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Micro Smart Grid Model for Indian Rural Society

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ABSTRACT

India is facing acute shortage of electricity especially in rural sector due to shrinking of conventional grid supply. The expansion of grid has become almost standstill due to depletion of raw material i.e., fuel, coal etc., day by day. As a result, the sustainability of power supply to rural houses has become poor. In this paper a Micro Smart Grid Model for Indian rural society has been proposed and developed to overcome such constraints. In the prototype model integration of power grid with micro grid consisting of renewable solar energy sources using 1kW intelligent bidirectional converter has been done to provide a good quality 24 x7 power supply to rural houses with grid power saving up to 50% or more. Sensitivity analysis on load profile on a prototype module has been done. Impact study on generation of self employment through vocational literacy classes among potential youth in rural society has been carried out with encouraging result.

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INTRODUCTION

The supply from conventional grid is shrinking due to the depletion of raw material such as fossil fuel etc. The conventional grid network expansion in rural sector have become almost standstill and thus affecting the growth of our nation. Integration of Renewable source with a hybrid system could thus found is supposed to be the best solution for rural electrification where power is produced from different energy sources such that it meets the demand with the least possible cost while giving the highest priority to the most suitable source. Attempts were made by Scientist and Engineers to develop such systems but due to lack of intelligent controller, the integration of these sources with conventional grid could not be implemented in a cost effective way. Further, use of complex mathematical techniques brought easy to build forecasting models to manage the intermittency in generation from these sources.

2.0 Micro Smart Grid Model of System:

A smart micro grid is integration of renewable energy secondary sources with primary electrical grid sources that uses communications technology to gather and act on information about the availability of grid power and Load profile in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the power supply. Electronic power conditioning and control of the generation from primary and secondary sources as well as the distribution of electricity are important aspects of the smart grid. The system model comprises of centralized grid network incorporating local power generation renewable energy sources (like solar, fuel cell etc) near to Load end. The other units comprises of Power Converter, PC as a Controller and Communication Network Devices for transferring Information etc. The load is normally powered by primary conventional grid source. But in case of low power or deviation in power quality as frequently encountered by the rural grid from time to time, sustainability of power across load is maintained by the secondary local renewable sources. The excess power, if generated by local sources is stored by feeding the same to grid storage device and draw the same from grid network whenever is needed.

In this project work a smart micro model has been developed to supply sustainable power supply. A simulation study has been carried out to explore the possibility of implementation of such model in Indian villages Ssingh 1, 2, 3, 4, 5].

2.1 Features of Smart Grid:

- Generalized and distributed power generation

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- Multi directional power flow
- Load follows generation
- Operation based on real time data
- Sustainability
- Reliability
- Cost effective

2.2 Smart Micro-grid Topologies:

The different micro-grid topologies are described below**:**

- Radial Grid
- Mesh Grid
- Ring Grid

Radial:

A radial type grid is the simplest setup. Known as a radial network, it involves a series of networks and sub-networks organized as radial trees that begin with a power source and distribute electricity through networks with progressively lower voltages, eventually ending with communities, homes and businesses.

Mesh:

A mesh network involves the radial structure but includes redundant lines, which are in addition to the main lines and organized as backups for the purpose of rerouting power in the event of failure to a main line.

Ring grids:

They are operated as ring and several secondary substations feed the same network. In ring grid there are two routes for power flow. Advantages of ring operation are better voltage stability and lower power losses.

2.3 Smart Control Strategies:

The control system of a micro-grid is designed to safely operate the system when it is connected to the grid or in stand-alone mode. This system may be based on a central controller or embedded as autonomous parts of each distributed generator.

