ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

Autonomous Microgrid for Rural Village Electrification

Arun A Palavila[1], K L Sreekumar[2]

PG Student [Power System and Control], Dept. of EE, Govt. Engg College BartonHill, Trivandrum, Kerala, India[1]

Associate Professor, Dept of EE, Govt. Engg College BartonHill, Trivandrum, Kerala, India[2]

ABSTRACT: A scalable and viable architecture for Microgrid to supply electrical power to off-grid communities where grid electricity is unavailable or is largely intermittent is proposed. The micro grid operates in autonomous mode. A micro grid for a rural village of 100 homes is taken into consideration. Load demands for households, agricultural loads, Small industries street lighting are calculated and by taking into consideration of these loads a standalone microgrid is designed. A 40 Kw photovoltaic system is designed and also a 63Ah battery is used in the system as a backup. The grid consists of both ac and dc loads and smooth power management is done for the same. The coordination control algorithm is proposed for smooth power management between ac and dc links for various operations for different load conditions, irradiation levels, different state charge of battery. A small microgrid has been modelled and simulated using Simulink in the MATLAB. The simulation results show the autonomous operation of the grid using the coordination control scheme in different conditions.

KEYWORDS: Microgrid,Converter,Photovoltaic system, grid control.

I.INTRODUCTION

In this current era about 18% of world population has no access to electricity and in India more than 10,000 Villages are unelectrified. According to ministry of power India has 1,21,225 fully unelectrified villages and 5,92,979 partially unelectrified villages which has no access of grid due geographic limitations as of June 2015. When power can be fully supplied by local renewable power sources, long distance high voltage transmission is no longer necessary.In this paper load demand for a village with 100 household are taken into consideration. Households loads, agricultural loads, small industries, street lighting loads are taken. The loads considered are both ac and dc loads. Fig1. shows overall set of the microgrid.The smart grid concept is currently prevailing in the electric power sector. A dc microgrid have been proposed in [1][2]. The objective of constructing a smart grid is to provide reliable, high quality electric power to digital societies in an environmentally friendly and sustainable way. One of most important futures of a smart grid is the advanced structure which can facilitate the connections of various ac and dc generation systems, energy storage options, and various ac and dc loads with the optimal asset utilization and operation efficiency. To achieve those goals, power electronics technology plays a most important role to interface different sources and loads to a smart grid.

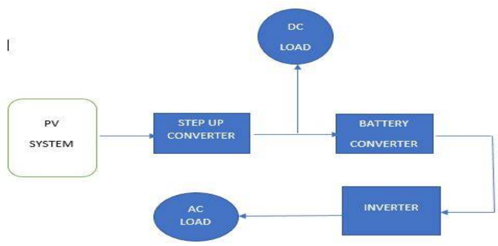

Fig.1 overall setup of the system

The renewable energy sources, like the photovoltaic (PV) energy have been attracted a lot of attentions and are becoming an effective solution to overcome the environmental pollution and energy shortage problems. The coordination control schemes among various converters have been proposed to harness maximum power from

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

renewable power sources, to proper power transfer between ac and dc loads, and to maintain the stable operation of both ac and dc grids under variable supply and demand conditions. The advanced power electronics and control technologies used in this paper will make a future power grid much smarter.

II.SYSTEM MODEL

USSAGE	AMOUNT	LOADS
Household	100 * 250 W	25 kW
5Hp Irrigation pumps	3 * 3.8 W	11.3 W
Street lights	100 * 20W	2 kW
TOTAL		38.3 kW

Table1.Load demand for a rural village of 100 homes.

The load demand for a rural village of 100 household are calculated and the system is configured according this. The loads are household, agricultural purposes, street lighting in a small rural village.A compact system model rural microgrid grid as shown in Fig. 2 which is modelled using the Simulink in the MATLAB to simulate system operations and controls. 40 kW PV arrays are connected to dc bus through a dc/dc boost converter to simulate dc sources. A capacitor C_{PV} is to suppress high frequency ripples of the PV output voltage. A 65 Ah battery as energy storage is connected to dc bus through a bidirectional dc/dc converter. Variable dc load (20 kW–40 kW) and ac load (20 kW–40 kW) are connected to dc and ac buses respectively. The rated voltages for dc and ac buses are 400 V and 400 V rms respectively. A three-phase bidirectional dc/ac main converter with R-L-C filter connects the dc bus to the ac load through an isolation transformer. When the total power generation is more than the total load, firstly the loads are supplied then the battery converter injects power to battery and thus the battery gets charged. When the total power generation is less than the total load in the micro grid, the battery discharges to feed the critical loads. DC bus voltage is maintained stable by a battery converter or boost converter according to different operating conditions. The main converter is controlled to provide a stable and high-quality ac bus voltage.

