CLEAN ENERGY SOLUTIONS

A Compilation of Studies from TERI India

teri NORTH AMERICA

For more information:
T E R I
Darbari Seth Block
IHC Complex, Lodhi Road
New Delhi – 110 003, India

Tel. 2468 2100 or 2468 2111
Fax 2468 2144 or 2468 2145
Web www.teriin.org
India +91 • Delhi (0)11

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Preface

TERI-North America was established in 1990 as a not-for-profit 501(c)(3) organization incorporated in the District of Columbia. As Mr Gus Speth, Founding President of the World Resources Institute, keeps reminding me, this was perhaps the first time that an institution from a developing country established a formal presence in any developed country, let alone the USA. The intention behind this initiative was to promote research and intellectual partnerships between the US and India in the fields of energy, environmental protection, and sustainable development. While many of us at TERI have spent a substantial amount of time in the U. S. and have forged strong relationships with institutions and individuals here, it was hoped that the formal presence of a TERI entity in the U. S. would provide a basis for expanding existing partnerships and creating new linkages.

The official launch of TERI-NA took place on September 10, 1990; then-Senator Al Gore was the Chief Guest and a large number of distinguished persons, including the late Dr Abid Hussain, then-Ambassador of India to the US, Mr. Gus Speth himself, and the late Senator Charles 'Chuck' Percy, were featured speakers at the event. The potential inherent in the establishment of TERI-NA, however, was realized to different levels during different periods of time. Energy issues have remained an integral part of TERI-NA's agenda, even as the emphasis of its work has varied since its inception. Given that support for TERI-NA's work has fluctuated over time, there were periods when activity levels were not quite satisfactory.

Since the beginning of 2012, however, TERI-NA has entered a new phase; financial support has allowed professionals from TERI in India to spend time in the US, conducting research on several topics in renewable energy and related fields. The output from this research will add to our understanding of these subjects and help link our two societies. Most of the work presented in this volume is the result of time spent by TERI researchers in New Haven, where they engaged with faculty members of Yale University and took advantage of Yale's vast library of research materials and resources.

The issues covered by TERI researchers that are included in this volume deal with subjects such as the potential applications of smartgrids, the challenge of universal energy access, knowledge flows in the field of industrial ecology, how to design policies for improved environmental governance, how to bring about a transition towards greater use of biomass fuels, and policy options for contending with the explosive growth of car ownership in India. The evolution and structure of the transport sector in India has major implications for energy choices that the country can exercise. It is becoming increasingly clear that the current trend of rapidly increasing private ownership of automobiles has some serious implications, not only with respect to mobility choices in the future, but also regarding the security of India's energy supply. These subjects have very high policy relevance, not only for India but also for other emerging economies and even developed countries that need to make major changes to the direction of their energy development.

This effort would not have been possible without the generous support of Mr Sanjeev Mehra and Mrs Karen Mehra of the 'GS Gives' Annual Giving Fund, who provided young and talented researchers with this unique opportunity. The researchers were both encouraged and challenged in the process of their research work at Yale and benefitted from their vibrant interactions with the academic community. I trust this grant and its unique products will have a lasting impact. Once again, we are extremely grateful to both Sanjeev and Karen Mehra, who had the foresight to back this endeavor when it was a mere concept and for their magnanimous support.

R K Pachauri

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Authors
Alekhya Datta; Sunil Dhingra; Sumit Kumar Gautam; Akshima T Ghate; Mukesh Gujar; Shilpi Kapur; Vivek Jha; Parimita Mohanty; K Rahul Sharma

Editor
- Moitreyee Chatterjee

TERI Press
- Editorial and Design team

Summit Coordinators
Aarti Narain, Vaaruni Eashwar, Taylor Gregoire-Wright

Annapurna Vancheswaran
Vice-President, TERI North America

Role of smart technologies in promoting distributed generation based mini-grids

Based on project experiences and lesson learned

Parimita Mohanty, Mukesh Gujar, Alekhya Datta, and K Rahul Sharma, TERI

Abstract

Energy is the key to economic development and sustenance of future world. Energy demand in India as well as in many countries across the world is ever increasing and expected to grow in future. If the Indian power scenario is viewed, although India's power sector has shown impressive growth over the last few years, the demand for power has increased more rapidly than its availability (The demand for electricity has increased at a rate of 6.27 per cent in the past two decades.) In addition to shortage of power and energy demand for the existing consumers, there is around 1.44 billion population in the world without access to electricity, out of which around 288 million of them are in India. Again India has more than 3.10 lakh telecom towers, 60 per cent of their power requirement are met by diesel gen-set which together consumes about 2 billion litres of diesel each year and result in 5.3 million tons of CO_2 emission). Against this backdrop, Distributed Generation based power solutions have been considered as one of the feasible options, where Distributed Energy Resources can not only deliver power to the local areas (where it is installed and distributed) more efficiently and reliably, but it can also feed excess power, if any, to the utility grid. In addition, these systems are environmentally benign.

Introduction

India has a strong history of using renewable energy technologies for the last thirty years. Renewable energy sectors got specific attention in planning process in India since the Sixth Five Year Plan with specific allocated budget. In the Seventh plan, the focus was on development and dissemination of renewable energy systems, whereas from the Eighth plan and onwards the emphasis has been developing integrated strategies to make renewable energy system techno- commercially viable. Mini-grid is one of the thematic areas within renewable energy sector which has got lot of focus because of its multiple advantages. However, mini-grids so far have been seen majorly from the point of view of providing minimum basic energy to the community in the remote, far-flung areas. Although there is a need of such mini-grids system in the rural areas, the scope of mini-grids should not be limited only to the remote, scattered and far flung areas only. There is an equally large potential of mini-grids in the urban and peri-urban sectors as well, such as in commercial and industrial complexes, hospitals, shopping malls/ complexes, apartments, residential complexes, and educational institutions to ensure maximum flexibility, reliability, and safety with enhanced efficiency of the overall electricity system.

