INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
B. Shalavadi et al., Vol.6, No.3, 2016

Modelling and Analysis of a Standalone PV/Micro Turbine/ Ultra Capacitor Hybrid System

Basavaraj Shalavadi*‡, Ravindranadh V** ,Udaykumar R.Y***

*‡ Research Scholar, Department of Electrical and Electronics Engineering, NITK Surathkal, Karnataka, India-575 025

** Department of Electrical and Electronics Engineering, GITAM University, Bangalore, Karnataka, India.

***Professor, Department of Electrical and Electronics Engineering, NITK Surathkal, Karnataka, India-575 025

(shalavadibs@gmail.com, ravi131665@gmail.com,udaykumarry@yahoo.com)

‡ Corresponding Author; Basavaraj Shalavadi, EEE Department, NITK Surathkal, Karnataka, India-575 025, shalavadibs@gmail.com.

Received: 22.03.2016 Accepted:23.07.2016

Abstract: Nowadays the distributed generation is being vastly implemented due to its various advantages. Generally a non renewable source is connected in parallel to a renewable source. Normally Photo Voltaic (PV) generation gives the power necessary by the load. The output of the PV is varying due to various reasons like temperature, irradiation, etc. Distributed generation using micro turbine is a realistic solution because of its friendliness with environment, small in size and high efficiency of energy. If the load is more than PV power capability, micro turbine supplies the remaining power. Due to the varying load conditions, the micro turbine practically compensates all the PV fluctuations of power. Even so, to reduce the fast fluctuations of power, one need to use an energy storage system like battery, ultra capacitor and flywheel etc. Ultra capacitor has been chosen, because of the its high power density and very fast energy storing capability. This paper documents the simulation and analysis of a standalone Photovoltaic / Micro turbine hybrid system and Photovoltaic / Micro turbine / Ultra capacitor hybrid system using MATLAB/SIMULINK simulation software. The system is implemented based on the concept of a parallel hybrid configuration**.** The simulation results validate the proposal.

Keywords: PV, Micro turbine, Ultra capacitor, Hybrid, Standalone

1. Introduction

Supplying power from the grid inaccessible areas is not a cost effective choice. This is because of high transmission losses and high cost of erecting transmission lines. The deregulation of power system allows distributed generation (DG) sources to be installed as standalone or grid connected hybrid systems.

Proper modelling of DG's is very important for analysing the operation and effect on the power system.

An effort is made in this work and the paper deals with implementation of a model to assess the working of a standalone PV/ micro turbine/ ultra-capacitor hybrid system using SIMULINK. The use of DGs will also create awareness among the consumers regarding the use of locally available resources to meet their energy needs in sustainable way. Hence, the proposal made in this paper becomes highly relevant in the present context, especially for the countries facing energy crisis problem

1.1. Photo Voltaic System

PV generation system designers require models which are dependable and can be implemented with ease. It is required to analyse the PV working under different operating conditions. PV models are of five main types. The simplest model is the ideal single diode model (ISDM). Even though it is simple, it does not give correct characteristics at MPP [1]. Some models use 2 or 3 diodes, for which the complexity is more but have more accuracy [3,4].

There are models in which the solar cell structure (amorphous or mono crystalline or poly crystalline) is taken into consideration [5]. The model selection depends on the expected accuracy level. Single diode model is used in this paper, for its ease of implementation and reasonable accuracy.

For SDM, five parameters which are not given in the datasheet are required for the development of the PV model. These parameters are obtained by solving five nonlinear equations. These equations are solved analytically by calculating Co-content function [6]. These are also estimated by regulating some parameters values until the characteristics matches three operating points mentioned in the datasheet [2, 8]. The method given in [2] is implemented in this paper.

The PV array output varies with the change in temperature and irradiation. Hence need to extract the maximum power at those conditions from the PV array. Incremental conductance (IC) is easy to implement and it tracks the MPP even at varying conditions, hence IC method is implemented in this paper [9, 10].

The MPPT algorithm gives the duty cycle at which the DC-DC converter should be operated [11]. Boost converter has been used in this paper as the PV voltage needs to be increased to the DC grid voltage level for integrating PV array to DC grid.

1.2. Micro Turbine Generator System

Since the PV power varies with time, it needs another DG system to match the load requirement. The Distributed generation using micro turbine generator (MTG) is a realistic and classic solution because it is small in size, environment friendly, durable, high energy efficient and fuel flexible [13, 14].

MTG works on Brayton cycle. Single shaft MTG system can be implemented using many models like Rowen's original model, Rowen's modified model, Rowen's simplified model, IEEE model, CIGRE model, GAST governor model, Frequency dependent model. For weak systems the frequency dependent model is used [15]. Single shaft MTG is modelled in this paper using Rowen's simplified model [14, 16].

Single shaft MTG systems use different interfacing topologies for connection to grid/isolated load. DC link with passive rectifier and inverter is used. There are different schemes for the control of the inverter, like PQ control, PV control and VF control. For a standalone system VF control is used [14]. In this paper AC-DC-AC conversion is done by a three phase diode bridge rectifier and three phase PWM inverter in combination with DC link.

1.3. Ultra Capacitor System

Ultra capacitors (UC) also called super capacitors and electric double layer capacitors (EDLC) are capacitors with values reaching up to 400 Farads in a single standard case. The advantages of ultra capacitor are high power density, low cost per cycle, long life time, very high rate of charge and discharge, environment friendly, good reversibility, extremely low internal resistance (ESR) and light weight [19].