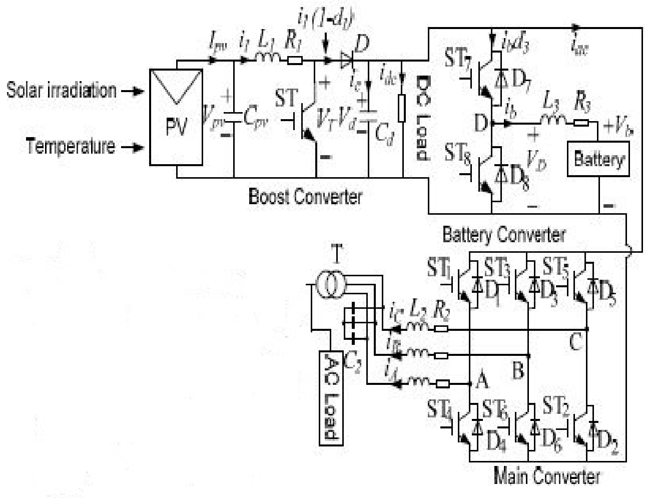

Fig2.A representation of the system model of rural microgrid

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

III.MODELLING AND DESIGN

A. PV Array Model

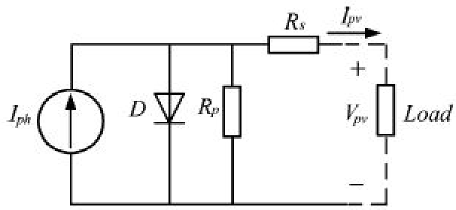

Fig3.Equivalent circuit of solar cell

Fig. 3 shows the equivalent circuit of a PV panel with a load. The PV module is modeling is done by considering it as a current source in parallel with an antiparallel diode. Takinginto account the internal losses series and shunt resistances are also added as in Figure 2 The modeling is done as per the equations in [3]. The relevant equations are given below.

By applying Kirchhoff's law,

$$I = I_{ph} - I_d - I_p \qquad (1)$$

Where I_{ph} is the photocurrent
I_d is the diode current and
$I_p$is the current leak in the parallel resistor

But $$I_d = I_0 \left[\exp \left(\frac{V + IR_s}{a} \right) \right] \qquad (2)$$

Where I_0 is the reverse saturation current
R_s is the series resistance
a is the modified ideality factor given by

$$a = \frac{AkT_c N_s}{q} \qquad (3)$$

Where A is the diode ideality factor (0.3 for Si)
k is the Boltzmann constant (1.381×10^{-23}J/K)
N_s is the number of series connected cells
T_c is is the cell temperature
q is the electron charge (1.602×10^{-19}C)
R_p is the parallel resistance

$$I_p = \frac{V + IR_s}{R_p} \qquad (4)$$

B. Modelling of battery

Two important parameters to represent state of a battery are terminal voltage V_b and state of charge (SOC).

$$V_b = V_0 + R_b . i_b - \mathrm{K} \frac{Q}{(Q + \int i_b dt)} + \mathrm{A}.\exp(\mathrm{B} \int i_b \, dt) \qquad (5)$$

$$\mathrm{SOC} = 100 + (1 + \frac{\int i_b dt}{Q}) \qquad (6)$$

where is R_b internal resistance of the battery, V_0 is the open circuit voltage of the battery, i_b is battery charging current,

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
(An ISO 3297: 2007 Certified Organization)
Website: www.ijareeie.com
Vol. 6, Issue 6, June 2017

K is polarization voltage, Q is battery capacity, A is exponential voltage and B is exponential capacity.

C. DC-DC Stage design

The dc-dc stage employs a boost converter to boost the low value of PV voltage to the value of required dc link voltage which should be higher than the peak value of grid voltage. The dc -dc stage helps to implement Maximum Power Point Tracking and enables better decoupling also. The relevant design equations are as given below

$$V_{DC} = \frac{V_{PV}}{1 - D} \tag{7}$$

The inductance value is chosen by assuming Δi_L=10% generally

$$L = \frac{V_{PV} \times D}{\Delta i_L \times f_s} \tag{8}$$

Where Δi_L is the ripple current

f_s is the switching frequency which is a design choice

D is the Duty Ratio & V_{DC} is the dc link voltage.