In both the segments, technology plays a very critical role in providing reliable, quality power at an affordable price. Reliable and quality power from any system is a function of optimised design, and not just design focusing purely on arriving at the least cost system. Often in the tendering and design process, decisions to reduce the up-front cost lead to a compromise on the efficiency, reliability and flexibility of a system; and this in most cases leads to high life-cycle costs of the system owing to frequent maintenance and repair, monitoring, outages, system failure and so on[7]. In both cases, these systems provide energy for crucial activities starting at simple household tasks such as cooking and studying to more complex business activities involving productive applications. An unreliable system (and especially one that stops functioning suddenly and prematurely after a certain period of time) can adversely impact the lives and incomes of those using the electricity, and in cases of poor and rural users, lead to a complete lack of access to basic services which they have now got accustomed to, and which are aiding in their development. Looking back at the large number of examples of such failures, it is clear that if a system is being installed, its efficiency, reliability and flexibility are of foremost importance and designs should be developed not just to achieve the basic minimum performance but with the larger aim of creating robust systems, which is possible with technologies available today.

This paper discusses the evolution of distributed generation based mini-grids in India along with different technological options that lies for mini-grid system. Subsequently, this paper conveys what role technology advancement and its up-gradation can bring for mini-grid system, applicable to both the segments (rural as well as urban/peri urban) and what steps can be followed in order to promote such systems at field. In this paper, two case studies from TERI's own work and extensive research are considered, which describe how the advancement in technology and its innovative applications meet the energy requirement as per the local need.

Evolution of distributed generation (DG) based mini-grids in India

In India, Distributed Generation (DG) is not a recent phenomenon. Diesel-based stand-alone DG systems (gensets) are commonly used by individual shopkeepers and house owners to provide back-up power during power failure. Large-scale power intensive industries and commercial buildings have also installed their own captive power plants. A mini-grid is defined as an electricity distribution network operating below 11 KV (in India, generally with 415 volts 50 Hz three-phase AC electricity supply), providing electricity to a community. The mini-grid has a small power plant (it could be as small as 2kW or as big as several kW), and spread within 2-3 km radius from the power plant. It supplies power through low-tension distribution networks to households for domestic power, commercial (e.g. shops, cycle repair shops, flour mills) activities, and community requirements. A mini-grid may or may not be connected to the wider grid.

Isolated mini-grid is defined as a mini-grid that is not connected to the utility grid in any way. It is a distinct island for which no point of common coupling (PCC) exists whereas connected mini-grid is defined as a mini-grid which may or may be connected to the utility grid. It may operate as a distinct island but features a point of common coupling that allows interaction with the utility grid.

If the history of renewable energy system in India is observed then technologically it has evolved with time.

In the 1980s, the renewable power systems are used either as stand-alone system such as solar lanterns, solar home systems, solar street lighting systems, wind pumps, etc., or as large-scale grid interactive system such as large-scale wind or micro-hydro system. There are two completely different sectors: one which is connected to grid and the other which is completely off-grid, remote and stand-alone small system. The small scale stand-alone solar home systems have been used for meeting the minimum lighting demand of the rural remote dispersed community for a period of three to four hours in a day. However, these systems are limited to household lighting application only and were not able to cater to productive activity requirement. There is also very little scope to further optimize the system.

In 1990s, several renewable energy based mini-grid systems [solar Photovoltaic (PV) based mini-grid, biomass gasifier based, micro-hydro based etc.] have been installed. These mini grids are typically of 10-150 kW and spread over two to three kilometres to provide power through low-tension distribution lines. Here, availability of power in villages helps to improve the quality of life of the rural people through lighting of rural homes, streets, community areas, and public places and trigger economic development and generate employment.

In a mini-grid system, from a user's perspective it has all the features of grid power supply, e.g., overhead Low Tension (LT) lines, service connections, tariff structure, etc., that brings it close to the conventional power supply system. An appropriately designed mini-grid can easily supply power for 8-10 hrs daily. Though there is no limit on the capacity of the mini-grid, these are typically in the range of 25-100 kWp. The installation and operation and maintenance (O&M) of these mini-grids are normally contracted on a turnkey basis to the technology supplier. At the local level, the village community is expected to play a critical role in facilitating payment collection, monitoring of theft, complaint redress, etc.

A Mini-grid with more than one renewable energy resource was used in the late 1990s to deliver more quantum of electricity at a cost-effective manner as compared to single resource based mini-grid. The combination also provides better demand side management.

Till recently, although multiple renewable energy resources are connected in a mini-grid, they are not hybridized in true sense and not optimally designed and managed. For example: the solar/ wind hybrid system generally implemented in the country are used to charge the same battery and subsequently the power is supplied only through the inverter. In such case, whenever solar and wind is available they are used to charge the battery only. There is no mechanism to optimally use the resources and load. While such system involves all the capital cost of the renewable power, it does not give maximum reliability. Hence there is a need for analysing and strategizing the existing technological configuration and re-examine what role technology advancement can play in sustaining the renewable energy based mini-grids.

DG based mini-grid in india-technology and recent development

Distributed generation options can be classified either on the basis of the prime movers used – engines, turbines, fuel cells or based on the fuel resources used, such as renewable and non-renewable. In India, many renewable energy technologies are being employed in a number of distributed generation projects. The technologies include biomass gassifier, solar photovoltaic and solar thermal systems, small wind turbines (aero-generators) and small hydro-power plants. Figure 2 illustrates the technology options for distributed power generation.

