BEHAVIOURAL ANALYSIS OF MICROGRID: A SUBSET OF SMART GRID

Dharshini G[1], Ramya J Rao[2], Sangeeta Modi[3]

[1]*Department of Electrical and Electronics PES University, Bangalore, India*
[2]*Department of Electrical and Electronics PES University, Bangalore, India*
[3]*Department of Electrical and Electronics PES University, Bangalore, India*

Abstract

Microgrid is a integration of distributed energy resources which can be tied to the utility grid through power electronic interface. The proposed system can be employed for rural electrification. In this paper active (P) and reactive (Q) power control is implemented for AC microgrid system in grid- connected mode. The power electronic interface used in the sytem is the multilevel inverter. The sources are coupled through three level inverter and connected to the utility grid. The selected microgrid configuration includes a 24kW of photovoltaic cell module, 20kW of PMSG based wind turbine module, fuel cell stack of 9.6kW. The PQ control strategy is applied to the three level inverter to maintain the system voltage and frequency. A phase locked loop is employed in the control strategy to synchronize utility grid and the microsources. The decoupled current (I_d & I_q) is used to control active and reactive power through PQ control algorithm and it is applied to inverter. Active and reactive power is controlled using I_d and I_q respectively. The control strategy is simulated in MATLAB/Simulink.

Keywords—*Microgrid, Distributed Energy Sources, Control of Microgrid, Grid-Connected Mode, Inverter Control*

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1. INTRODUCTION

The microgrid(MG) is energy system consisting of distributed energy sources, it is solution to the increasing energy demand and the alternative to the existing conventional grids. It can operate independently and even it can be connected to the utility grid. It reduces the green house effect using renewable energy sources. A small scale microgrid behaves as a basic system for future smart grids. Introducing microsources(MCs) to the grid will provide continuous power flow to the consumers.

The decentralized and centralized are the controls applied to microgrid. In centralized approach, the sources are controlled from a central master controller and this operates with large bandwidth for the control. In decentralized approach, the individual sources are controlled with individual local controller as per the capability of distributed energy sources for power flow[1], [2].

The inverter control strategy used in this system implements the P and Q control using decoupled currents. The MG voltage and frequency should be properly matched with main grid frequency and voltage in grid connected mode. [3][8].

The microgrid has PV, wind and diesel system.[4] The PV system is modeled with a DC/AC inverter with a MPPT for tracking maximum power and fixed turbine induction generator based wind turbine is used. This system studies the intermittent operation of microgrid between the sources.

The hybrid system in islanded mode of operation with PV, wind turbine and fuel stack is reported in [5]. In this system inverter output is connected to a RLC load for the power analysis with constant DC link voltage.

2. SYSTEM DISCRIPTION

The schematic diagram of a AC microgrid system under study is as shown in the Fig.1. The distributed energy sources used are photovoltaic panel, wind turbine and fuel stack. All the microsources are connected to the common DC link and through inverter it is integrated to the grid

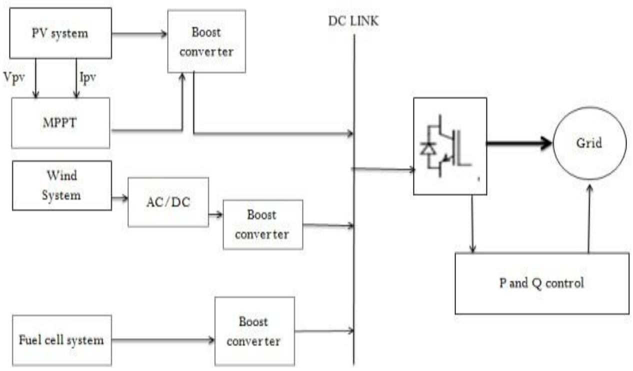


Fig.1. Schematic diagram of hybrid system

2.1 Photovoltaic System

The PV system is designed to generate power of 24kW of rated power regarding 25 degree Celsius and irradiation of 1000W/m^2. The irradiation is oscillated between 250W/m^2 and 1000W/m^2, to track this irradiation at maximum power point(MPP) the tracking algorithm is needed. Incremental conductance is the MPPT technique used in this system. The MPPT is used to reduce the oscillations in power and losses, and it is done by dc-dc boost converter by adjusting the duty cycle. Table 1 gives the parameters for the PV cell which can be changed as per the commercial PV value.[4]

$I = I_{sat}$ [exp(V_d / V_T)] (1)
I = Diode current (A)

I_{sat} = Saturation current of diode. (A)
V_d = Diode voltage (V)

V_T = Temperature voltage.
$V_T = (k.T) / (q.Q_f.N_{mod}.N_{str})$ (2)
T= cell temperature(K)
k= Boltzman constant= 1.3806J.K^-1
q= Electron charge= 1.6022e-19 C
Q_f= Diode quality factor
N_{mod}= Number of series connected cells per module
N_{str}= Number of series connected modules per string

2.2 Wind Turbine System

The PMSG based wind turbine is used, it is a variable speed wind turbine. The variable speed turbine is more efficient than fixed speed wind turbine. An uncontrolled diode bridge rectifier is used between the wind generator terminals and the input of boost converter. The wind module is connected to the common DC link. Table 1 gives the parameters of wind system.

