to satisfy reliability issues. Many a times, such generators are supported by other generating technology and/or storage device to supply a common load. Such an assembly is known as hybrid generator. Few popular hybrid generation systems include wind-diesel, wind-PV cell, etc. Technically as well as economically the hybrid generation is more viable than relying upon one particular technology.

A step towards more sophisticated way of utilizing these resources does not end with the hybrid generation. The renewable resources in absolutely stand-alone mode do not perform satisfactory due to their dependance on weather conditions. Hybrid connection of different resources and/or storage devices improve the reliability of the system. But the backup or slave generator required in such a system almost sizes the same as the master generator. A more profound approach is to connect the resources into a MicroGrid. The concept of the MicroGrid supersedes all the advantages of a single generator and a hybrid generator. Moreover, it includes all the advantages of the networking at mini scale. Since different type of resources are interconnected, diversity in fuel and loading conditions can be achieved. The components of the MicroGrid complement with each other, thus reduce the dependence on the main grid. As shown in Fig. 1, the MicroGrid concept involves small T&D network. This small self-sufficient system would allow maximum extraction of the renewable power by coordinating control between the renewable and the fossil fuel based generators. All the advantages of a MicroGrid may not become apparent at first site because of higher cost of energy as compared to the grid power [5]. The decision making process, however, should include multiple attributes like cost of energy, loss of load probability, energy not served, thermal load, etc. [6] presents comprehensive analysis of a MicroGrid including multiple objectives.

D. Information and communication technologies [7]

The infrastructure development for the existing power system and the information and communication technology (ICT) are highly important to realize sustainable energy scenario. European research has taken an initiative to realize this need. The research has aim to make the conventional power system more intelligent, self-managing, and self-healing. The ICTs in this regard are capable of catering for many of the functionalities of the future electricity network. Two successful advanced ICTs are software agents and electronic markets.

- The agents are pieces of software that represent someone or something (e.g. wind power generator). They negotiate with other agents for the allocation of resources, and communicate this to the controller softwares. The agents are known from the web services, and provide automated means of technical coordination and optimization in a system with many diverse components.

- An electronic market is a technical coordination mechanism within cells (i.e. a group of agent controlling an area) of a grid. One of the applications of such an agent-based electronic market is to combine different DERs and renewable energy sources into a commercial cluster or a MicroGrid. In a day-ahead market, the electricity producers and the traders forecast their production/consumption on a daily basis, and communicate this to the transmission system operator (TSO). In real-time, deviations from the forecasted value are compensated by the TSO through contracting regulating power. With the use of the electronic markets, the field experiments in the European
markets show that, the real-time deviations and need of regulating power can be reduced.

Few of the important outcomes of ICTs are described below.

1) Universal connectivity: An ICT creates universal connectivity between a large variety of grid devices including power production resources, network nodes, and local loads. This provides new and better technical foundations for distant control of highly distributed networks on an increasingly large scale. The universal connectivity is a key enabler for the proper management of any future energy network.

2) Services over the internet and web: With the help of internet and web, an ICT can provide new ways for real-time interaction between suppliers, distributors, and customers in the grid. Beyond monitoring, the internet enables new web services based on two-way communication between suppliers and customers. Automated demand response, balancing services, dynamic pricing, and buying and selling of power in real-time are few of the promising applications to come in future due to advanced ICT solutions.

3) Increasing the intelligence of the grid: An ICT for power is the new technique in hardware and software which injects intelligence into the grid. The electricity system inherited from the 19th and 20th centuries has been a reliable but centrally coordinated system. With the liberalization of the electricity markets and the spreading of DERs and renewable energy resources, top-down central control of the grid no longer meets modern requirements. Future grid needs decentralized ways for information, coordination, and control of the grid to serve the customer. The ICT is central to achieving these innovations.

4) Advanced fault detection and handling: The agents representing a part of the grid are also useful in fault detection, localization, isolation and reconfiguration. In a cell of the grid, messages can be exchanged between devices in a few tens of ms. Faults can be isolated correctly in less than 10 s, up to one min, even if data communication rates are as low as 10 kbps. Hence, this approach can drastically reduce the interruptions observed today on the distribution system.

5) Intelligent load shedding: Intelligent load shedding involves interaction between load and supply. Such methods can be implemented by any utility or system operator with today’s technology and products, even without sophisticated communication schemes to modern ICT.

### IV. Activities of European Union and United Nations in Sustainable Energy Development

#### A. European Union [9], [10]

Research and technology development (RTD) activities in the European Union (EU) framework program (FP) actively participate in sustainable development. The EU has a vision of integrating DERs on large scale for sustainable development. Conventional fossil fuel based generation systems emit CO₂ to the environment. EU identifies cost-effective technologies to meet its targets under the Kyoto Protocol with main emphasize on the renewable energy.