In India, the DG based options (both renewable and non-renewable) are mainly operate in two modes off grid – for electrification of remote

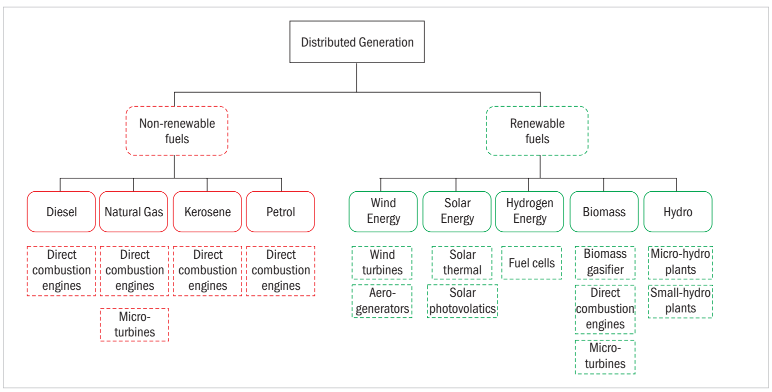

Figure 1 Technology options for distributed power generation

villages or supply captive power to industries, commercial institutions and apartments and grid connected— to augment the electricity supply. The following sections give a brief description about different DG based technologies that are being used in various mini-grids in India.

Small capacity solar photovoltaic based mini-grids

In villages where households are not very spread out, power plants or mini-grids are a preferred configuration as they have the option of supplying AC electricity that can be used for various domestic and commercial applications. They use state-of-the-art batteries and inverters to ensure long life and reliable field performance. The typical size of the SPV based mini-grids in India is of 10-200 kW and is spread within two-three kilometres radius. It supplies power for four to six hours every day through a low tension distribution network. The installation, operation and mainten ance of these mini-grids are normally contracted on a turnkey basis to the PV supplier. At the local level, the village community is expected to play a critical role in facilitating payment collection, monitoring theft, complaint redress, etc.

Biomass gasifier based mini-grids

There are two most common technologies for conversion of biomass energy into electricity form:

- **Direct combustion mode:** In this process the biomass is combusted in a boiler to produce steam and then steam is used in turbine to generate electricity. This type of technology is economically feasible in multi-MW capacities. Large quantity of water is also required for this type of technology.
- **Biomass gasification:** In this process biomass is converted into a combustible gas through thermo-chemical process. This gas after cooling and cleaning is fed into IC engine to generate electricity. This type of technology is generally suitable from a few kW to 500 kW capacities. Biomass gassifier power plants are of two types:
  - **Dual fuel engine based:** In this case, produce r gas is used in diesel engine under dual fuel mode (i.e. fuel-mix is a mixture of diesel and producer gas), resulting in upto 80 per cent replacement of diesel by producer gas.
  - **100 per cent producer gas engine based:** Recently, focus has shifted to developing biomass power plants, which do not consume diesel for operation and operate solely on producer gas. In such system, spark-ignited engines (natural gas or modified diesel engine) are used.

The typical size of the biomass gassifier based mini-grids in India is in the range of 10kW to 500kW.

Micro-hydel/Small hydro based mini-grids

Micro-hydel systems generate power by converting energy in water flowing down a gradient into electrical energy. To generate electricity, water from a natural stream flowing down a gradient is tapped at a convenient higher elevation, passed through a water conducting system and then let into a turbine installed at a lower elevation. The turbine drives an electrical generator producing electricity.The typical size of the micro-hydel system in India is in the range of 5kW to 10 MW.

Wind/ PV hybrid power based mini-grids

In order to maximize the benefits of the complementary nature of solar and wind resources, and to optimize the cost of systems, hybrid is a viable option. The combined capacities of the wind generator and solar module are able to generate the required energy at costs lower than that of solar PV alone. Hybrids have the advantage of supplying energy for longer duration as batteries are constantly receiving charge both from the wind and from the sun. The typical size of the wind generator used in the hybrid system in India depends upon the location/ region and is in the range of 3 kW to 2 MW.

Role of smart technology in mini-grids

The two case studies that follow describe how the advancement in technology in terms of smart techniques and system and its innovative applications meet the energy requirement as per the local need.

Case study A: Effect of technology up gradation for solar based mini-grids to cater the energy need in the rural and remote locations

Currently, mini-grid dissemination in India is largely limited to donor and grant driven initiatives. In spite of huge potential of implementing such projects, private developers are unwilling to invest in mini-grid systems in such rural locations, because of two key reasons:

a. Private developers see lots of risk involved in getting the revenue back from such system and the risk factor is much more if the system operates unreliably owing to non-optimized designs and reduced performance due to uncertain resource availability and climatic conditions.
b. They feel that all mini-grids will be redundant when the grid is extended to the site and thus leading to a loss for their business as users shift to less expensive grid electricity.

If we see the dominant design for solar photovoltaic systems in India today (Figure 1) it normally follows a series configuration, leading to the constant presence of the battery in the system loop. Since the battery is the weakest link in the system (with the shortest life and potential to

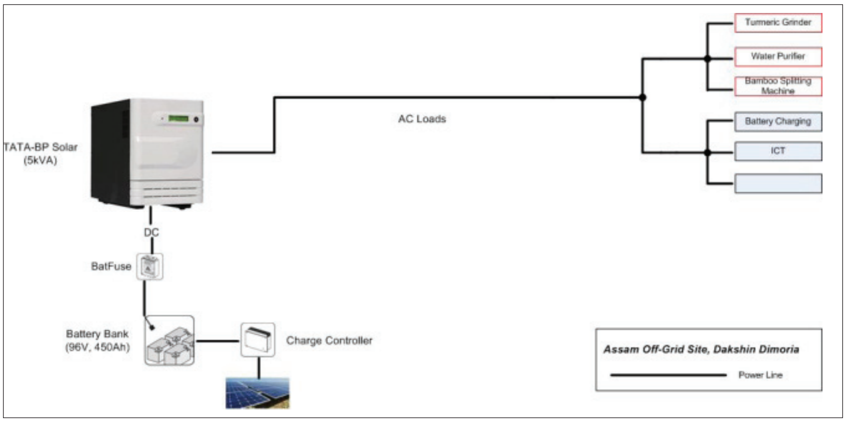

Figure 2 Dominant design for solar photovoltaic systems in India today

deep-discharge during rainy/cloudy months), such a system configuration often leads to shut down of the entire system.TERI's own experience and other observations from the field show that with such system design, if the battery is in bad condition (low voltage owing to deep-discharge), it is likely that the entire system is also non-functional even on sunny days.