The mechanical power (P) delivered by wind turbine can be expressed as in (3)

$$P = C_p (\lambda_w, \beta_w) \rho A_w v^3{}_w / 2 \quad (3)$$

Where power coefficient of the turbine is C_p, ρ is the air density (kg/m3), A_w is turbine swept area (m^2), v_w is wind speed (m/s), β_w is blade pitch angle (degree) and λ_w is tip speed ratio given by (3). [4]

$$\lambda_w = \omega_r R / v_w \quad (4)$$

2.3 Fuel Stack

The fuel cell employed in the system is alkaline fuel cell (AFC) and preset model is available in simulink is used. The electrochemical reactions are used to convert chemical energy of fuel cell to electrical. The Table 1 gives the design parameters of fuel cell.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (5)$$

$$O_2 + 2H_2O + 2e^- \rightarrow HO^- + OH^- \quad (6)$$

$$HO^- + H\ O + 2e^- \rightarrow 3OH^- \quad (7)$$

Table 1: Design parameters of AC microgrid system

Solar energy plant	
Rated power of each panel	305.6 W
Open circuit voltage (V_{oc})	64.2 V
Maximum power voltage	54.7 V
Short circuit current (I_{sc})	5.96 A
Maximum power current	5.58 A
Series panel in each array	5
Number of parallel array	16
Wind energy plant	
Generator type	PMSG
Nominal voltage	960 V
Rated power	20kW
Maximum power	20kW
Rated speed	12m/s
Stator phase resistance	0.0485Ω
Torque	1800Nm
Fuel Cell Energy Plant	
Number of Cell	68
Maximum Current	50
Vnom at Max. operating point	48
Nominal stack efficiency (%)	58
Nominal supply pressure [Fuel (bar), Air (bar)]	[6 1]
Nominal Air flow rate (lpm)	300

2.4 Multilevel Invereter

Inverter is the power electronic device for the conversion of DC signal to AC signal. The multilevel inverter is used as an alternative to the high power and medium voltage. It is easily used in renewable energy sources for interfacing to the utility grid as it is high power applications. The main advantage of using multilevel inverter is to reduce harmonics. Through common DC link inverter is interfaces distributed energy sources to the utility grid.

3. CONTROL STRATEGY

The microgrid implemented uses centralized control, it uses an control strategy for controlling P and Q. This control 2 is applicable only when distributed energy resources are integrated to the utility grid. The reference will be considered from utility grid voltage and frequency. [7][8]

The basic principle of PQ inverter control strategy is to control active and reactive power instantaneously and independent of each other. Fig 2 shows the P and Q control scheme for inverter. This control principle operates in dq reference frame and hence obtained three phase voltage is converted from abc to dq reference frame through Park's transformation. The PLL technique is employed to detect the phase angle of grid voltage to synchronize the delivered power. The input to PLL is three phase grid voltage and current and tracked phase angle is the output from PLL. The phase angle is tracked using the PI regulator.

The outer control loop controls the current from measured DC link (V_{dc}) and the reference V^{*}_{dc}. Active power flow or dc voltage level is controlled with I_d. Similarly, reactive power is controlled with I_q under grid connection.

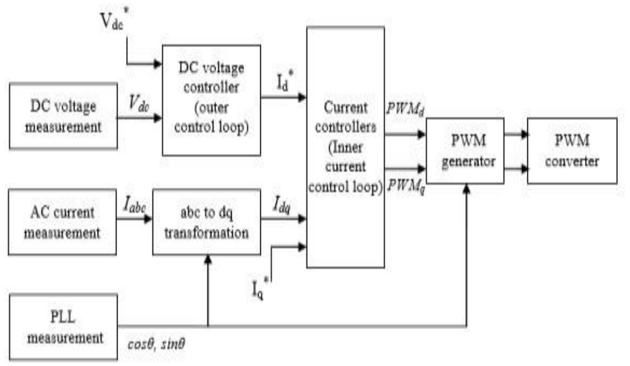


Fig 2. PQ control strategy

The inner current control loop takes the error between the reference current and measured current as input. The PI regulator is used to rgulate the error and the decoupling terms. The desired converter voltage is obtained in dq reference frame. This is given as control to inverter through pulse generator. [7][8] The equation 8 shows the power calculation in dq reference frame.