The equivalent model of the ultra capacitor is a resistance in series with a parallel RC circuit [20]. The design of the ultra capacitor bank required is carried out according to method implemented in [21].

The load variations will be reflected as change in DC bus voltage. To mitigate these variations UC system is connected to DC bus through a bidirectional converter. Which will facilitate power absorption as well as power feeding. The control of the converter is achieved by using 2 PI controllers for the dc voltage and the ultra capacitor current [22].

2. PV Modelling

The basic equation for I-V characteristic of the photovoltaic module is given in equation (1).

$$I = I_{pv} - I_o\left[\exp\left(\frac{v + IR_s}{av_t}\right)\right] - \left[\frac{v + IR_s}{Rp}\right] \tag{1}$$

The equivalent circuit of the one diode model of PV cell is in Figure. 1.

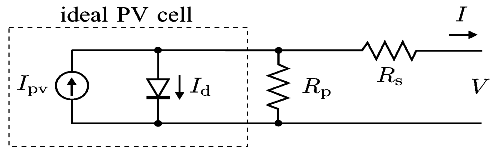

Figure. 1 Single diode model

For a PV array with N_{ser} modules in series and N_{par} modules in parallel and the equivalent circuit is as shown in Figure. 2 [2].

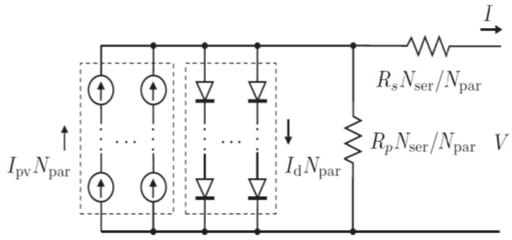

Figure. 2 Equivalent circuit of PV array

The I-V characteristic equation of the photovoltaic array is as shown in equation (2,3,4).

$$I = N_{par}I_{pv} - N_{par}Io\left[\exp\left(\frac{V + IR_s\frac{N_{ser}}{Npar}}{aV_tNser}\right)\right] - \frac{V + IR_s\frac{N_{ser}}{Npar}}{R_p\frac{N_{ser}}{Npar}} \tag{2}$$

$$I_o = \frac{I_{scn} + K_I\Delta_T}{\exp\left(\frac{V_{ocn}Kv\Delta_T}{aV_t}\right) - 1} \tag{3}$$

$$I_{pv} = \left(I_{pvn} + K_I \Delta_T\right) \frac{G}{G_n} \quad (4)$$

The PV array characteristics are shown in the Figure. 3.

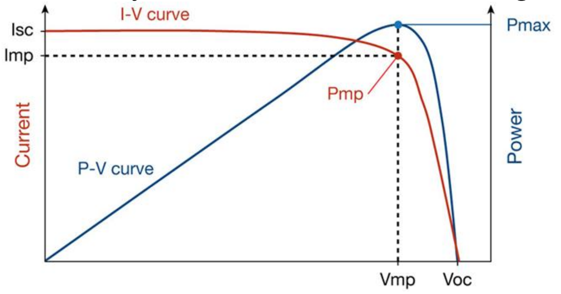

Figure. 3 PV array characteristics

2.1. Parameters Estimation

For parameter estimation from datasheets, PV array Manufacturers do not provide required parameters. All PV array datasheets bring basically the following information as shown in equation (5, 6).

$$R_p = \frac{V_{mp}\left(V_{mp} + \mathrm{I}_{mp} R_s\right)}{\left\{ I_{pv} V_{mp} - I_o V_{mp} \exp\left[\frac{V_{mp} + \mathrm{I}_{mp} R_{sq}}{a N_s K T}\right] + I_o V_{mp} - P_{\max e} \right\}} \quad (5)$$

For initial calculations, the R_s = 0 and

$$R_{p\,\min} = \frac{V_{mp}}{I_{scn} - \mathrm{I}_{mp}} - \frac{V_{ocn} - V_{mp}}{\mathrm{I}_{mp}} \quad (6)$$

And the nominal photo voltaic current is as shown in equation (7).

$$I_{pvn} = \frac{R_p + R_s}{R_p} I_{scn} \quad (7)$$

The I-V points are easily obtained by numerically solving G(V, I) = I − F(V, I) = 0. To solve the above equation Newton method is used. The complete algorithm for parameter estimation is as shown in Figure. 4 [2].

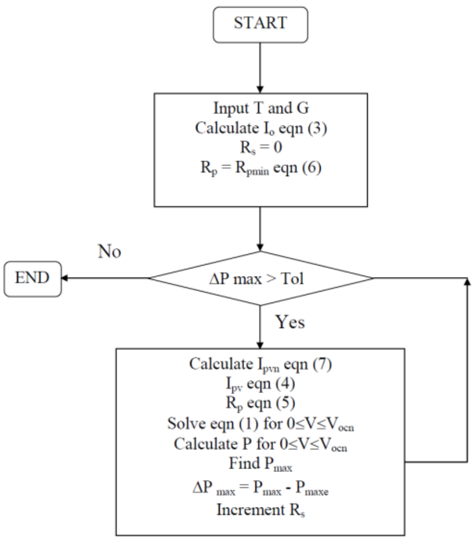

Figure. 4 Parameter estimation algorithm

2.2. Incremental Conductance Algorithm

The basic idea of IC is that the slope of *P-V* curve becomes zero at the MPP and a relative location of operating point for MPP can be found by looking at the slopes of PV characteristics. Figure. 5 shows the Incremental Conductance algorithm.