Micro-grid controllers must ensure that:

- Micro-sources work properly at predefined operating point or slightly different from the predefined operating point but still satisfy the operating limits;
- Active and reactive powers are transferred according to necessity of the micro-grids and/or the distribution system;
- Disconnection and reconnection processes are conducted seamlessly;
- In case of general failure, the micro-grid is able to operate to sustain the power supply across the Load
- Energy storage systems of grid network can support the micro-grid

Mode of Operation:

Control of the micro-grid under different mode of operation is as follows

a) Voltage/ Frequency control: When the Micro-grid is disconnected from the grid, control system must control the local voltage and frequency and provide the instantaneous active and reactive power to loads.

b) Frequency control: When the micro-grid is in stand-alone mode, frequency control is the most important problem. The frequency response of conventional systems is based on rotating masses and these are considered as essential for the stability of the systems. In contrast, micro-grids are inherently converter-dominated grids with very little directly connected rotating masses. Thus, the electronic converter control systems must be adapted to provide the response previously obtained from directly connected rotating masses.

c) Voltage Regulation: It is considered the second main objective of networks to guarantee their local reliability and stability. It has been observed that systems with high penetration of distributed generation experience voltage and/or reactive power changes and oscillations in the connection point. Local voltage control must be designed to avoid these changes and the circulation of reactive currents between sources.

3.0 Micro Smart Grid Model for Rural India:

3.1 Model:

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The proposed model of smart grid for Rural India is given below

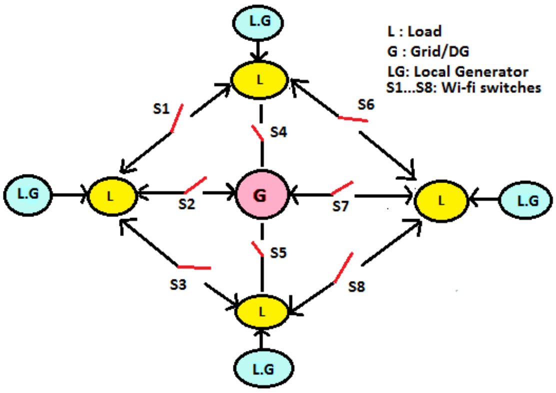

Fig. 1: Proposed Micro Smart Grid Model for Rural India.

3.2 Control Algorithm:

The control action of smart grid is performed through programme. The demand response and load management is balanced to generate a sustainable power supply across the load .The algorithm reflect the operation as follows:

Step 1: System collects data from main grid and load

Step 2: Data is inputted through communication link to know the availability of power in local generating Sources.

Step 3: Load is switched over to local power sources in case of availability of more power than the required load power.

Step 4: In case of more demand the load is shared with grid in time sharing mode or shifted to other period of existence of low demand

Step 5: The process is repeated and initiated again at an interval as received on change of demand of Load linked through wi-fi communication link.

4.0 Local Power Generation Module:

The Local generation is produced nearest to the load. The PV hybrid system comprises of the following module**:**

- PV module
- Battery 150 Ah
- Inverter 1kW
- Load matrix (Max 1kW)

A prototype PV system module, as proposed, has been developed [6] and installed in laboratory as per computed load energy requirement of rural house over a period of 24 hours of the tribal village in the outskirt remote area of Jamshedpur city (India). The primary source of power supply to house is the PV power stored in the battery Load power is managed either by battery back up PV system or supplementary integrated grid/DG source..

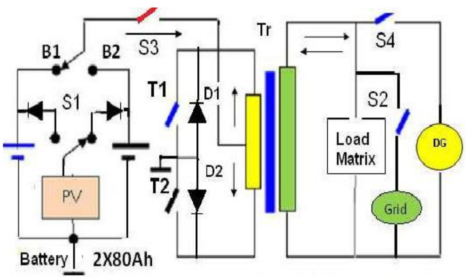

Fig. 2: Power Circuit and Prototype Local Power Source Module of Micro smart Grid.