Since the battery is always in the loop, the overall efficiency of such system is also not optimal (considering maximum watt hour efficiency of battery). Additionally, such designs often do not incorporate inverters that can easily feed electricity back into the grid, or integrate with other sources of energy, leaving it very inflexible for adapting future requirement.

Lessons learned from such inflexible system design

a. Mini-grids need a bigger battery bank. This implies high replacement and maintenance cost.
b. Since these systems are not grid compatible, most components of the current system become redundant and have to be discarded and replaced with new components that are grid-compatible This significantly adds to life-cycle cost besides making the system highly unreliable due to the presence of a weak link (the battery) between the source and the load.
c. Downtime of such system is quite high-forcing less services and income for the operator and users and high risk for investment for the developer.

The experiences clearly indicates that clean energy systems in rural and remote locations need to be designed taking into account that access to frequent service, repair, and maintenance is difficult, that is, the system should be reliable. Also, since the capital cost of clean energy systems is high, it is imperative that the efficiency of such systems is optimized so that cost per unit of electricity generated is optimum. Lastly, the system should have a significant level of flexibility such that both the grid (when it is eventually extended to an off-grid site) and other sources of energy can be coupled with the existing system as and when required. Therefore, the option to easily connect to the grid and earn revenue from sale of electricity must exist.

The above requirement can be met not through huge investment in capital cost but mainly through proper planning, optimum design and reconfiguration of the system. The incremental cost involved here can be easily repaid through the kind of efficiency, reliability, and flexibility such system offers in long run.

Proper planning involves categorization of load (day load, night load) with load profile, type of load, how critical the load is (such as vaccine refrigerators) and so on. Although such planning does not involve any cost, it helps optimally designing and sizing the energy storage/battery system. An optimal design leads to reduction in capital cost as well as replacement and maintenance cost, while significantly improving system performance.

Again, changing the configuration (moving from series to parallel configuration), adds more flexibility and probability of supply of power, even in poor weather and local operational conditions.

One of the probable designs used in few TERI's pilot sites, implemented under Norwegian Framework

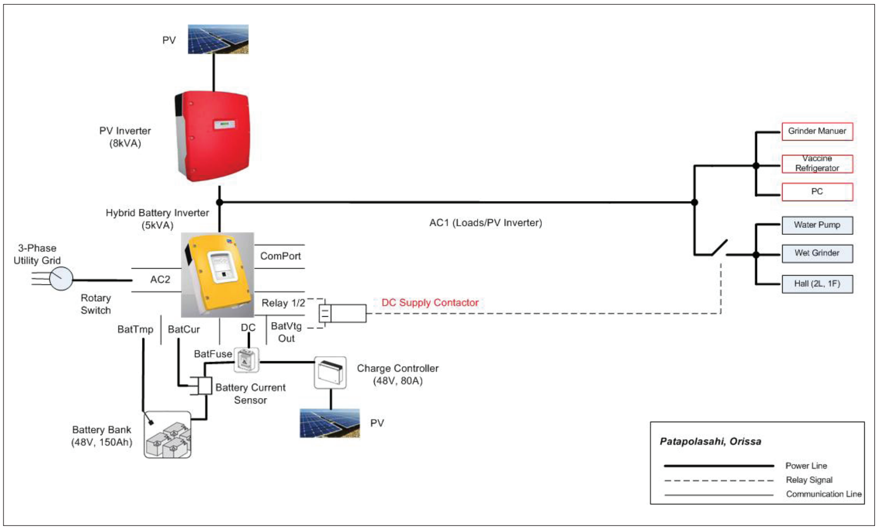

Figure 3 Typical parallel configuration with solar PV system

Agreement is shown in Figure 2. Here the design is such that it splits the inverter into two (as per the requirement of the load) and includes a few smart and advanced techniques to allow these inverters to manage the load as per the resource availability through coordinated control. Such inverters are selected in a way that grid integration and integration of additional renewable energy sources at a later stage are feasible. In addition to this, these inverters are made with remote monitoring features through which daily output and utilization data can be recorded remotely. Such data is especially useful for planning of future systems in areas where cloudy and rainy weather conditions are prevalent for long periods of time.

Although such systems involve some additional cost, in this case, more than the cost, it is the way the system is selected, designed and configured that improves the overall system performance. And field experiences show that whatever additional cost is involved, it is adjusted in the cost which would have been invested for local monitoring, manual intervention for managing the fluctuating load, larger battery size and thus cable size, bigger construction and other associated cost.

So, this is basically a choice between relative high capital cost but substantial low life cycle cost *vs* relatively low capital cost but substantial high lifecycle cost.