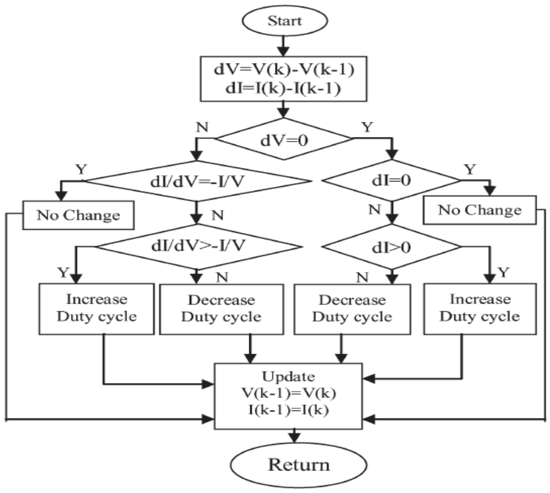

Figure. 5 Incremental Conductance algorithm.

In practice, the condition *dP/dV* = 0 (or *dI/dV* = *-I/V*) seldom occurs, thus, a small margin of error (*e*) should be allowed *dP/dV* = ±*e* and is obtained as shown in equation (8). The value of *e* is optimized based on steady-state tracking error and a risk of oscillation of the operating point. A simple proportional integral (PI) control can then be used to drive *e* to zero [10].

$$\frac{I}{V} + \frac{dI}{dV} = e \quad (8)$$

2.3. DC-DC Boost Converter

The boost converter increase the input voltage to the required higher level. The boost converter configuration is as shown in the Figure. 6 .

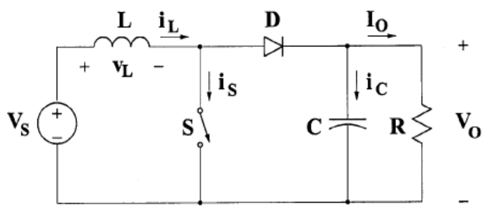

Figure. 6 Boost Converter

The dc voltage transfer function turns out to as shown in equation (9).

$$\frac{V_o}{V_s} = \frac{1}{1-d} \quad (9)$$

The current ripple as shown in equation (10).

$$\frac{\Delta I_L}{I_L} = \frac{R_d\left(1-d\right)^2}{LF} \quad (10)$$

The voltage ripple as shown in equation (11)

$$\frac{\Delta V_o}{V_o} = \frac{d}{RCF_s} \quad (11)$$

3. Micro Turbine Modelling

This paper uses slow dynamics of the MTG system for power management of MTG combined with other DG system [14]. Figure. 7 shows the per-unit representation of a micro turbine, along with its control system.

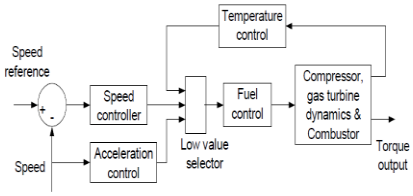

Figure. 7 Block diagram of a micro turbine

3.1 . Speed and Acceleration Control

The speed control operates on the speed error signal formed between a reference (one per-unit) speed and the MTG system rotor speed. In this work a lead lag transfer function has been used to represent the speed controller, as shown in Figure. 8.

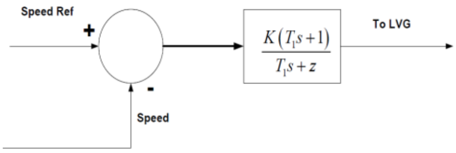

Figure. 8 Speed Control

3.2. Fuel Control

Fuel system consists of the fuel valve and actuator. Fuel Control system is as shown in Figure.9.

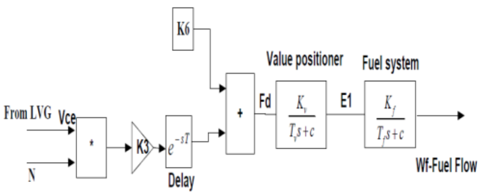

Figure. 9 Fuel Control system

3.3 Compressor and Turbine

The compressor-turbine is essentially a linear, non dynamic device. The torque characteristic of single shaft gas turbine is given by the equation (12).The block diagram of the compressor-turbine package is shown in Figure. 10.

$$Torque = K_{HHV}\left(W_{f2} - 0.23\right) + 0.5\left(1-N\right) \quad (12)$$

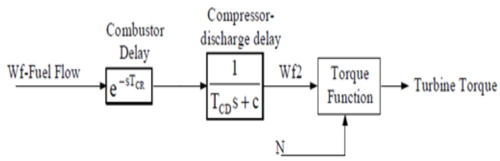

Figure. 10 Compressor and Turbine system

3.4 Permanent Magnet Synchronous Generator

Few assumptions are made in the modelling such as Saturation is neglected [17]. With the assumptions the stator dq equations are as given in equations 13 through17and are:

$$\frac{dI_d}{dt} = \frac{V_d}{L_d} - \frac{RI_d}{L_d} + \frac{L_q}{L_d} pw_r I_q \quad (13)$$

$$\frac{dIq}{dt} = \frac{V_q}{L_q} - \frac{RI_q}{L_q} + \frac{L_d}{L_q} pw_r I_d - \frac{\lambda pw_r}{L_q} \quad (14)$$

$$T_e = 1.5p\left(\lambda I_q + \left(L_d - L_q\right) I_d I_q\right) \quad (15)$$

$$\frac{dw_r}{dt} = \frac{1}{J}\left(T_e - Fw_r - T_m\right) \quad (16)$$

$$\frac{d\theta}{dt} = w_r \quad (17)$$

4. UC Modelling

Equivalent circuit of a ultra-capacitor unit is as shown in Figure. 11 [20].