The main impetus for accelerating the pace of renewable energy development was provided by the United Nations (UN) conference on new and renewable sources of energy held in the year 1981 in Nairobi, Kenya. Since then, the UN assists the developing countries to evolve their own energy strategies to promote more sustainable energy development. For assessing the potential of renewable sources of energy and for energy planning purposes, data on different renewable energy source are needed. In order to generate such data systematically on a comparable basis, activities have been undertaken involving provision of methodological inputs and training for different renewable sources of energy. The UN efforts enabled several countries like China, Egypt, India, Thailand, Mexico, and Brazil to prepare solar and wind data handbooks and atlases. Several entities of the UN have extended assistance to countries in undertaking demonstration and pilot projects in order to prove the value of the renewable energy technologies.

### V. Towards Sustainable Energy Development: A Case Study in India

India faces formidable challenges in meeting its energy needs and in providing adequate energy of desired quality in various forms in a sustainable manner and at competitive prices. India needs to sustain an 8% to 10% economic growth rate, over the next 25 years, if it is to eradicate poverty and meet its human development goals. Currently, installed capacity in Indian power system is shown in Table II. To deliver a sustained growth rate of 8% through 2031 – 32 and to meet the lifeline energy needs of all citizens, India needs, at the very least, to increase its primary energy supply by 3 to 4 times and, its electricity generation capacity/supply by 5 to 6 times of their 2003 – 04 levels [12].

---

**TABLE II**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Hydro</th>
<th>Thermal</th>
<th>Nuclear</th>
<th>RES</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>25621.7</td>
<td>38274.9</td>
<td>3499.8</td>
<td>604.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Private</td>
<td>1306.2</td>
<td>4241.4</td>
<td>5663.9</td>
<td>597.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Central</td>
<td>6672.0</td>
<td>26682.5</td>
<td>4419.0</td>
<td>0.0</td>
<td>3900.0</td>
</tr>
<tr>
<td>Total</td>
<td>33549.9</td>
<td>69198.8</td>
<td>13581.8</td>
<td>1201.7</td>
<td>3900.0</td>
</tr>
</tbody>
</table>

---

Authorized licensed use limited to: INDIAN INSTITUTE OF TECHNOLOGY BOMBAY. Downloaded on December 5, 2008 at 00:23 from IEEE Xplore. Restrictions apply.
TABLE III
RENEWABLE SOURCES OF ENERGY IN INDIA AS ON 31 – 03 – 2006 [13]

<table>
<thead>
<tr>
<th>Renewable technology</th>
<th>Potential in MW</th>
<th>Achievement in MW</th>
<th>Rank*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>45000</td>
<td>5340.60</td>
<td>4</td>
</tr>
<tr>
<td>Biomass power</td>
<td>19500</td>
<td>912.53</td>
<td>4</td>
</tr>
<tr>
<td>Biomass gasifier</td>
<td>NA</td>
<td>60.87</td>
<td>1</td>
</tr>
<tr>
<td>Solar hydro (&lt; 25 MW)</td>
<td>20 MW/km²</td>
<td>2.74</td>
<td>5</td>
</tr>
<tr>
<td>Energy from waste</td>
<td>2700</td>
<td>45.78</td>
<td>NA</td>
</tr>
</tbody>
</table>

* India's global position in renewable technology installation, NA = Not available

TABLE IV
RENEWABLE POWER PURCHASE OBLIGATION

<table>
<thead>
<tr>
<th>State</th>
<th>Renewable energy (% of total consumption)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>minimum 5%</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>0.5%</td>
</tr>
<tr>
<td>Karnataka</td>
<td>minimum 5% and maximum 10%</td>
</tr>
<tr>
<td>Gujarat</td>
<td>1%</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>3%</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>10%</td>
</tr>
</tbody>
</table>

Various renewable energy potential and achievement in India are shown in table III. The Electricity Act 2003 has radically changed legal and regulatory framework for the renewable energy sector. The Act provides for policy formulation by the Government of India and mandates the state electricity regulatory commissions (SERCs) to take steps to promote renewable and non-conventional sources of energy. Accordingly, different SERCs in India have directed the utilities to use renewable resource. As shown in table IV, the SERCs have released order known as renewable power purchase obligation (RPPO) for electricity generation from renewable resources.

A. Indian ministry for renewable energy

The ministry of new and renewable energy sources (MNRE) has been supporting R&D for technology and manpower development in renewable energy. The thrust areas mainly covers programs related to rural electrification using solar energy, energy from urban and industrial wastes, wind power generation, biomass, small hydro, etc. [14]. Indian renewable energy development agency limited (IREDA) is a public limited government company established in the year 1987, under the administrative control of MNRE. It promotes, develops and extends financial assistance for renewable energy and energy efficiency/conservation projects [15].

B. Case study of Solar Photovoltaic Installation

Although India shining has become a common slogan, just consider these facts:

- Over 80,000 villages live in complete darkness even now. These villages do not have hope of getting grid electricity in the near future. Of these only 52% of the households are electrified.
- Others still depend on kerosene and firewood to meet their energy requirement.
- 13-14 hours of power outages everyday thereby severely restricting the economic growth of such villages.