Case study B: Smart Mini-Grids(SMG)—Innovative, intelligent solutions for urban, peri-urban sectors

Given India's current power scenario, with the demand far outpacing supply, several power stations of very high capacity need to be installed in order to meet the exponentially growing and projected energy requirements. By their very nature, these large scale power plants are centralized, that is, the power is generated centrally and distributed far and wide. A significant amount of power, given the existing average transmission and distribution losses of around 30 per cent, would be lost before delivering at the required sites, thereby also reducing the overall efficiency of the electrical system. Even if the resources for such power plants—in terms of financial, fuel, and real estate—suddenly became available (current headlines would beg to differ), the centralized power option is not feasible from many cases in India. Most of the cities and towns face black-outs and brown-outs throughout the year, especially in summers. The campuses and condominiums have to depend on captive DG set based power generation, which apart from being expensive, is polluting as well. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a 'Micro-grid'. During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the Micro-grid's load from the disturbance without harming the transmission grid's integrity.

Recent failures of the northern grid and multiple grids also suggest that the focus should be on smarter local grid or smart mini-grids. Hence, while waiting for the overall power situation to stabilize and provide sustained electricity access, it is prudent to explore other viable options for obtaining cost-effective, clean, green, and most importantly, reliable electricity. One of the major challenges of micro-grid protection system is that it must respond to both island and grid connected faults [17]. And Islanding is the major challenge in micro/mini-gird; it is a small-scale representation of the future interconnected grid with a high density of distributed generations. The micro-grid provides a benchmark between island and the interconnected grid. It can be used in the large interconnected grid with the high penetration of distributed generation. The islanding control strategies are very important for the operation of a micro-grid in autonomous mode.

In order to hasten the deployment of the Smart Grid initiatives in the country, the Government of India (GoI) created the India Smart Grid Task Force (ISGTF) and the India Smart Grid Forum (ISGF), and the pilot projects announced in 2012 are positive steps in this direction. The ISGF is divided into several working groups (WGs) focused on specific areas and one of working groups i.e., WG: 9 on 'Renewables and Micro-Grids' are responsible to develop an architecture and methodology for micro-grids both 'offgrid' and 'grid connected' so that the same can be isolated from the grid and also develop set of standards, guidelines and technology recommendations for integration and efficient operation of renewable sources into the grid; and recommend suitable grid codes.

Campuses and complexes generating and distributing their own power through distributed generation and renewable energy (RE) resources—in essence through personalized mini grids—are therefore a more dependable, feasible, controllable, practical, and greener solution. Furthermore, these mini grids are easily set up to seamlessly interface with the existing utility grid. (Officially, a mini-grid is defined as an electricity distribution network operating at below 11 kV levels, which is sometimes connected to the wider utility grid.)

A mini-grid system can be operated through a combination of multiple energy resources, both renewable such as solar, wind and biomass, and conventional such as diesel. However, the intermittent nature of these renewable generators does not always provide the flexibility of utilizing the power as per the requirement of the industry or community. This means that periods of high renewable energy generation might not coincide with high demand, and similarly in the case of non-availability of renewable. This will result in an undesired mismatch between resources and loads (usage), loss of extra power when available, and requirement of expensive conventional power sources during other times.

Hence, for a urban, peri urban segment, where the requirement of availability of reliable, quality power over cost is more important, the more appropriate solution is a Smart Mini-Grid (SMG) system which can optimally, and intelligently manage the load (usage) and distributed generation resources. A SMG system thus utilizes digital information technology to intelligently balance multiple and varied energy supply resources against the dynamically varying and complex loads of the system. The SMG communicates within itself and with external networks, seamlessly resolving problems and delivering uninterrupted energy service. In addition, an SMG not only increases the overall efficiency, but also helps improve the overall power quality of the system.

SMG controlled distributed energy sources can then be added to increment generation capacity, whenever and wherever required. These systems can not only deliver power to the local areas (such as campuses, complexes, etc.) more efficiently and reliably, but can also feed excess power into the utility grid.

Institutions, campuses, localities applying an SMG for secure power availability can ensure the maximum utilization of renewable energy (RE) resources through careful coordination between energy demands and the electricity production. This enables a relatively lower installed RE capacity—and in conjunction possibly decreased battery sizes—which result in reduced upfront capital costs. The SMG system also helps minimize the use of any fossil fuel based generation by an intelligent management of loads through smart controls and techniques. This allows for reduced ongoing operating costs while simultaneously improving power quality, efficiency, and flexibility of the overall system.

SMGs are applicable not only for remote or rural applications, but are powerful solutions for the reliable energy requirements of campuses such as office complexes, factories, residences, hospitals, hospitality institutions, shopping complexes, and even suburban neighbourhoods.

Essential features of smart mini-grids

- Intelligent load and energy resource management through smart controllers and advanced control techniques.
- Accommodation of multiple Distributed Energy Resources and Energy Storage into the common grid.
- Self-healing,self-configuring, plug and play (the grid has the ability to rapidly detect, analyse, respond and restore itself from any disturbances.)

Benefits of smart mini-grids

- Foster Demand Side Management and Demand Side Response.
- Reduce power outages: Increase reliability, efficiency and safety of the grid.
- Reduce carbon footprint, minimize fossil fuel consumption.
- Provide better autonomy to customers to govern their electricity needs.

