Smart Integrated Renewable Energy Systems (SIRES) for Rural Communities

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Abstract: **More than one billion people are living in energy-deprived rural areas of the world with little or no access to basic energy and other needs. In this work, a Smart Integrated Renewable Energy System, or in short "SIRES", is proposed to "energize" the rural areas and not just "electrify" them. It is a viable and effective strategy to provide basic needs such as biogas for cooking, water for domestic and irrigation purposes and electrical energy for lighting, communication, cold storage, educational and small- scale industrial purposes, by smartly matching them to available resources. It will promote sustainable socio economic development and improve the living environment by fulfilling the fundamental energy requirements with the help of low cost renewable technologies and intelligent energy management systems.**

***Index Terms*—Energization; Energy Management; Integrated Renewable Energy Systems; Rural communities.**

I. Introduction

Majority of our energy requirements at present are met by fossil fuels, which are depleting and are also in need for various other purposes. Rapid depletion of fossil fuels and the ever-increasing need for energy is opening up new opportunities for alternative energy sources to supply energy in a sustainable manner. Moreover global environmental concerns such as climate change and high levels of CO_2, coupled with steady progress in renewable energy technologies has increased interest in the use of renewable energy. Significant cost reductions in the past few decades have made a number of renewable energy options competitive with fossil fuels for various applications.

For overall development of rural areas, it is important to provide energy for three main categories of needs [1]:

1. Energy required to improve the basic living environment
2. Energy required to make progress in agriculture production and increase field fertility
3. Energy needed to set up small-scale industries and hence expand job opportunities in the rural areas.

All the above types of catergories should be fulfilled in order to improve the social and economic standards of the rural sector. Table 1 gives the percentage of population living in rural areas that are deprived of basic energy needs [8-10].

There is a lack of fossil fuels in developing countries for rural electrification and funds for the development of these areas are limited. However, importing the needed resources will make the situation financially very untenable. Supplying electricity from a central grid is also inefficient and unfeasible because these areas are isolated with low load factors and that leads to high transmission and distribution costs [2]. The difficult terrain in many rural regions also increases expansion costs significantly. Mountainous or forest areas, for instance will be difficult to access for machinery, require more time and resources to install transmission lines [3].

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TABLE 1. PERCENTAGE OF ENERGY DEPRIVED RURAL AREAS [8-10]

Basic Needs	Population without access (in world)	Percentage living in rural areas
Safe water	750 million	90%
Proper stove for cooking	2.5 billion	85%
Electricity	1.3 billion	85%

Although electricity came into vogue in the late 19^{th} century, a major challenge the world still faces is providing electricity and other basic needs to more than one billion people living in isolated rural areas around the world, where fuel delivery and grid extension are not cost effective options [4]. Table 2 gives an estimate of the grid extension cost in certain selected countries in $ per kilometer.

TABLE 2. COSTS OF GRID EXTENSION IN SELECTED COUNTRIES ($/KM) [3]

Country	Labor & other costs	Materials	Total
Bangladesh	$ 350	$ 6,340	$ 6,690
Laos	$ 1,420	$ 7,230	$ 8,650
El Salvador	$ 2,090	$ 6,160	$ 8,250
Kenya	$ 6,590	$ 5,960	$12,550
Senegal	$ 5,150	$10,810	$15,960
Mali	$ 2,590	$15,170	$19,070

The fact that developing countries are "developing" generally implies that development takes place primarily in urban areas, whereas rural areas continue to be highly under-developed. Development in the urban areas takes place on social, political and economic grounds whereas development in rural areas is neglected and overlooked. People living in rural area are caught in an agonizing race between demography and development [5]. The increasing yearn for better standard of living along with extremely slow growth of opportunities in rural areas have forced a rapid and massive rural-to-urban migration, resulting in an explosive growth and expanding slum areas around large cities. Hence, steps must be taken to improve the basic living environment and meet the energy and other necessities of the rural areas as a top priority [7].

Approaches for rural developments are discussed in section II. In section III, components of SIRES and a schematic diagram with its components is illustrated. In section IV, the three stages of implementation: initial analysis, planning and implementation are presented. In section V, summary and concluding are succinctly presented.

II. Approaches to Rural Development

Renewable energy sources such as insolation, wind and falling water are abundantly available in rural areas. Also it is a known fact that majority of rural population depends on agriculture and hence uses traditional biomass resources extensively. Another added advantage of rural areas is open spaces that can be utilized to set up renewable energy systems. Hence integrating all these resources in a smart and effective manner will fulfill the needs of rural areas. As an approach to use renewables resources for the development of rural areas, several methods have been designed and implemented. Table 3 gives a comparison of various approaches introduced in the past in chronological order.