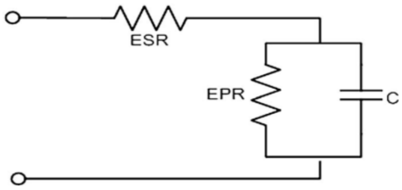

Figure. 11 Ultra capacitor equivalent circuit

For an ultra-capacitor bank, the energy E_{uc} given by equation (18)

$$E_{uc} = \frac{1}{2} C_t \left(V^2 \max - V^2 \min\right) \quad (18)$$

The total capacitance, C_t and series resistance ESR_T are given by equations (19)and (20).

$$C_r = \frac{N_p}{N_s} C_{uc} \quad (19)$$

$$ESR_T = \frac{N_s}{N_p} ESR_{uc} \quad (20)$$

N_s is the number of individual capacitor connected in series is as shown in equation (21)

$$N_s = \frac{V \max}{V_{uc}} \quad (21)$$

Where N_s is the number of individual capacitor connected in series, N_p is the number of capacitor branches connected in parallel, V_{uc} is individual capacitor voltage, ESR_{uc} is individual capacitor series resistance and C_{uc} is the individual capacitance of the capacitor.

4.1 Bidirectional DC-DC Converter

To mitigate the voltage variations, UC system will be connected to DC bus through a bidirectional converter. Bidirectional converter will facilitate power absorption as well as power feed. The schematic of the bidirectional converter is as shown in Figure. 12.

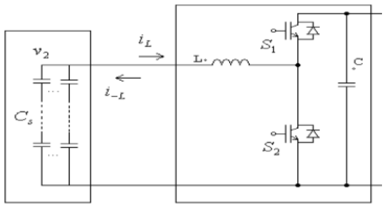

Figure. 12 Bidirectional DC-DC converter

5. Hybrid System

The Photo voltaic (PV) system consists of the PV array, which gives the DC power under varying temperature and irradiation conditions. The PV array when connected to the DC grid has output voltage less than DC grid voltage. So a DC- DC Boost converter, which boosts the PV output voltage to the DC grid voltage level, is to be used for connecting the PV model to the grid.

The Micro turbine generator system consists of Micro turbine, PMSG, 3 phase diode bridge rectifier and Buck converter. Micro turbine generator gives AC output but at very high frequency, so a 3 phase full wave bridge diode rectifier is used for converting AC to DC. DC – DC Buck converter is used for getting a constant DC grid voltage as output, so that the rectified output can be connected to the DC grid.

The ultra capacitor bank is connected to the DC grid using a bidirectional dc-dc converter. The UC bank is used for maintaining constant voltage under varying load conditions.

A 3ϕ inverter is used for converting DC power to AC. To reduce the harmonics in the inverter AC output, a LC low pass filter is used. The load is connected to the AC bus. The AC bus is not connected to grid as this is a standalone system. The hybrid PV/MTG/UC standalone system is as shown in the Figure. 13.

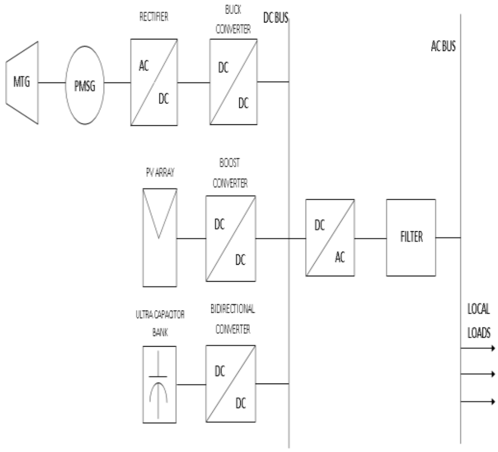

Figure. 13 PV/MTG/UC hybrid standalone system

6. Results

6.1.PV Module Parameter Estimation

The adjusted values of the KC200GT module with parameter estimation algorithm are as shown in Table 1. The algorithm implementation with I-V curve-adjusting Rs and Rp and P-V curve-adjusting peak power are as shown in the Figure. 14 and 15 respectively.