$$P = v_d i_d + v_q i_q$$

$$Q = v_q i_d + v_d i_q \qquad (8)$$

4. SIMULATION RESULT

The selected AC Microgid test bed is simulated as in fig 3 and performed to analyze the generated power from each microsources. The below fig 4 shows the output power from each renewable energy sources. Fig 4a shows the power generated from the PV source to the variations in irradiation. The PV source is applied with MPPT (Incremental conductance) to tack the maximum power for different irradiation. 24kW is the power generated from PV. Fig 4b shows the output power of wind for 12m/s wind speed. 14kW is the power from wind. Fig 4c gives the power output from fuel stack. 8kW is the power from fuel.

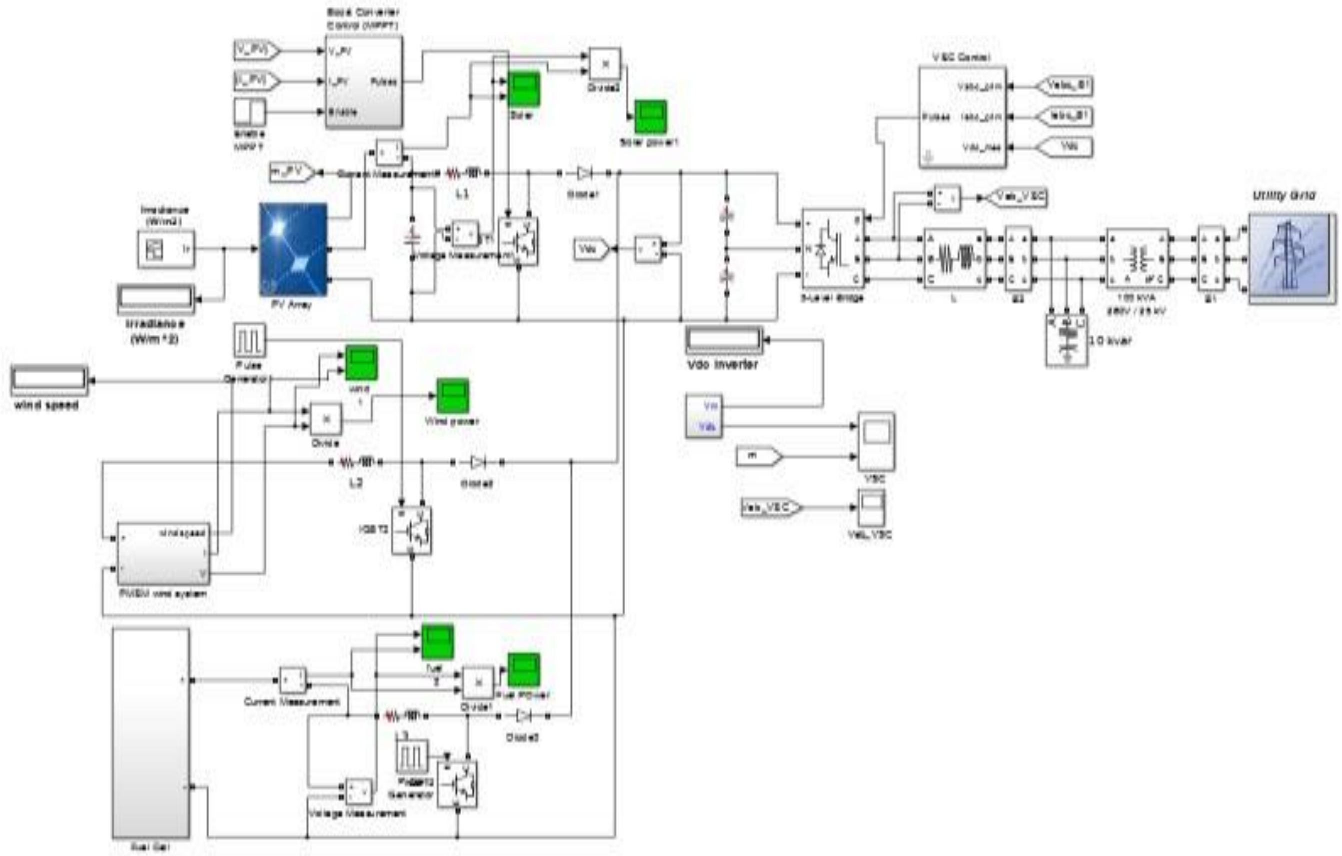
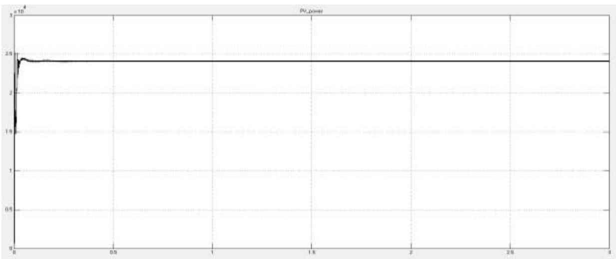