The power converter unit of the PV system takes the low 12V DC voltage input from PV backed up energy source, stored in battery bank, as shown in Fig.2 and convert it into usable 220VAC, 50 Hz 300W/750VA output with the help of a transistorized centre tapped transformer (Tr) based push-pull configured BJT/MOSFET bi-directional converter (inverter) circuit. The controller circuit generates PWM square wave control pulses of 50Hz using IC CD 4047, to activate and switch on IRF 540 MOSFET/2N3055 transistors T1 and T2 alternatively producing AC PWM voltage with low THD at the output of secondary of transformer across the load. DG set is connected to load when the stored PV energy falls below load energy in absence of grid or when the battery reaches a discharge cut off level of 10.4V. It remains on till battery attains a charge level to match with load energy requirement in the range of 12.8V to 13.4V. The intelligent, adaptive control action of the controller performs load power/energy management and thus monitor and manage to deliver continuous power to load. The charging operation is performed either by PV source or grid/DG source through bidirectional converter (inverter) circuit in its rectifying mode (comprising of diodes D1 and D2 while transistor T1 and T2 remain off). The intelligent controller prevents the battery to go into deep discharge/or overcharge as the case may be and thus battery never allows attaining a cut-off low voltage of 10.4V for deep discharge condition or 13.4V in case of overcharging.

In case of load which exceed critical load of 300W the intelligent controller share the power with grid limiting the withdrawal of energy up to 300W-hr only from the PV source .the rest of energy is drawn from the grid sources/DG.

4.1Specification:

The system is designed for a rural home as per load energy requirement with the specifications as given below:

- **Load Energy** = 1800 – 2000 Watt-hours over a period of 24 hour, with a demand factor of 0.9 and 50% sharing with grid power.
- **PV size** = 4 x 75 W_p, 12 V
- **Battery Size** = 2 x Dual 150 Ah, 12V low self discharge inverter grade tubular lead acid battery.
- **Load(s)** =CFL lamps, Fans, TV and pump etc.
- **Converter** = 300 W/750 VA, 12 DC ~ 220 V SPWM AC, 50 Hz (Distortion 5- 15%)
- **Grid/DG Set** = Grid distributed network/Portable LPG 2x550VA/Diesel based 1.5 KVA

5.0. Design of PV - Grid Power System

Power consumption of a typical rural home is computed [6, 7] considering its requirement on per day basis, taking Load as TV, light /Fan and pump etc and is reflected in Table -1.

Table 1: Power Consumption.

Electrical appliance	Power (Watt)	Time (hr)	Energy (watt-hr)
Light/Fan	5x20W	8 Hr	800 W-h
TV	100W	4Hr	400 W-h
Pump	750 W	1Hr	750 W-h
Total			2000 W-h

5.1 PV Sizing:

The PV size is computed considering the sun hour falling on surface of PV module as 6 hours (9AM - 3 PM) and its efficiency of conversion as 0.9.

i.e., No. of PV Module ($75W_p$)=(Energy consumption (W-h)/(75Wp* 6hr* η= 0.9) (1)

5.2 Battery Sizing:

The battery store the electrical energy converted by PV module during the sun hour

Battery sizing: Energy consumption / Battery voltage (12V)

i.e., = 2000 W-h/12V= 150 Ah (2)

5.3 Inverter:

The Converter unit converts DC voltage into usable AC Voltage 220V, 50V 50Hz. To deliver a peak load of 1kW, the Inverter is selected to sustain this load. The Inverter has been designed as a bi directional converter which charges the batter bank of 2*150 Ah also.

5.4 DG Set:

In case of grid failure, the power is drawn from DG set. It must sustain the peak load of 1.5 KVA.

RESULTS AND DISCUSSION

6.1 Load Power Management:

Demand scheduling and switching: A key parameter that is absolutely crucial in designing a model for rural electrification is scheduling of the varying demand. Usually grids are designed to cater to a flat demand curve. After the loads are scheduled to obtain a near-flat demand curve and the plant size is optimized, a fuzzy control

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program [7] is coded to make load switching decisions intelligently deriving inputs from measurement algorithms using the schedule in the form of control rules.

The power delivery to load(s) is governed by the adaptive energy balance equation

i.e., $P_L = P_{GRID} + (P_{PV} + / - P_{BATTERY})$ (3)

The consistency in load power (P_L) delivery is obtained due to integration of input sources i.e. PV (P_{PV}), grid (P_{GRID}) and battery source ($P_{BATTERY}$).

6.2 Load Sensitivity Analysis:

It has been conducted with varying load as well as isolation and the results were found consistent. The bar diagram for the results found is shown in the Fig.3.