A. Rural Electrification

Extension of grid, commonly known as rural electrification, is the earliest solution to electrify rural areas. A major drawback of this solution is lack of generation capacity due to unavailability of fossil fuels and other conventional resources. It is an infeasible and ineffective option because of the high cost of grid extension as discussed earlier.

B. Microgrids

According to US department of energy, microgrids are a group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that act as a single controllable entity with respect to grid [and can] connect and disconnect from the grid to enable it to operate in both grid-connected or islanded mode. For the development of rural areas, several microgrids have been installed with ratings ranging from as little as 1 kW to as large as a few hundred kilowatts. Microgrids can either be AC or DC. These microgrids fulfill a range of needs from lighting, communication to commercial purposes. Seven such cases installed in India, Malaysia and Haiti have been studied in depth in reference [11]. These case studies include microgrids which are powered by resources such as PV, micro-hydro, diesel, and biomass to provide electricity to communities with population less than 500.

C. Integrated Renewable Energy Systems (IRES)

Four decades ago, a concept called Integrated Renewable Energy System (IRES) was introduced [4]. IRES can be described as a system that harnesses two or more forms of locally available renewable energy resources to supply a variety of energy and other needs of a remote area in a most efficient, cost effective and practical way, with the ultimate goal of amalgamating the benefits at the user end. The fundamental requirement of IRES is to match various forms of resources to the needs of an isolated area in an efficient and economical manner [7].

IRES is a stand-alone system that makes remote rural areas self-sufficient for basic needs such as cooking, domestic and potable water supply and electricity in a cost effective and efficient manner. The prime distinction of IRES is its focus to “energize” remote rural areas rather than “electrify” as promoted by hybrid systems and microgrids, in order to

Table 3. Comparison of Various Approaches to Rural Developments

Approach to rural development	Purpose	Resources used	Needs Fulfilled	Storage devices	Sensors and controllers
Rural electrification	Extending grid to remote areas with no electricity	Conventional resources	Providing electricity to remote rural areas	---	---
Microgrids	Providing basic electrical access to areas which have little or no access to electricity.	Diesel Biomass PV Wind Small Hydro	Providing electricity for lighting, cell phone charging and few appliances	Batteries Flywheels Energy capacitors	Used occasionally
IEEE Smart Village	Providing basic electrical access and educational services to the rural areas.	Portable PV and Battery kit	Lighting, cell phone charging and basic electrical access	Batteries	Battery Charge controllers
IRES	Providing basic needs and electricity with help of “energization” rather than electrification	Biogas Water Solar Wind	Basic needs such as biogas for cooking, water for domestic and irrigation purpose and electricity.	Pumped hydro Biogas digesters Batteries	---
SIRES	Providing basic needs and electricity with help of “energization” rather than electrification. Also using smart energy management techniques and intelligent control.	Biogas Water Solar Wind	Basic needs such as biogas for cooking, water for domestic and irrigation purpose and electricity. Other needs such as low grade and medium grade heating also fulfilled.	Pumped Hydro Biogas digesters Batteries	Smart sensors used to check resource availability. Intelligent controllers to turn on and off the renewable technologies.

achieve sustainable development and improve the basic living environment of rural masses. [6].

D. IEEE Smart Village

In 2009, Community Solutions Initiative (CSI) was launched to address the situation of rural population who have no access to electricity. A model was developed and demonstrated in Haiti after an earthquake had hit the region. Since then this model was introduced in various African countries which were highly deprived of electricity. CSI's technical model consists of a standardized charging station called SunBlazer. It is a mobile platform with up to 80 portable battery packs (PBKs) and home lighting kits per station. Each kit provides power for lighting up to 2 rooms and operates auxiliary 12V DC loads. Every station can charge 80 battery packs every 3-4 days to provide electricity to about 500 people. With the help of SunBlazer, about 1162 homes (around 7000 people) obtained access to electricity. After successful design, testing and installation of SunBlazer, a new model called SunBlazer II was introduced in 2014. Major improvements obtained were delivery in kit form instead of a complete plug-and-play assembly on a trailer. Other improvements in the new design were lighter weight, simpler and versatile solar panel mounting, better station battery security and lower cost [12].