This situation has emerged because the cost of supplying power through conventional power system infrastructure is very expensive as described below:

- Cost of laying a 11 KV line from a 33 KV grid point: INR 200,000 per km.
- Cost of installing transformers & laying LT distribution line in the village: ranges from INR 50,000 (25 kVA) to INR 200,000 (200 kVA).
- Cost of laying a distribution line to each household, internal wiring, fixtures, etc: INR 1,500 per household.
- Further operations and maintenance costs and transmission and distribution losses are incurred over and above the high capital costs.

Thus the key determinants of rural electrification with conventional power are captured in the figure 2.

Thus we expect to find situations in rural India, where solar electricity has parity with grid prices e.g. a village using solar photovoltaic (PV) with 120 households about 50 km from the grid enjoys parity with grid power. With the expected drop in prices in solar PV, smaller villages with less than 80 households about 20 KM to the grid will be competitive by 2010 as shown in figure 3.

A classic example is the state of Chattisgarh where 50 % of the land is covered by thick forest. Thousands of villages in the state are un-electrified out of which 950 villages are so isolated...
that they have been declared as in accessible to grid power. Further besides high cost of extending the transmission and distribution network to these areas, connecting these villages to conventional grid power would mean denuding large areas of forest. Absence of electricity has severely hampered economic development in this state.

Considering the above scenario, where quality power is to be provided to the villages in dense forests and that too without cutting a single tree, it was decided that solar power plants from Tata BP solar would be a good solution. A photograph of a typical installation is given in Fig. 4.

Solar power plants totalling 470 kW in 113 villages across 5 districts were installed. Each power plant would provide power for street lights and homes. The scope of work for Tata BP Solar, the equipment vendors include supply, installation, commissioning of solar power plants, along with construction of a control room in each village. A typical village has a 4 KW plant which lights up about 60 homes each with 2 lights between 5 PM and 11 PM in the evening and for an hour at dawn. The plant also lights 12 street lamps and has also a back up reserve for a rainy week. There is a INR 10 charge for 2 lights a month per household. Villagers say they are saving fuel costs on home made kerosene lamps.

The impact of installation of solar PV has been to improve the quality of life of tribal through:

- Increased time for income generating activities
- Women save cooking time on an average by 90 minutes which is productively used for other activities
- More time for children to study and establishment of night coaching classes
- Reduced incidence of snake bites
- Decrease in negative health and environmental repercussions of using kerosene lamps

C. Major obstacles in exploring renewable energy sources

In India, the private investors play a major role in installing renewable powered generators. Almost more than 60% of the renewable energy installation is done through private industries. In spite of noticeable initiative taken from the industry side, the realized tapping is still far less than the potential. The discussion with MEDA personnel indicate that, the availability of financial assistance and policy structure are the major obstacles in exploring the opportunities of renewable energy development through private sector. Some private players take undue advantages of lack of the standards and strict regulations, and loose the credibility. For example, few of the biomass power generation plants are sealed because they started using coal as a cheaper alternative to biomass.

VI. CONCLUSION

The volatility of fossil fuel prices has opened a ground for renewable energy sources. The renewable energy technologies and other non-conventional technologies will play an important role to enable the sustainable development. With the inherent unpredictability, the wind and PV cell should be supported by upcoming technologies like MicroGrid and ICT. With the help of these technologies, the intermittency of the renewable resources can be abated. Large scale implementation of the renewable energy resources need to have motivating government policies and well established standards. Proper financial support is the governing factor for a generation deficient and developing country like India.

ACKNOWLEDGEMENT

We are thankful to Mr. S. R. Chaudhari (General manager, Energy Conservation & Power Generation) and Mr. H. M. Kulkarni (Project executive) from MEDA, Pune, India for technical discussions. We would also like to thank Mr. Subramanya Krishnappa, CEO, Tata BP Solar, India for technical discussion and providing details of the case study of solar PV generation system.

REFERENCES

S. A. Khaparde (M’87–SM’91) is Professor, Department of Electrical Engineering, Indian Institute of Technology Bombay, India. He is member of Advisory Committee of Maharashtra Electricity Regulatory Commission (MERC). He is on editorial board of *International Journal of Emerging Electric Power Systems* (*IJEEPS*). He has co-authored books on Computational Methods for Large Sparse Power System Analysis: An Object Oriented Approach, as well as, *Transformer Engineering*, published by Kluwer Academic Publishers and Marcel Dekker, respectively. His research area includes Distributed Generation and power system restructuring.

Arunavo Mukerjee (M’06) is Vice President, Energy Business development, of Tata International Ltd, Mumbai. He has degrees in Electrical Engineering and Business from Indian Institute of Technology, Kharagpur, and Carlson School of Management, University of Minnesota, Minneapolis, USA. He has extensive experience in the energy sector spanning Power / LNG project development, introducing energy related legislation, Distributed Generation and power system restructuring.