IV.COORDINATION AND CONTROL OF THE CONVERTERS

There are three types of converters in the microgrid grid. Those converters have to be co-ordinately controlled to get high quality power to variable dc and ac loads under variable solar irradiation as the grid operates in isolated mode. The control algorithms for those converters are presented in this section. In order to maintain stable operation of the grid under various supply and demand conditions, a coordination control algorithm for booster and main converter is proposed. The control block diagram is shown in Fig.4-6. The reference value of the solar panel terminal voltage is determined by the basic perturbation and observation (P&O) algorithm based on solar irradiation and temperature to harness the maximum power [4], [5]. Dual-loop control for the dc/dc boost converter is described in where the control objective is to provide a high-quality dc voltage with good dynamic response. This control scheme is applied for the PV system to track optimal solar panel terminal voltage using the MPPT algorithm. The outer voltage loop can guarantee voltage reference tracking with zero steady-state error and the inner current loop can improve dynamic response. Fig4 shows the control strategy of PV step-up converter. When a sudden dc load drop causes power surplus at dc side, the main converter is controlled to transfer power from the dc to the battery side. The active power absorbed by capacitor C_d leads to the rising of dc-link voltage V_d. The negative error (V_d^* -V_d) caused by the increase of V_d produces a higher active current i^*_d reference through the PI control. The active current i_d and its reference i^*_d are both positive. A higher positive reference i^*_d will force active current i_d to increase through the inner current control loop. Therefore, the power surplus of the dc grid can be transferred to battery thus battery charges.

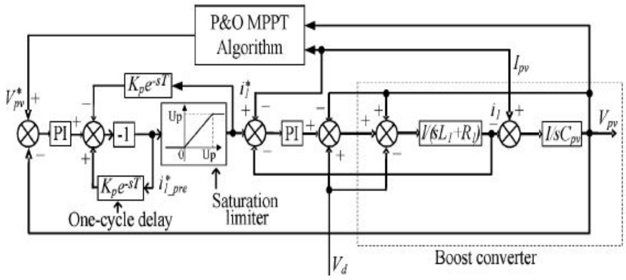

Fig4. Control strategy of PV step up converter

Similarly, a sudden increase of dc load causes the power shortage and V_d drop at the dc grid thus the battery gets discharged making V_d stable.

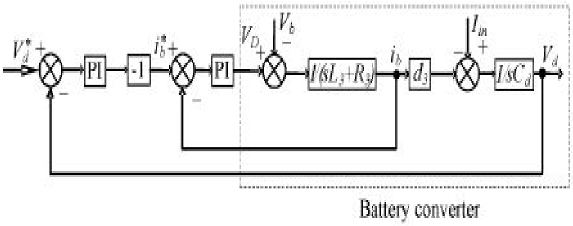

Fig5. Control strategy of battery converter

The stand-alone mode the coordinated control block diagram for battery converter is shown in Fig. 5. To provide a stable dc-link voltage, the dual loop control scheme is applied for the battery converter. The injection current to battery $I_{in} = i_1 (1- d_1) – i_{ac} – i_{dc}$. It should be noted that the output of the outer voltage loop is multiplied by -1 before it is set as the inner loop current reference. Current is defined positive when flowing into the battery, where the present dc-link voltage V^*_{dc} is set to constant 400 V. The ac side current equations of the main converter in - coordinate are as follows

$$C_2 \frac{d}{dt}\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix}\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} - \begin{bmatrix} i_{od} \\ i_{oq} \end{bmatrix} \quad (9)$$

Where i_{od} and i_{oq} are d-q currents at the converter side of the transformer respectively. Multi-loop voltage control for a dc/ac inverter is described in [6], where the control objective is to provide a high-quality ac voltage with good dynamic response at different load conditions. This control scheme is applied for main converter control to provide high quality ac voltage in the stand alone rural microgrid.

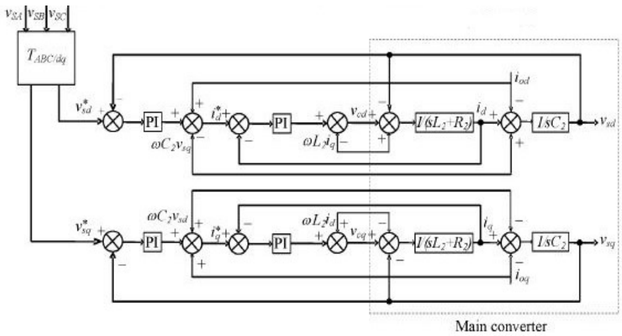

Fig 6. Control strategy of main converter

V. SIMULATION RESULTS

The operations of the hybrid grid under various source and load conditions are simulated to verify the proposed control algorithms. The parameters of components for the hybrid grid are listed in Table2.