Table.1. Adjusted parameters of PV module

R_{pmin}	42.966 ohm
R_p	415.405 ohm
R_{smax}	0.867 ohm
R_s	0.221 ohm
a	1.300
$P_{max,m}$	200.143 W
$P_{max,e}$	200.143 W
P_{error}	0.000
I_{pv}	8.214 A
I_{sc}	8.210A
I_{on}	0.000A

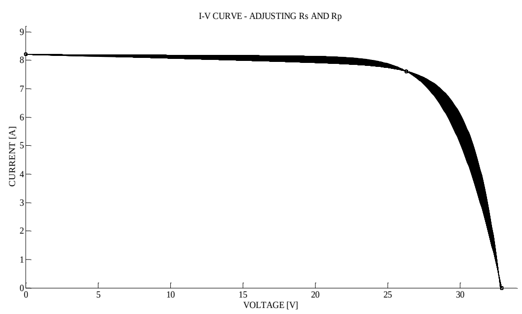

Figure. 14 I-V curve - adjusting Rs and Rp

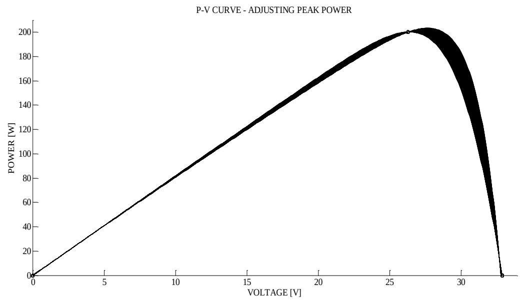

Figure. 15 P-V curve - adjusting peak power

6.2. PV/MTG Hybrid system

The one diode model with Rs and Rp is implemented in MATLAB/ SIMULINK [2]. A PV array of capacity 6 KW is connected to the DC link, through a DC-DC boost converter. The Incremental conductance method is used as MPPT. The MPPT block gives the duty cycle at which the boost converter should operate. The incremental conductance is implemented with a PI control and error margin of ±0.02. The 6 KW PV system is connected in parallel with a 30 KW MTG system. The DC output of the boost converter in PV system is connected to the DC link of the MTG system. The micro turbine system has the micro turbine model connected to a PMSG. The PMSG output is connected to a 3 phase diode bridge rectifier, for converting high frequency AC to DC [14]. Since the connection can be done only at common DC voltage, the output of the rectifier in MTG is connected to a buck converter with PI control. The PI control regulates the MTG system DC voltage to a lower level of 700 V. A 3 phase SPWM inverter is used for converting the DC to 50 Hz AC. The VF control is used for the voltage control of inverter [14]. The load is varied from 15 KW at t=0 to 20 KW at t=5. The RMS line voltage is 440 V. The hybrid standalone system involving PV / MTG is implemented in simulink as shown in Figure.16. The PV array system implemented in simulink is shown in the Figure. 17. The Micro turbine system implemented in SIMULINK is as shown in Figure. 18 and the voltage control subsystem is as shown in Figure. 19.

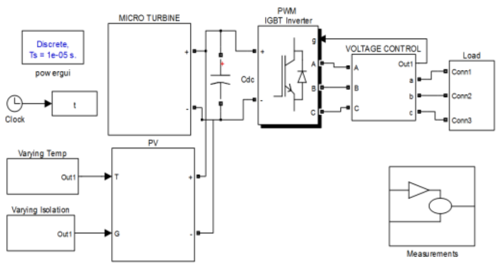

Figure. 16 Standalone PV / MTG hybrid system

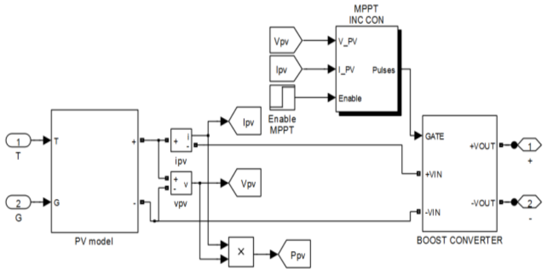

Figure. 17 Simulink PV system model

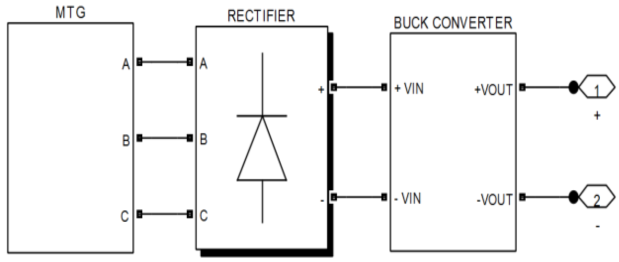

Figure. 18 The Micro turbine subsystem

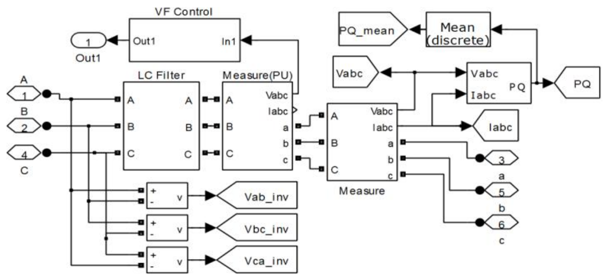

Figure. 19 Voltage control subsystem

The temperature is varied from 25ºC to 45ºC in steps of 5ºC for every 2 seconds and irradiation is varied from 400 to 800 W/M^2 in steps of 100 W/M^2 for every 2 seconds. The variations are shown in Figure. 20.

