Smart Micro Grid Model for Rural India

Dr. S. N. Singh, V. S. Prathiba, and Nikhil Katiki

***Abstract*—**India is facing acute shortage of electricity, especially in remote area of rural sectors 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 these rural houses has become poor. In this paper, a Micro Smart Grid Model with PV system integrated with grid has been done. The PV system consist of 300W/1kW intelligent bidirectional converter producing SPWM AC power of 230 Volt, 50 Hz and 1800Wh battery storage unit has resulted a grid power saving up to 50% or more. Further, impact of utility interfaced solar powered literacy training houses has resulted in generating skill development for self employment among potential youth.

***Keywords*—**Renewable Solar Energy Sources, SPWM–single Pulse width Modulation Converter, Load Sensitivity etc

I. Introduction

ELECTRICITY is the basic need of all living beings. The supply from conventional grid (utility) is shrinking due to the depletion of raw material such as fossil fuel etc. Thus the conventional grid expansion in rural sector has become almost standstill. Integration of Renewable solar energy sources with conventional grid seems to be an optimal solution, as in this hybrid system power is shared by both the sources, meeting the demand of the user with the least possible cost. Attempts were made by Scientist and Engineers to develop such systems in the past but could not be implemented in a cost effective way. A smart micro grid model has been proposed to overcome the same and prototype system module for rural house consuming 1800Wh energy per day has been developed. The result has been found an encouraging one with a saving of 50% or more power from grid supply.

II. Micro Smart Grid Model Of System

A smart micro grid as proposed is integration of renewable energy as primary source with electrical conventional grid sources that uses wireless 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 unit and control of generation from primary source as well as the distribution of electricity sharing with grid are important aspects of the smart grid. The system model comprises of centralized grid source distributed in a network through nodes connected in ring topology, local power generation renewable energy sources (like solar, fuel cell etc) near to load end. The other units comprises of Power Converter, PC or Micro Controller as an intelligent controller and communication network devices for transferring information etc. The load below 300W is normally powered by primary PV source, where as in case of peak load, sustainability of power across load is maintained by the secondary conventional grid sources. The excess power, if generated by local PV sources is stored by feeding the same to grid/local power storage device i.e., Battery or super capacitor and draw the same from micro grid network nodes whenever is needed. [1, 2, 3 4, 5].

In this project work a smart micro model with a local generating source of 1800Wh capacity has been developed to supply sustainable power to a rural house. A simulation study has been carried out to explore the possibility of implementation of such model in grid connected remote area of Indian villages

A. Features of Smart Grid

1) Generalized and distributed power generation
2) Sustainability
3) Reliability Multi directional power flow
4) Load follows generation
5) Operation based on real time data in optimal way
6) Cost effective

B. Smart Micro-grid Topologies

The different micro-grid topologies are described below:

1) Radial Grid
2) Mesh Grid
3) Ring Grid

1) *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.
2) *Mesh:* A mesh network involves the radial structure but includes redundant lines connecting nodes, which are in addition to the main lines and organized as backups for the purpose of re-routing power in the event of failure to a main line.
3) *Ring grids* They are operated from secondary grid nodes interconnecting in ring network and feeding power to loads. In ring grid topology there are two routes i.e., backward and forward to access any node for power flow. Advantages of ring operation include feature like better voltage stability and low power losses.

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C. Smart Control Strategies

The control system of a micro-grid is designed to safely operate the system when it is connected to the grid node 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:

1) Micro-sources work properly at predefined operating point and satisfy the operating limits ;
2) Active and reactive powers are transferred from grid according to necessity of the micro-grids and/or the distribution system ;
3) Disconnection and reconnection processes are conducted through communication link seamlessly ;
4) In case of general failure of grid, the micro-grid is able to operate to sustain the power supply across the Load ;
5) Energy storage systems or DG of grid network must support the micro-grid to maintain sustainability.

III. Micro Smart Grid Model For Rural India

A. Model

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

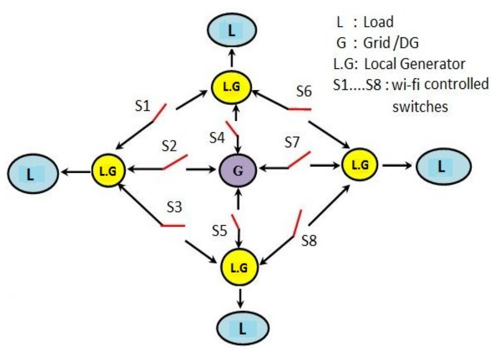

Fig. 1 Proposed Micro Smart Grid Model for Rural India

B. Control Algorithm

The control action of smart grid is performed by controller through program. The demand response and load management is balanced to generate a sustainable power supply 24x7 across the load. The algorithm reflects the operation in the following steps:

1) System collects data from main grid, PV micro grid and load.
2) Data is inputted through communication link to know the availability of power in local generating Sources.
3) Load is switched over to local power sources in case of availability of more power than the required load power.
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.
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.