Symbol	Description	Value
C_{PV}	Capacitor across the solar panel	110µf
L_1	Inductor for step-up converter	2.5mH
Cd	Capacitor across the dc link	4700µf
L_2	Filter inductor for inverter	2.5mH
C_2	Filter capacitor for inverter	60µf

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

L_3	Battery converter inductor	3mH
R_3	Resistance of L_3	0.1
F	Frequency of AC grid	50 Hz
f_s	Switching frequency	10KHz
V_{dc}	DC link voltage	400 V
$V_{rms\ ac}$	AC voltage	400 V
N_1/N_2	Transformer ratio	2 : 1

Table2. Component parameters for microgrid

Simulation analysis is done in different cases normal case, sudden change in load, change in irradiation level

A. Normal case

Here 20Kw load is connected to dc link and 15 Kw load is connected to the ac link. Solar irradiation level is set fixed at 1000 W/m^2 both the loads are fed in this case and the remaining power produced is given to the battery and thus the battery gets charged. The battery SOC is fixed at 50 % and we can see the SOC is increasing. Fig 7-8 indicates voltage and current in dc link.

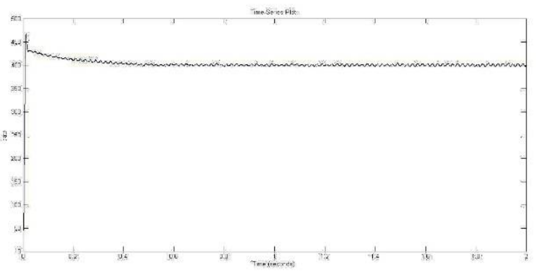

Fig7. DC link voltage

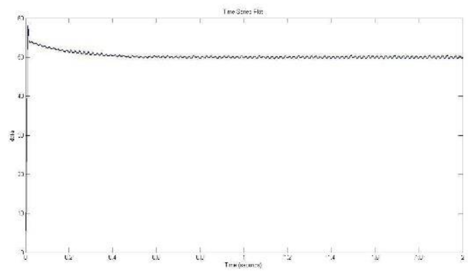

Fig8. DC link current

Fig.9 SOC of battery which is increasing due to excess power and Fig10. AC side voltage is also shown which feeding the ac load THD analysis is done for the same which is 3%.

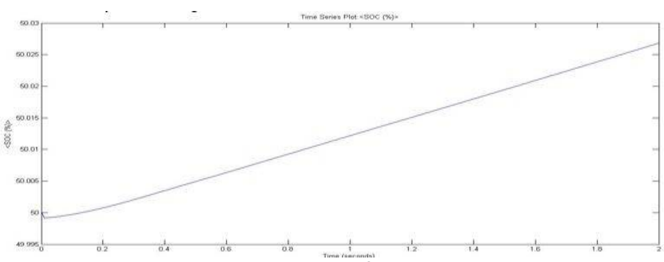

Fig9. SOC of battery

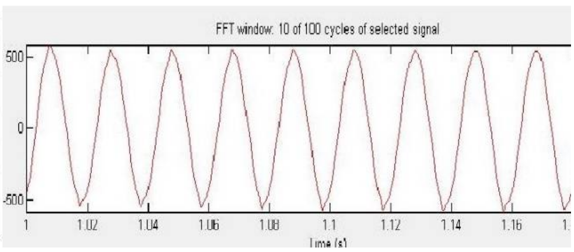

Fig10. AC side voltage

B. SUDDEN VARIATION IN LOAD

Here the system initially is in normal mode, at 1th sec a load of 15Kw is added to dc bus which cause a sudden variation in load.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