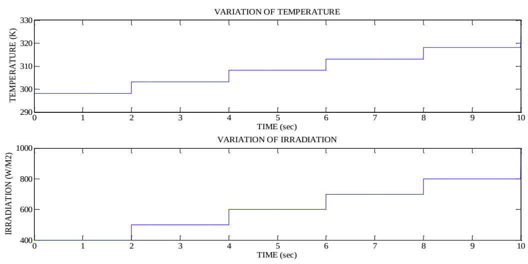

Figure. 20 Temperature and Irradiation variations

The MPPT tracks the maximum power point with nearly 98 % effectiveness even for variations in temperature and irradiation. The tracking ability of MPPT for various changes in temperature and irradiation is as shown in Figure. 21. The boost converter gives output power with efficiency of nearly 92 %.The load is 15KW for first 5 seconds and 20KW for next 5 seconds. The PV is primary and MTG is secondary power source. Speed,tourque and power of MTG are shown in Figure. 22. The deficit power is given by MTG to match the load power as shown in Figure. 23. The load phase voltage Vabc and current Iabc at 7.2 and 7.3 sec are shown in Figure. 24.

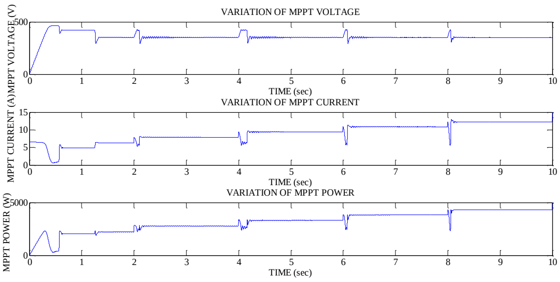

Figure. 21 MPPT voltage, current and power waveforms

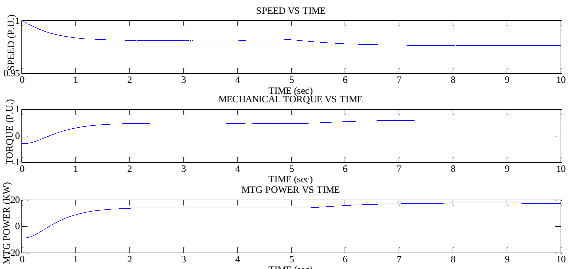

Figure. 22 Speed,tourque and power of MTG

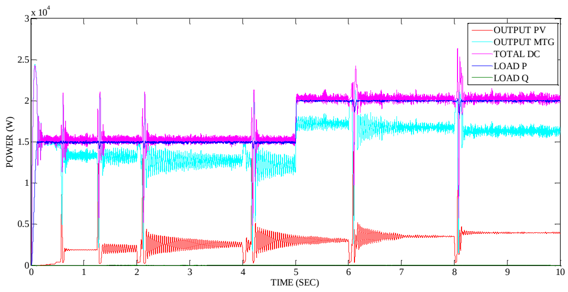

Figure. 23 Power in PV/MTG system

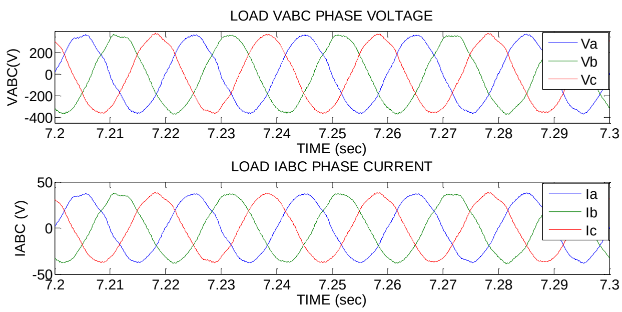

Figure. 24 Part of Vabc and Iabc

6.3. PV/MTG/UC Hybrid system

The only difference between the PV/MTG/UC hybrid system and PV/MTG hybrid system is that, there is an ultra capacitor system connected to the DC link in the PV/MTG/UC hybrid system. All other models and their parameters are the same. The temperature, irradiation and load are also varied the same. The hybrid system of standalone PV / MTG/ UC is implemented in simulink as shown in Figure. 25. The UC subsystem is implemented as shown in Figure. 26.

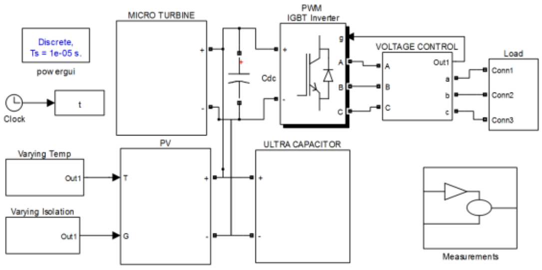

Figure. 25 PV/MTG/UC hybrid system

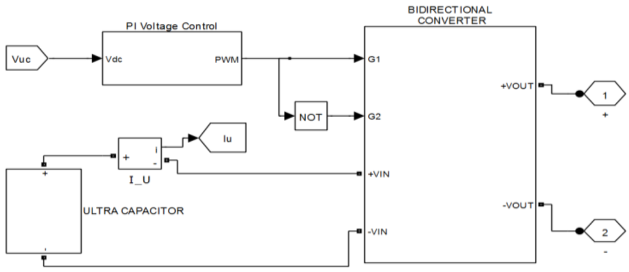

Figure. 26 Ultra capacitor subsystem

The bidirectional converter control system is impleneted in simulink [22]. The MPPT voltages, current and power are obtained as shown in Figure. 27. The speed,torqueand power of MTG system are shown in Figure. 28. The comparison of the voltage at DC link in PV/MTG hybrid system and PV/MTG/UC hybrid system is as shown in Figure. 29. Power of PV/MTG/UC hybrid system are shown in Figure. 30. The load phase voltage Vabc and phase current Iabc at time 7.2 and 7.3 seconds are shown in Figure. 31.