IV. Local Power Generation Module

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

1) PV module 4x75Wp
2) Battery 160 Ah
3) Bidirectional converter 300W/ 1kW
4) Load Matrix (Max 1kW)

A prototype PV system module integrating with grid/DG sources, 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 these houses is the PV power stored in the battery. Load power is managed either by battery backed up PV system or supplementary integrated grid/DG source.

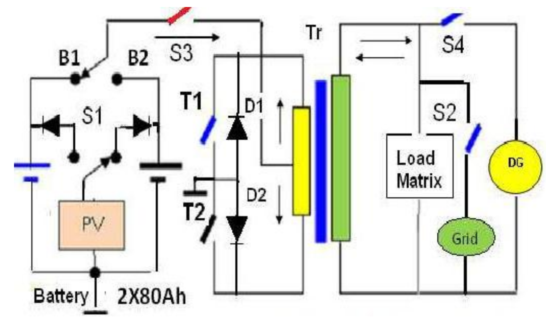

Fig. 2 Power Circuit and Prototype Local Power Source Module of Micro smart Grid

The bi directional converter unit of the PV system unit takes the low 12V DC voltage input from PV backed up energy source, stored in dual battery bank, as shown in Fig.2 and convert it into usable 220V SPWM AC, 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 SPWM 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 SPWM 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 10.4 V. 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 Microcontroller unit performs load power/energy management and thus monitor and manage to deliver continuous i.e., sustainable 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 during the sharing period of power (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

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10.4 V for deep discharge condition or 13.4 V in case of overcharging.

In case of load which exceed critical base load of 300W the intelligent controller share the power with grid if exceeded beyond this limit i.e., 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. The controller access such load power requirement and allow the time of delivery from PV source limiting to 300Wh energy per hour basis only on varying the load demand and the remaining from conventional grid/DG supply.

A. Specification

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

1) Load Energy = 3600 Watt-hours over a period of 24 hour, with a demand factor of 0.5
2) PV size = 4 x 75 W_p, 12 V
3) Battery Size = 2 x Dual 80 Ah, 12V low self discharge inverter grade tubular lead acid battery.
4) Load(s) = CFL lamps, Fans, TV and pump etc.
5) Converter = Bidirectional 300 W/750 VA, 12 DC ~ 220 V SPWM AC, 50 Hz (Distortion 5- 15%)
6) Grid/DG Set = Grid distributed network/Portable LPG 2x550VA/Diesel or Kerosene oil based 1.5 KVA.
7) Controller = Intelligent micro-controller allowing oscillator circuit to generate SPWM control pulses and sharing power with grid in time sharing mode of its operation.

V. Design Of Pv - Grid Power System

Power consumption of a typical rural house of a cluster in a remote area near Jamshedpur City (India) of village is computed [6, 7] The average power requirement on per day basis, considering Load as TV, light /Fan and pump etc. and the same has been reflected in Table - I.

TABLE I
POWER CONSUMPTION

Electrical Appliance	Power (Watt)	Time(hr)	Energy(Watt-hr)
Light/Fan	*5x20 W*	*8 hr*	*800 W-hr*
TV	*100 W*	*3 hr*	*300 W-hr*
Pump	*750 W*	*1 hr*	*750 W-hr*
		Total	*1800 W-hr*

A. PV Sizing

The PV size is computed considering the sun hour, i.e., light falling on surface of PV module, as 6 hours (9AM - 3 PM) and its efficiency of conversion as 90 %.

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

B. Battery Sizing

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

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

i.e., 1800 W-h/12V= 150 Ah (2)

C. Bi-Directional Converter

In the inverter mode, the Converter unit converts 12V DC voltage into usable SPWM AC Voltage 220V, 50V 50Hz. To deliver a peak load of 1kW, the Inverter is designed to sustain this intermittent peak load. The Inverter has been designed as a bi-directional converter which charges the battery bank of 2*80 Ah also.

D. DG Set

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

VI. Results and Discussion

A. Load Power Management

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

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

The consistency in load power (P_L) delivery is obtained due to integration of input sources i.e. PV module stored energy in Battery P_{BAT} and grid (P_{GRID}).

B. Load Power Sensitivity Analysis

It has been conducted with varying load as well as isolation (energy stored in battery) and the results were found consistent. The load profile i.e., load power consumption per day on an average basis of rural house under one cluster unit has been shown in the Fig.3.