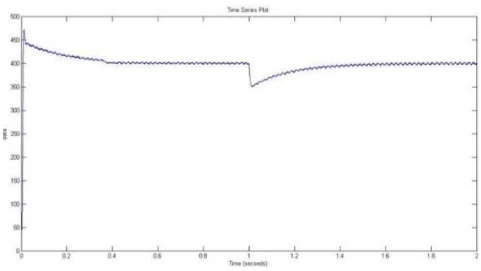

Fig11. DC link voltage during load variation

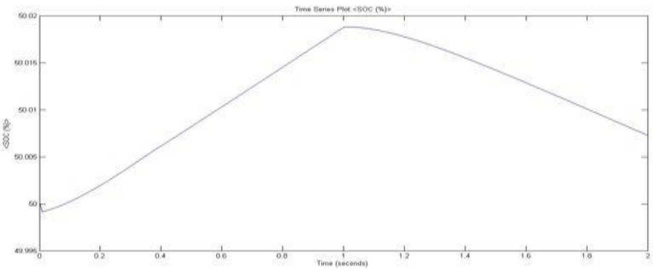

Fig12. SOC of battery during sudden load change

Fig11 shows the dc link voltage, at time 1 sec the voltage decreases due to load addition and thus the charging battery turns to discharging mode keeping the dc link voltage to stable value ie 400V. Fig12.Shows battery SOC increasing and decreasing in the first and second seconds respectively.

C. IRRADIATION ANALYSIS

Irradiation is kept fixed at 1000W/m^2 for the first second and for the next second the irradiation is decreasing gradually to zero irradiation level. Fig13 shows the irradiation levels. Fig14. Indicates dc load current. Here the irradiation level is 1000W/m^2 for first second and in the 2nd secondsthe irradiation level is reducing to zero value. The dc link voltage is stable for the first second and theexcess power produced is used to charge the battery and when the irradiation goes on reducing and at point the source cannot manage the load thus the battery starts discharging to make the dc link current and voltage to a stable value.

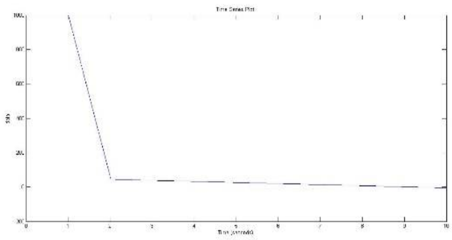

Fig13. Irradiation levels

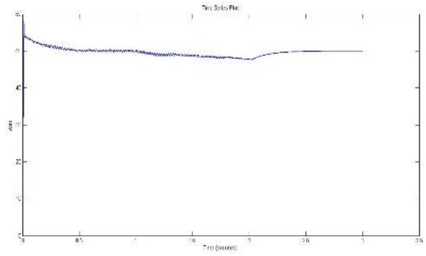

Fig14. DC load current during irradiation level change

VI. CONCLUSION

A small microgrid for a rural village is proposed and comprehensively studied in this paper. The models and coordination control schemes are proposed for the all the converters to maintain stable system operation under various load and resource conditions. The coordinated control strategies are verified by MATLAB/Simulink. Control methods have been incorporated to harness the maximum power from sources and to coordinate the power exchange between dc and ac loads

Different resource conditions and load conditions are tested to validate the control methods. The simulation results show that the microgrid can operate stably in the isolated mode. Stable ac and dc bus voltage can be guaranteed when the operating conditions or load capacities change in the two modes. The power is smoothly transferred when load condition changes. The micro grid may also be feasible for some small isolated industrial plants with PV system and other resources as the major power supply.

REFERENCES

[1] M. E. Baran and N. R. Mahajan, “DC distribution for industrial systems:Opportunities and challenges,” IEEE Trans. Ind. Appl., vol. 39, no. 6, pp. 1596–1601, Nov. 2003.

[2] Y. Ito, Z.Yang, and H. Akagi, “DC micro-grid based distribution power generation system,” in Proc. IEEE Int. Power Electron. Motion Control Conf., Aug. 2004, vol. 3, pp. 1740–1745.

[3] Habbati Bellia , Ramdani Youcef Moulay Fatima “A detailed modeling of photovoltaic module using MATLAB” NRIAG Journal of Astronomy and Geophysics (2014) 3, 53-61

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 6, June 2017

[4] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, "A variable step size INC MPPT method for PV systems,"IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2622–2628, Jul. 2008
[5] D. Sera, R. Teodorescu, J. Hantschel, and M. Knoll, "Optimized maximum power point tracker for fast-changing environmental conditions," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2629–2637, Jul. 2008.
[6] P. C. Loh, M. J. Newman, D. N. Zmood, and D. G. Holmes, "A comparative analysis of multiloop voltage regulation strategies for single and three-phase UPS systems," *IEEE Trans. Power Electron.*, vol. 18, no. 5, pp. 1176–1185, Sep. 2003.