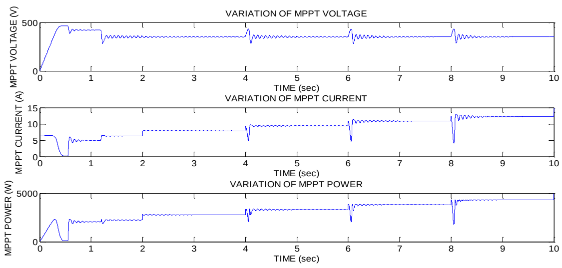

Figure. 27 MPPT voltage,current and power waveforms

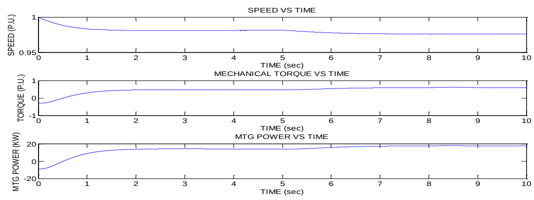

Figure. 28 Speed,tourque and power of MTG

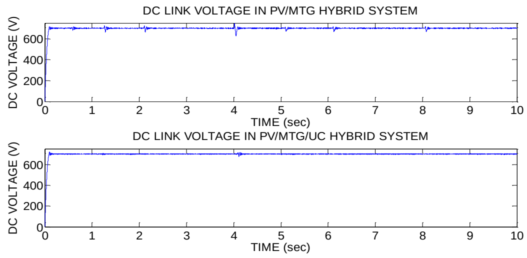

Figure. 29 Comparison of DC link voltages

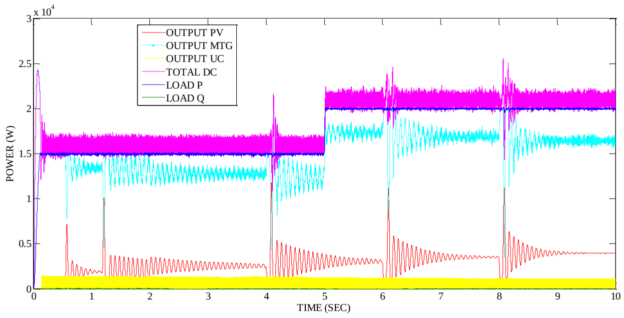

Figure. 30 Power of PV/MTG/UC hybrid system

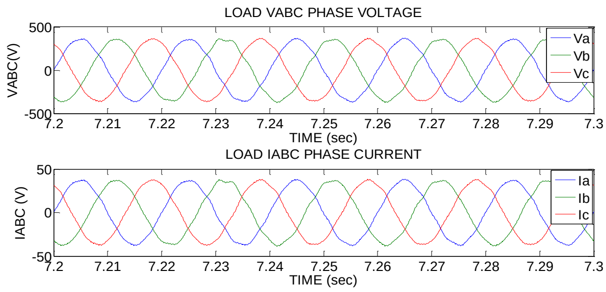

Figure. 31 Part of Vabc and Iabc

The load matching is done as per the requirement i.e. 15 KW for first 5 seconds and 20 KW for the next 5 seconds. The MPPT is tracking the MPP with 98% efficiency and the PV output power is around 92 % . The MTG is generating the deficit power to meet the load requirement. The speed of the MTG drops to 0.981 p.u. for 15 KW and 0.976 for 20 KW. The ultra capacitor makes the DC link voltage to be almost constant at 700 V. The rms phase voltage is 255 V and frequency is 50 Hz.Thus the standalone PV/MTG/UC hybrid system is implemented.

Specifications of PV/MTG/UC hybrid system are as shown Table. 2.

Table. 2. Parameters of PV/MTG/UC hybrid system

System	Parameters
KC200GT PV module (STC)	I_{mp} = 7.61 A, V_{mp} = 26.3 V,$P_{max,e}$ = 200.143 W, I_{sc} = 8.21 A,V_{oc} = 32.9 V, K_v = -0.1230V/K,K_i = 0.0032A/K, N_s = 54.
PV array	N_{ss} = 15, N_{pp} = 2, P_{max} = 6 KW.
Boost Converter	ΔIo = 20 %, ΔVo = 5 %, Fs = 10 KHz, L = 7e-3,C = 50e-6, C1 = 5000e-6
Buck Converter	Kp = 0.001, Ki = 1, L = 4 mH,C = 10 μF, Fs = 10 KHz.
PMSG	R = 0.25 Ohms, P = 1,L_d = L_q = 0.6875 mH, λ = 0.0534 Wb, J = 0.006 Kgm^2.
Inverter	Kp = 0.4, Ki = 500, Fs = 2 KHz.
Ultra Capacitor Bank	R_{suc} = 0.29 mΩ, C_{uc} = 15.6771 F,V_{uc} = 2.7 V, N_s = 140,N_p = 1,C_t = 0.1120 F, R_t = 40.6 mΩ.
Bidirectional Converter	Lu = 7 mH, Fs =10 KHz,K_p = 0.01, K_i = 1.
Load	Line voltage = 440 V rms, F = 50 Hz.