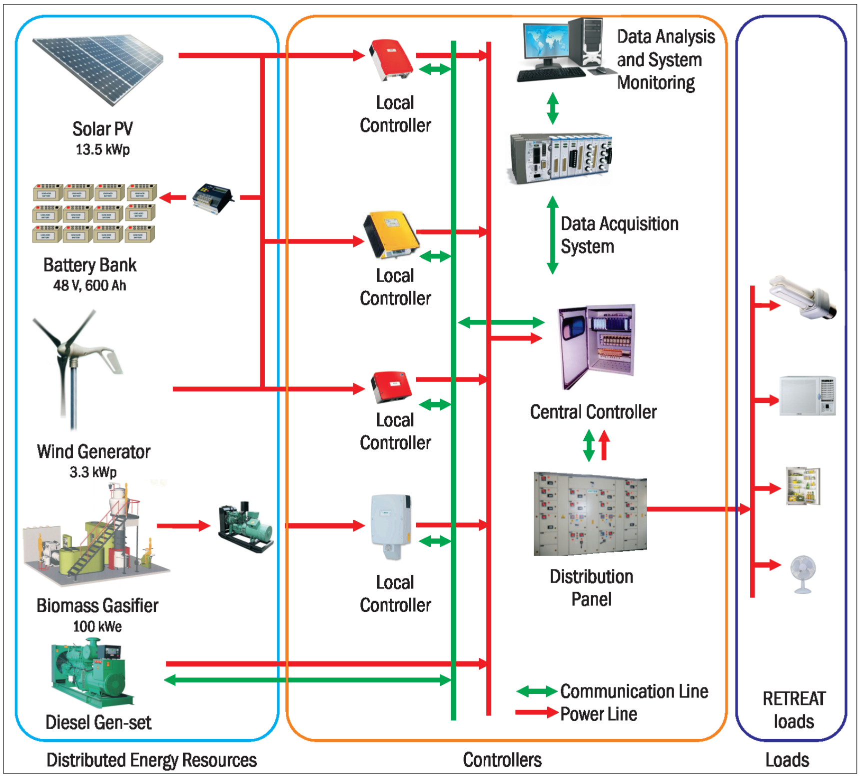

Figure 4 Schematic diagram of the SMG at TERI

TERI's smart mini-grid

A one of its kind SMG was setup at TERI's campus at Gual Pahari, Gurgaon in 2011. The unique features of the SMG system at TERI include:

- Optimum renewable energy utilization, i.e., solar, wind, and biomass at different operating conditions to serve the required energy service.
- Improved efficiency flexibility and ensuring supply of reliable good, quality power and of the system through incorporation of smart, intelligent tools and techniques, allowing for automatic adding or removing of the loads and resources based on their availability and set priorities.

The following energy resources are available at the facility:

- 12.5kW solar PV system (crystalline solar module) system
- 2kW Solar PV system (crystalline solar module)
- 1kW thin-film solar PV system
- 3.3kW wind electric generator
- 10 kW/100kW biomass gasifier system
- 600Ah, 48V storage battery
- Diesel generator backup

Development of dispatch controller and SCADA system for SMG

The heart and main brain behind Smart Mini Grid system at TERI is the Smart Controller which has been developed using Compact-RIO[20]

Unique features of TERI's smart mini-grid system

- Integration of multiple (Distributed Energy Resources) DERs, ensuring maximum utilization of renewable energy sources.
- Resource and load profiling, controlling and forecasting; Centralized control (Intelligent Smart Dispatch Controller) for resource optimization and demand management.
- Load prioritization (total loads have been classified into critical, essential and non-essential loads).
- Integrated, high-speed, Field Programmable Gate Array (FPGA) based digital communication using NI LabVIEW[19] (a software platform for acquiring data, sending and receiving controls) platform;
- Real-time data acquisition and monitoring of several electrical, weather and physical parameters through installed sensors;
- Minimized outages and fast response to network disturbances through automatic connect/disconnect of system components.

provided by National Instruments. NI Compact-RIO 9022 is used along with required C-Series modules from National Instruments. NI Compact-RIO 9022 has the following features:

- Embedded controller runs LabVIEW Real-time for deterministic control, data logging and analysis;
- 533 MHz Processor, 2 GB non-volatile storage and 256 MB DDR2 memory;
- Dual Ethernet ports with embedded Web and file servers for remote user interfacing;
- Hi-Speed USB host port for connection to USB flash and memory devices;
- RS232 Serial port for connection to peripherals, dual 9 to 35 VDC supply inputs;
- -20 °C to 55 °C operating temperature range.

A third-party GSM/GPRS C-Series module, i.e., SA 1802 is used as a communication medium that enables communication between NI Compact-RIO and the SCADA System (Figure 4). The data collected from the various data nodes are transmitted via Ethernet using Modbus Protocol and GSM modem using TCP/IP.

National Instruments LabVIEW Developer Suite including DSC and RT-FPGA modules have been used to develop the dashboard for Smart Mini-Grid system in which all the real-time information such as: electrical and weather parameters, daily energy consumption, etc. will be provided. The dashboard of Smart Mini-Grid system (Figure 5) is used to communicate with SMG SCADA system using Ethernet (Mod-bus Protocol).

Such smart, reliable systems can be set up at any campus or facility and will go a long way in decreasing reliance on the main grid while increasing the consumption of cheaply and locally generated renewable energy. Through the implementation of SMG technology, communities and complexes will be empowered to better manage and utilize their energy resources while also decreasing costs across the board. Many such SMGs setup across the country will eventually lead to the grounds-up smartening of the main grid while simultaneously reducing the need for larger, expensive, and environmentally damaging centralized power plants.