CSI was rebranded as IEEE Smart Village in November 2014. Its mission is "to empower off-grid communities through education and creation of sustainable, affordable, locally owned entrepreneurial energy businesses". It is being funded by qualified non-government organization (NGO) partners who receive sufficient seed funding to start-up and demonstrate implementation of micro utilities. IEEE Smart village has been serving numerous countries such as Benin, Cameroon, India, Kenya, Malawi, Namibia and so on [13].

E. Smart Integrated Renewable Energy Systems (SIRES)

Smart Integrated Renewable Energy System (SIRES) is an improved and a smarter version of IRES. In SIRES, each system component is optimally sized to minimize cost and maximize the reliability using techniques such as genetic algorithm. Smart sensors will be strategically placed at locations where amount of resources have to be monitored. Sensors will also be placed at locations where the status of system components should be monitored. Intelligent controllers will be used to turn on/off renewable technologies. Data obtained from the sensors can be transmitted through a basic telemetry/cellular network for use in further research and improvement. Intelligent energy management techniques will be later implemented. The basic working of SIRES and its components is discussed in the following section.

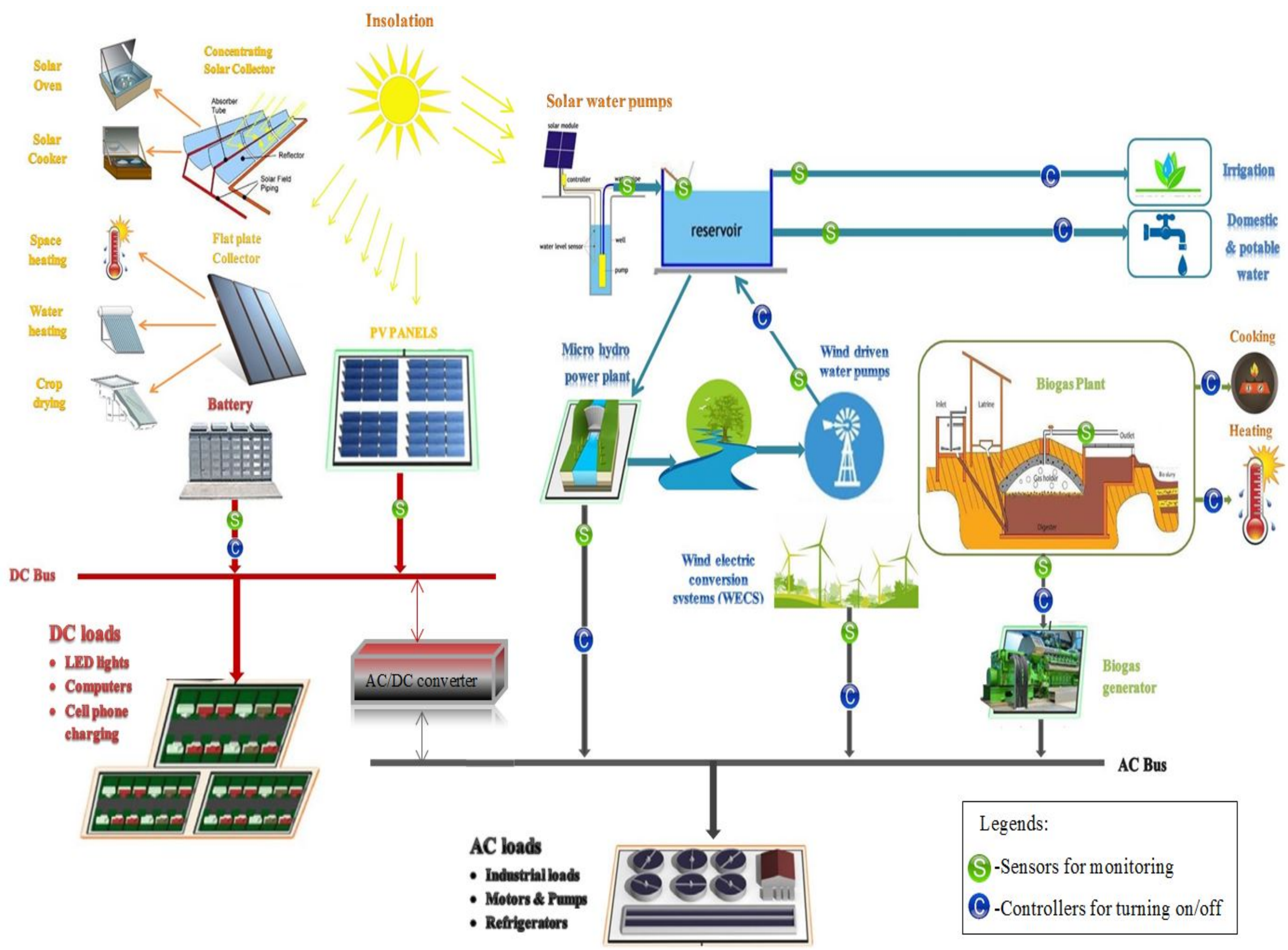

Figure 1. Schematic diagram of SIRES

TABLE 4. COMPARISON OF CURRENT APPROACHES AND SIRES

Needs	Current Approach	Technologies to be used in SIRES
Cooking	• Woodstoves • Biomass • Charcoal	• Biogas obtained from biogas digesters and household digesters • Solar Cooker • Improved cooking stoves
Water (drinking, domestic and community purpose)	• Hand pumps • Wells • Electricity powered pumps	• Wind turbines powered water pumps • PV powered water pumps • Water available in reservoir • Biogas driven water pumps
Lighting (domestic and community including street lighting)	• Oil and kerosene lamps • Unreliable and short duration electricity	• PV cells • Electricity from SIRES with several sources like micro-hydro power, WECS, PV, biogas fueled generator
Small- scale industries, shops, educational institutions, cold storage, hospitals	• Grid based or no electricity • Human and animal power for motive power • Traditional methods	• Electricity from SIRES
Communications (radio, television sets, cell phone chargers)	• Grid based • Battery banks and charging stations in a few places	• Solar home systems • Electricity from SIRES
Low grade heating (space and water heating, crop drying)	• Wood • Charcoal • Animal dung and crop residues	• Flat plate solar collectors • Solar crop dryers • Biogas
Medium grade heating (industrial process heating, crop processing)	• Wood • Biomass	• Concentrated solar collectors • Electricity from SIRES
Water (irrigational purpose)	• Electricity powered water pumps	• Wind turbines powered water pumps • PV powered water pumps