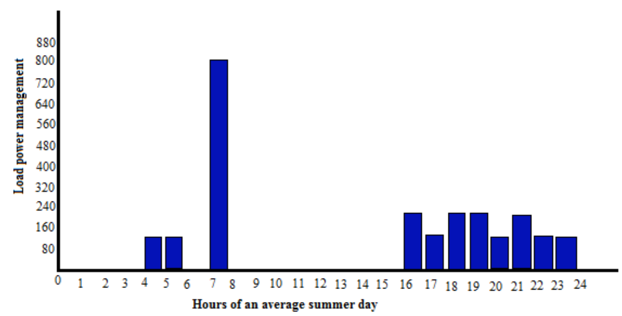

Fig. 3 Load Power consumption

C. 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-II.

TABLE II
POWER SHARING (APPROX) BETWEEN MICRO GRID (PV SYSTEM) AND GRID/DG

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

D. Payback Period

The system feasibility and cost has been evaluated and found that the payback period falls within 5-6 years only. It has been observed that the cost of Electricity, initially found as high value, reduces with time. This has been reflected in Fig.4.

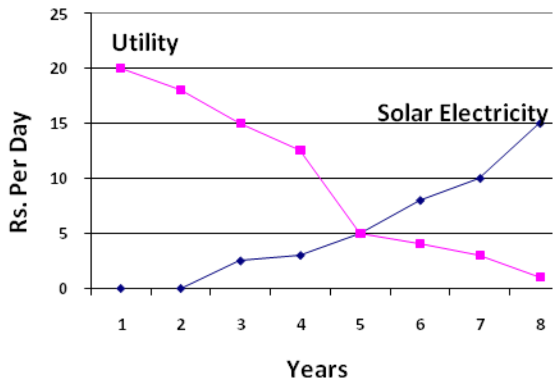

Fig.4 Payback period of PV power supply

VII. Socio Economic Impact On Society: Self Employment - A Case Study

The study of a literacy house running in a rural house reveals that availability of power from the grid was observed as very poor ranging from 6-10 hours only. During its frequent failure or load shedding period, k.oil fed Petromax lamp 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 through these houses is reflected in Fig.5.

The impact of sustainable power to these houses from the integrated sources could be able to bring many benefits and summarized as follows:

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

1) Female illiterate and neo-literate beneficiary specially belonging to socially and economically backward society were trained intrades e.g. cottage industry products (candle, agarbatti, masala, pickle, jam-jelly and papad making etc).
2) They could start the production of agro-based products like vermi compost and Mushroom, garment/bag making, Jute product (like Bag, wall hanging) items, Handicraft items, Photo frames, Interior home decorative items, Soft toys making etc.
3) School dropout children, along with their mother started going to literacy schools and thus literacy rate could be increased from 30% to 60.
4) 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

VIII. Conclusions

The smart micro grid power system model of 300W capacity has been developed for rural hose for villager. The system can be scaled to higher limit and can work as a standalone unit also at places where Grid connectivity is very poor. The system offers various other features like: less maintain ace 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:

1) Lighting, Pumps used for irrigation or drinking water supply,
2) Running schools for children as well as for adults, community centers, shops, clinics, nursing homes and dispensary weekly Sunday market, cottage industry equipment etc.

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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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REFERENCES

[1] S.N.Singh et al, "Rural Home Energy Management by Fuzzy control Model for utility interfaced autonomous solar (PV) –DG power system in India", IJAEST, Vol. 14, Issue 1, (Feb 2012) pp 15-21.
[2] S.N.Singh, A.K.Singh, "Optimal design of a cost effective solar home power system–an alternative solution to DG for grid deprived rural India", Vol. 2, issue1 (Jan 2010).
[3] S.N.Singh et al, "Intelligent Home energy management by Fuzzy adaptive control model for solar (PV)-Grid /DG power system in India", IJPCSC, Vol. 2, No1, Jan-June (2011), pp 61-66.
[4] S. N. Singh, et al," Rural Home Energy Management by Fuzzy Control Model for Autonomous Solar (PV) - Diesel Power System in India", IJAEST (2011), Vol. 4, Issue 1, pp 15- 21.
[5] S.N.Singh, A.K.Singh, "Design and development of Grid-assisted adaptive solar (PV) power converter for water-pumping system in Indian villages", Journal of ARISE (2009).
[6] S.N.Singh, A.K.Singh, "Modeling and dynamics of a PWM sinusoidal Inverter for water pumping system for use in agriculture and household application", Journal of IEEMA Jan (2008) pp 114-122.
[7] V.S.Prathiba and Dr S.N.Singh "Design of Fuzzy Controller for Sustainable Utility Interfaced Solar Powered Literacy Houses", 10th All India Peoples' Technology Congress,(6th -7th February, 2015) Kolkata (India)

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