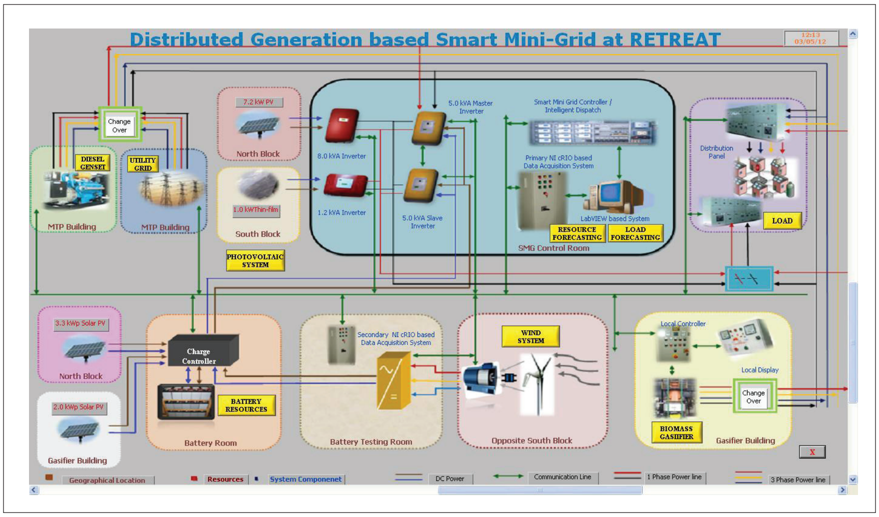

Figure 5 SCADA system of Smart Mini Grid (SMG)

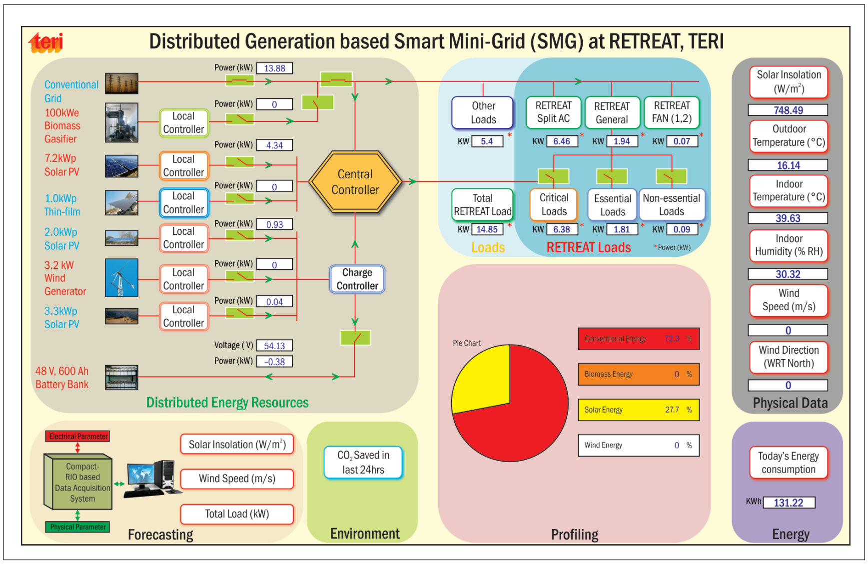

Figure 6 Real Time Data Acquisition Dashboard for SMG

Conclusion and way forward

The possible steps for pr omoting mini-grids for different sectors such as rural setup and urban and peri-urban setup are given in the following section.

For the mini-grids at rural setup

- Although earlier designs are economically more feasible but the analysis of Cost *vs* Reliability should be done with futuristic vision of supplementing the mini-grids with main grid and the project cost should not be decided only on the basis of minimum performance of the system. Therefore, there is a need to look at the scope for re-designing and re-configuring the system.

- There is also a need of developing Standard Operating Procedures for proper installation, operation and maintenance of the mini-grid system.
- Training, awareness generation workshop on application of new technology and techniques, exchange and exposure visits, etc., are very much required to implement the appropriate, new generation, yet cost-effective technology.
- R&D focus should not only be on hard-core component level research but also on applied research on system integration, re-engineering and so on.

For the mini-grid at urban and peri-urban setup:

- Large scale implementation of such SMG systems in the country can be well integrated with the existing programs of Ministry of New and Renewable Energy (MNRE) such as Jawaharlal Nehru National Solar Mission (JNNSM) as well as the National Rural Electrification programme.
- SMGs are evolving as enabling technologies for future dynamic energy needs. Hence, they need the support of a conducive policy and regulatory regime for the concept to flourish and the market to develop. Since SMGs encompass lots of advantage in terms of its multi-sectoral benefits, currently the focus should be to implement projects with these innovative technologies, develop the sustainable business model along with cost benefit analysis.
- There is a need of finalizing the guidelines and best practices for integrating renewable energy based mini-grid system into the main conventional grid.
- There is also a need of a consistent, long-term policy to encourage open access, incentive to allow the use of advanced technologies that increase capacity, improve efficiency and reliability. Also mechanisms such as pilot demonstrations need to be created to bring together numerous industries, including power, information and communication technology, manufacturing, government, etc., towards advancing this agenda, creating a roadmap for successful implementation of smart grids.

References

Planning Commission Five Year Plans, http://planningcommission.nic.in/plans/planrel/fiveyr/welcome.html, 28th March 2013.

Kumar, A., Kumar, K., Kaushik, N., Sharma, S., and Mishra, S. *Renewable energy in India: Current status and future Potentials*. Renewable and Sustainable Energy Reviews, 14(8), 2010,pp 2434-2442.

Thirumurthy, N., Harrington, L., Martin, D., Thomas, L., Takpa, J., and Gergan, R. *Opportunities and Challenges for Solar Minigrid Development in Rural India* (No. NREL/TP-7A20-55562). National Renewable Energy Laboratory (NREL), Golden, CO., 2012

R.B. Hiremath, Bimlesh Kumar, P. Balachandra, N.H. Ravindranath, B.N. Raghunandan. *Decentralised renewable energy: Scope, relevance and applications in the Indian context*. Energy for Sustainable Development, Volume 13, Issue 1, March 2009, pp 4-10.

Kazem, H. A., Khatib, T., & Sopian, K. Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman. Energy and Buildings, Vol 61, June 2013, pp 108–115.

Thirumurthy, N., Harrington, L., Martin, D., Thomas, L., Takpa, J., & Gergan, R. Opportunities and Challenges for Solar Minigrid Development in Rural India (No. NREL/TP-7A20-55562). National Renewable Energy Laboratory (NREL), Golden, CO., 2012.