7. Conclusions

The available power from the renewable energy sources is highly dependent on the environmental condition such as radiation, and ambient temperature. To overcome this deficiency of the solar cell it is integrated with the micro turbine generation system. The voltage variation at the DC link is found to have fluctuations within the tolerable band. To reduce the fluctuations at DC link, the ultra capacitor system is connected. The use of ultra capacitor bank has reduced the voltage fluctuations at DC link almost completely and the integrated system generates and suppies matching power in sustainable manner.

References

[1] Y. Mahmoud, W. Xiao, and H. Zeineldin, “A Simple Approach to Modelling and Simulation of Photovoltaic Modules”, IEEE Transactions on Sustainable Energy, vol. 3, pp. 185-186, 2012.

[2] M.Villalva, J. Gazoli, and E. Filho, “Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays”, IEEE Transactions on Power Electronics, vol. 24, pp. 1198-1208, 2009.

[3] K.Ishaque, Z. Salam, H.Taheri, and A. Shamsudin, “A critical evaluation of EA computational methods

for Photovoltaic cell parameter extraction based on two diode model" Elsevier Solar Energy, vol. 85, pp. 1768–1779, 2011.

[4] K. Nishiokaa, N.Sakitanib, Y.Uraokab, and T. Fuyukib, "Analysis of multicrystalline silicon solar cells by modified 3-diode equivalent circuit model taking leakage current through periphery into consideration", Elsevier Solar Energy Materials & Solar Cells, vol. 9, pp. 1222–1227, 2007.

[5] U.Stutenbaeumer, and B.Mesfin, "Equivalent model of mono crystalline, poly crystalline and amorphous silicon solar cells", Elsevier Renewable Energy, vol. 18, pp. 501-512, 1999.

[6] A. Conde, F. Sanchez, and Juan Muci, "New method to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I–V characteristics", Elsevier Solar Energy Materials & Solar Cells, vol. 90, pp. 352–361, 2006.

[7] M. Zagrouba, A. Sellami, M. Bouaicha, and M. Ksouri, "Identification of PV solar cells and modules parameters using the genetic algorithms: Application to maximum power extraction", Elsevier Solar Energy, vol. 84, pp. 860–866, 2010.

[8] M. Merbaha, M. Belhamelb, I. Tobiasa, and J. Ruiza, "Extraction and analysis of solar cell parameters from the illuminated current–voltage curve", Elsevier Solar Energy Materials & Solar Cells, vol. 87, pp. 225–233, 2005.

[9] T.Esram, *and* P. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", IEEE Transactions on Energy Conversion, vol. 22, pp. 439-449, 2007.

[10] N.Onat, "Recent Developments in Maximum Power Point Tracking Technologies for Photovoltaic Systems", International Journal of Photo energy, Vol. 2010, no. 245316, pp. 1-11, 2010.

[11] A.Safari, and S.Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter", IEEE Transactions on Industrial Electronics, vol. 58, pp. 115-1161, 2011.

[12] M.Rashid, Power Electronics Handbook, San Diego, California, USA, Academic press, 2001.

[13] D. Gaonkar, and S. Nayak, "Modelling and Performance Analysis of Microturbine Based Distributed Generation System, A review", IEEE Energy tech, Cleveland, USA, pp. 1-6, 2011.

[14] D. Gaonkar, and R. Patel, "Modelling and simulation of micro turbine based distributed generation system", Proceedings of the IEEE Power India conference, New-Delhi, India, pp. 256-260, 2006.

[15] S.Yee, J. Milanovic, and F. Hughes, "Overview and Comparative Analysis of Gas Turbine Models for System Stability Studies", IEEE Transactions on Power Systems, vol. 23, pp. 108-118, 2008.

[16] S. Guda, C. Wang, and M. Nehrir, "A simulink based micro turbine model for distributed generation studies," Proceedings of the 37th Annual Power Symposium, pp. 269-274, *2005*.

[17] G.Ofualagba, "The Modelling and Simulation of a Micro turbine Generation System", International Journal of Scientific & Engineering Research, Vol. 2, pp. 1-7, 2012.

[18] H.Nikkhajoei, and M. Iravani, "A Matrix converter based micro turbine distributed generation system", IEEE Transaction on Power Delivery, vol. 20, pp. 2182-2192, 2005.

[19] M. Jayalakshmi, and K. Balasubramanian, "Simple Capacitors to Supercapacitors - An Overview", International Journal on Electrochemicals Science, vol. 3, pp. 1196 – 1217, 2008.

[20] A. Santhoshakumar, D. Gaonkar, and S. Nayak, " Performance Study of Grid Connected Fuel Cell Based Distributed Generation System with Ultra capacitor", IEEE PES Conference on Innovative Smart Grid Technologies, Jeddah, Saudi Arabia, pp. 1- 4, 2011.

[21] S. PrashantKumar, S. Shetty, and S. Chacko, "Application of Super Capacitor Energy Storage in Microgrid System", IEEE GCC Conference and Exhibition, Dubai, UAE, pp. 581-584, 2011.

[22] J. Cho, and W. Hong, "Power control and modelling of a solar ultra capacitor hybrid energy system for stand-alone applications", International Conference on Control, Automation and Systems, Gyeonggi-do, Korea, pp.811- 814, 2010.