Energy Storage	• Battery	• Biomass and biogas energy storage • Potential energy in form of water • Battery storage

III. WORKING OF SIRES

A. Components of SIRES

The basic tenet of SIRES is to match various forms of energy resources to the needs of an isolated rural area in an efficient and economical manner. SIRES utilizes several renewable energy sources, conversion technologies, and end-use technologies to provide a variety of energy and other needs. It primarily comprises of biogas digesters and stoves, wind-electric conversion systems, wind mechanical conversion systems, PV modules, PV-powered water pumps, micro hydro power plants, elevated water storage tanks, biogas powered generator, biogas powered water pump, batteries, fuel cells, converters and inverters. Fundamental needs of rural areas include potable and domestic water, water for irrigation, medium grade thermal energy for cooking, low-grade heating, and electricity for lighting, communication, cold storage and educational purposes.

System may be connected to a central grid or can be stand-alone. The ultimate goal of SIRES is to integrate the benefits at the user end. One possible schematic of SIRES employing multiple resources and needs at a particular site is shown in Figure 1.

B. What is "smart" about this approach?

Several aspects of SIRES make it smart. Firstly, SIRES maximizes the impact by "energization" as compared to "electrification" which is not efficient and cost-effective for demands such as cooking, water pumping etc. Although electricity can be used for cooking, it is more efficient and cost-effective to use biogas instead. Similarly, it is smart to use wind and solar based pumps to pump and store water in an overhead reservoir for distribution and for energy storage.

Secondly, needs are prioritized based on necessities of daily life. For example, cooking would be on a higher priority when compared to electricity, and water for domestic purpose would be on a higher priority when compared to irrigation water. Resources are matched to needs "a-priori". Third aspect of SIRES that makes it smart is genetic algorithm, which optimizes the operation of system components to minimize annualized cost of system and maximize reliability. Lastly, operation and resiliency are enhanced by using smart sensors and intelligent controllers.

IV. STAGES OF IMPLEMENTATION

SIRES will be implemented in three stages. Initial analysis of resources is performed in Stage 1. Stage 2 comprises of planning. The final implementation will take place in stage 3. Figure 2 shows the stages of implementation with the objectives associated with each stage.

In order to fulfill basic needs of a rural area, it is mandatory to determine the most appropriate and affordable technologies, equipments and facilities. For this purpose, the first stage will be to determine the energy requirements. Resources and energy requirements are site specific. Basic needs, current approaches and technologies to be used in SIRES to fulfill these needs are described in Table 4.