Ismail, O. S., Ajide, O. O., &Akingbesote, F. Performance Assessment of Installed Solar PV System: A Case Study of Oke-Agunla in Nigeria. Engineering, 4(8), 2012.

Palit, D., Sovacool, B. K., Cooper, C., Zoppo, D., Eidsness, J., Crafton, M. & Clarke, S. The trials and tribulations of the Village Energy Security Programme (VESP) in India. Energy Policy, Vol 57, June 2013, pp 407–417

Narula, K., Nagai, Y., & Pachauri, S. The role of Decentralized Distributed Generation in achieving universal rural electrification in South Asia by 2030, 2012, Energy Policy.

Lidula, N. W. A., & Rajapakse, A. D. Microgrids research: A review of experimental microgrids and test systems. Renewable and Sustainable Energy Reviews, 15(1), 2011, pp 186-202.

Technical report on " Mini-grids- scope and definition" under the project " Accelerating the deployment of Smart Mini-grids in APP country" , 2011, CSIRO, Australia

J.L Monaco," The Role of Distributed Generation in the critical power infrastructure"-IEEE power engineering society summer meeting, vol 1, 2001, pp 144-145,

"Study on Improved Rural Electricity Services through Renewable Energy based Distributed Generation and Supply - Comprehensive Review of Experiences of Distributed Generation projects in India" prepared by TERI for the World Bank, 2011, New Delhi

Rural Electrification Programme with Solar Energy in Remote Region – A Case study in an Island by Snigdha Chakrabarti, Subhendu Chakrabarti, Econimic Research Unit Indian Statistical institute, Published in Energy Policy, 2002, Vol. 30/1, pp 33-42 of Elsevier Science,

Sustainable biomass power for rural India: Case study of biomass gasifier for village electrification, by N. H. Ravindranath, H. I. Somashekar, S. Dasappa, C. N. Jayasheela Reddy, Current Science, Vol. 87, No. 7, 10th Oct. 2004.

Robert H. Lasseter, PAOLO PIAGI ,Microgrid: A Conceptual Solution, PESC'04 Aachen, Germany 20-25 June 2004

Md Razibul Islam, Hossam A. Gabbar ,"Study of Micro Grid Safety & Protection Strategies with Control System Infrastructures ",Smart Grid and Renewable Energy, 2012, Vol 3, No 1, pp 1-9, Feb 2012

"Microgrids_The_BRICS_Opportunity_July_2012_Smart_Grid_Insights_Zpryme_Research(http://smartgridresearch.org/wp content/uploads/sgi_reports" accessed on March 1 ,2013

National Instrument – LabVIEW software (http://www.ni.com/labview) accessed on March 3 ,2013

National Instrument–Rugged and Reconfigurable Control and Monitoring System (http://www.ni.com/compactrio/) accessed on March 3 ,2013

National Instrument–field program gated array(FPGA),(http://www.ni.com/labview/fpga/) accessed on March 3 ,2013

MNRE-JNNSM (http://www.mnre.gov.in/file-manager/UserFiles/mission_document_JNNSM.pdf) accessed on March 3 ,2013

H.-M. Kim, T. Kinoshita, Y. Lim, "Talmudic Approach to Load Shedding of Islanded Microgrid Operation Based on Multi agent System," Journal of Electrical Engineering & Technology, Vol.6, No.2, 2011, pp.284-292,

A. Misra, H. Schulzrinne, "Policy-driven distributed and collaborative demand response in multi-domain commercial buildings," Proceedings of the 1st International Conference on Energy-Efficient Computing and Networking (e-Energy '10), 2010, pp.119-122.

R.H. Lassseter, "Smart Distribution: Coupled Microgrids," Proceedings of the IEEE, Vol.99, Issue 6, June 2011, pp. 1074-1082.

F. Katiraei, M. R. Iravani, "Power management strategies for a microgrid with multiple distributed generation units," IEEE Transactions on Power Systems, Vol. 21, Issue 4, Nov. 2006, pp. 1821-1831.

N. Hatziargyriou, H. Asano, R. Iravani, C. Marnay, "Microgrids: an overview of ongoing research development and demonstration projects," IEEE Power & Energy, 2007. Available: (http://eetd.lbl.gov/ea/emp/reports/62937.pdf) accessed on Feb 22 ,2013

C. K. Sao and P.W. Lehn, "Control and power management of converter fed microgrids," IEEE Transactions on Power Systems, vol. 23, no. 3, 2008, pp. 1088–1098,.

A. Dimeas and N.D Hatziargyriou, "Operation of a multiagent system for microgrid control", IEEE transaction on power systems, Vol. 20, No. 3, August 2005. pp. 1447-1455.

Chowdhury, A.A.; Agarwal, S.K.; Koval, D.O., "Reliability modeling of distributed generation in conventional distribution systems planning and analysis," Industry Applications, IEEE Transactions on , vol.39, no.5, Sept.-Oct. 2003 pp. 1493-1498,.

H. Falaghi; M.-R. Haghifam, "Distributed Generation Impacts on Electric Distribution Systems Reliability: Sensitivity Analysis," Computer as a Tool, 2005. EUROCON 2005.The International Conference on, vol.2, no.4, 2005pp.1465-1468,.

Borges, C.L.T.; Falcao, D.M., "Impact of distributed generation allocation and sizing on reliability, losses and voltage profile," Power Tech Conference Proceedings 2003, IEEE Bologna, vol.2no 6, 2003, pp. 5.

McDermott, T.E.; Dugan, R.C., "Distributed generation impact on reliability and power quality indices," Rural Electric Power Conference 2002. IEEE , vol.23, no.5, pp.D3-D3_7, 2002