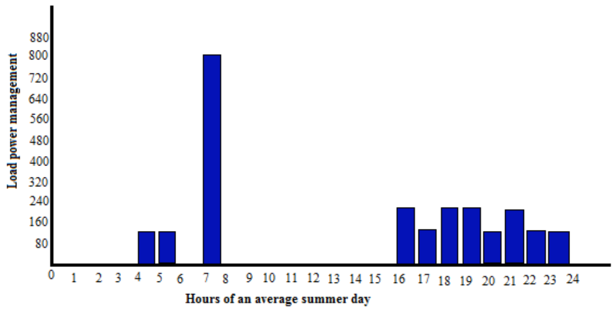

Fig. 3: Load Power consumption.

6.3 Power Saving:

The average approximated power drawn by the PV system and shared with Grid during each month of year 2014 is reflected in Table-2.

Table-2: Power sharing between Micro grid (PV) and Grid.

Month	*Micro grid*	*Grid*	*Month*	*Micro grid*	*Grid*
Jan'14	50	50	July'14	40	60
Feb'14	45	55	Aug'14	35	65
Mar'14	40	60	Sep'14	50	50
Apr'14	45	55	Oct'14	45	55
May'14	50	50	Nov'14	50	50
June'14	40	60	Dec'14	40	60

6.4 Payback Period:

It has been observed that the cost of Electricity, initially at high value, reduces with time .Thus prices reduces with a payback period of 5-6 years while compared with cost of grid sources. This has been reflected in Fig.4.

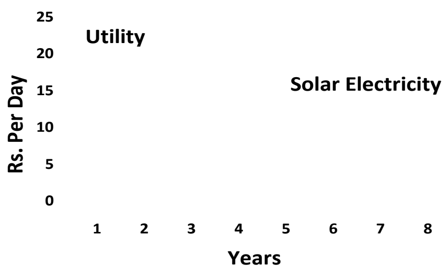

Fig. 4: Payback period of PV power supply.

7.0 Socio Economic Impact on Society: Self Employment - A Case Study:

The study reveals that availability of power from the grid in rural houses was observed as very poor. During its frequent failure or load shedding period, Petromax and Kerosene oil lamps were being used for lighting in these houses which were causing inconvenience to potential youth and women clientele group trainee/ learners, continuing their study/training leading to unsafe environment. This could become possible with the use of proposed solar integrated grid power source provided to these rural houses. An example of spreading Vocational Literacy in rural society is reflected in Fig.**5**

The impact of sustainable power from the integrated sources could be able to bring many benefits and upliftment in rural society in the field of literacy such as**:**

Approximately 30 - 40% potential youth were trained in income generating vocational skill formation courses in solar powered lighting schools.

- Female illiterate and neo-literate beneficiary specially belonging to socially and economically backward society were trained in cottage industry products (candle, agarbatti, masala, pickle, jam-jelly and papad making etc).
- They could start the production of Agro-based products like Vermi Compost and Mushroom, garment/bag making, Jute product items, Handicraft items, Jute bag item, Photo frames, Interior home decorative items, Soft toys making etc.
- School dropout children, along with their mother started going to literacy schools and thus literacy rate could be increased from 30% to 60.
- Villagers could be able to engage themselves in production of cottage industry products during evening hours. Thus economic status increased by 30%.

Fig. 5: Vocational literacy Training for self employment run by rural houses.

6. Conclusions:

The smart micro grid power system has been designed for rural masses. The system can work as a standalone unit also at places where Grid connectivity is very poor. The system offers various other features like: high efficiency, simple solar conversion technology, generation of pollution free green electricity etc. The system can find its applications in many areas of rural sectors of Indian villages for supplying power for:

- Lighting, Pumps used for irrigation or drinking water supply,
- Running schools for children as well as for adults, community centers, shops, clinics, cottage industry equipment etc.

The experimental results prove that the proposed micro grid system can reduce the Energy Consumption drastically to an extent of 50% or more and give a reliable support to the Grid. But the technology still has shortcomings such as high initial installation cost and low energy-conversion efficiency 15%, thus requiring continuous improvements of both PV cell and power inverter technologies. The impact on rural society in spreading literacy for self employment was found with excellent result.

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