As discussed earlier, the advantage of SIRES is prioritization of needs and resources to fulfill basic requirements of rural area. Hence in the first stage, resources are matched to needs in a smart and efficient manner. The order of priority of needs based on everyday use is decided empirically: cooking, potable and drinking water, electricity, irrigation water. Order of priority of resources can be also decided empirically based on the need.

Stage 2 is the planning stage. The objectives of this stage

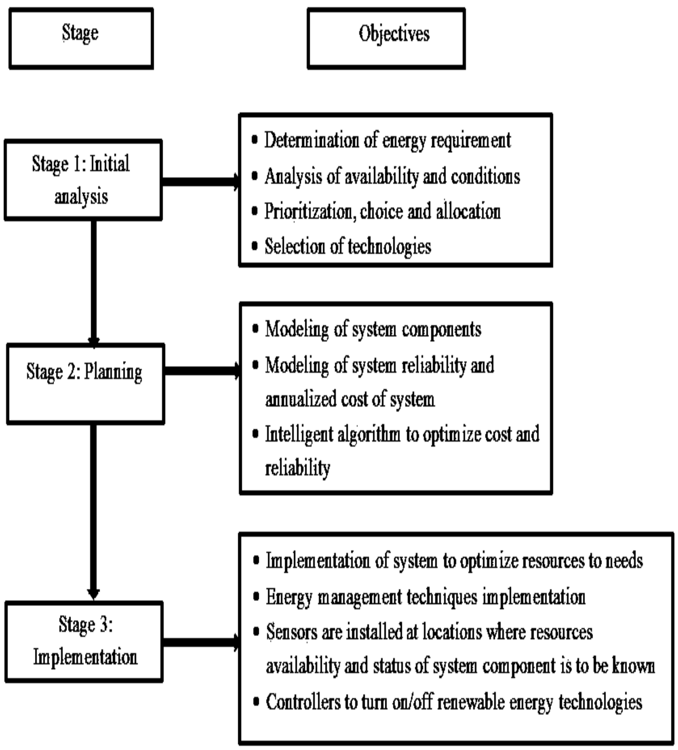

Figure 2. Implementation Stages

are to model system components, system reliability and annualized system of cost. System components such as biogas generator, PV panels, wind turbines, microhydro power plant, PV powered water pumps, wind powered water pumps, biogas powered water pumps and batteries are modeled. Loss of power supply probability (LPSP) and loss of water supply probability (LWSP) are used as measures of reliability. For a considered period, LPSP is the ratio of all the loss of power supply over the total load required during that period. It is defined as the probability that an insufficient power supply results when SIRES is unable to satisfy the load demand. Similarly, LWSP is the ratio of all the loss of water supply over the total water required during that period.

Based on the concept of Annualized Cost of System (ACS), an economical approach is developed for the cost analysis. The annualized cost of system comprises of annualized capital cost, annualized replacement cost and annualized maintenance cost. To optimize the size of system components, genetic algorithm is used to minimize annualized cost of system and reliability is considered as a constraint.

At the end of stage 2, the optimum numbers of system components to fulfill basic needs are found. To validate whether the number of system components found by applying genetic algorithm are sufficient in order for SIRES to work reliably, simulation must be carried out in MATLAB. For the smart operation of SIRES, smart sensors and intelligent controllers must be installed in stage 3. Sensors are installed at locations where the resource availability and status of system component are required. Controllers will be installed at locations where system component must be turned on/off.

V. Concluding Remarks

For the socio-economic development and growth of rural areas, basic needs such as domestic and potable water, cooking and electricity must be provided in a sustainable manner. Renewable energy resources such as biogas, hydro, insolation and wind are locally available in rural areas and can be harnessed in an efficient manner to fulfill these basic requirements in remote rural areas. SIRES is an effective and a viable strategy that can be employed to harness renewable energy resources to “**energize” (**not just electrify) remote rural areas of developing countries. Applying intelligent techniques to implement SIRES for a selected area makes it more advantageous when compared to hybrid energy systems. Introduction of SIRES in rural communities brings about improvements in living environment and community welfare by supplying the basic needs such as biogas for cooking, water for domestic, potable and irrigation purposes and electrical energy for lighting, communication, cold storage, educational and small- scale industrial needs. SIRES is flexible in implementation and is easily adaptable. Its configuration can be modified depending on available resources and needs of the particular rural area under consideration. Along with social and economic improvements in the rural community, implementation of SIRES can provide employment opportunities for the local people.

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