Fig 3. Simulation circuit



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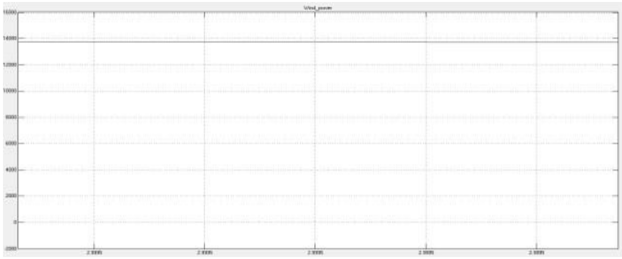

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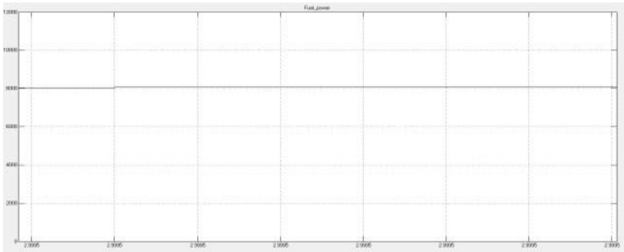


(c)

Fig 4. power generated from (a) PV source (b) Wind source (c) Fuel stack.

The microsources integrated together through a common DC link and an inverter interfaces the distributed energy sources to the utility grid. The 500V is maintained at DC link voltage and fig 5 gives the output of a inverter.

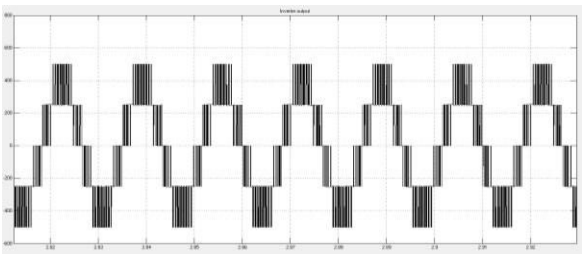
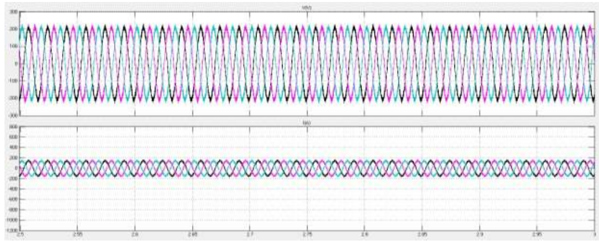


Fig 5. Inverter output waveform.

4.1 Case 1: Grid Connected Mode

The microsources and the uitilty grid supplies the load. The DC link is maintained constant by VSC control by tuning the PI regulators, and the control algorithm uses PLL to maintain the system voltage and frequency. In this case the load is set for 60kW and 100 var. The total capacity of the microsources are 46kW. The microgrid local sources are supplying 44.8kW of real power. The below fig 6 shows load voltage and current, active and reactive power across load. The remaining 15kW and 100var of power to the load is supplied from utility grid as shown below. The fig 7 shows the voltage, current, active and reactive power across the grid. This also indicates that the PLL implemented in Simulink is operating successfully in synchronizing the microgrid with the utility grid.



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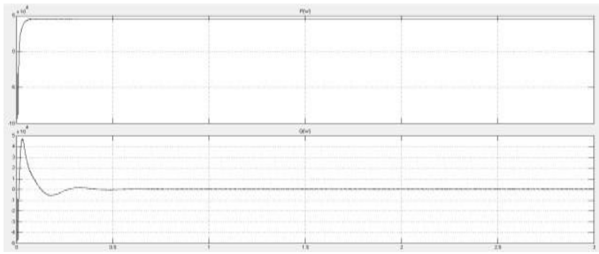
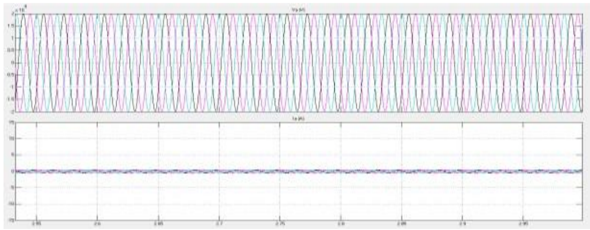


(b)

Fig 6. (a) load voltage and load current, (b)Active and reactive power delivered from sources.



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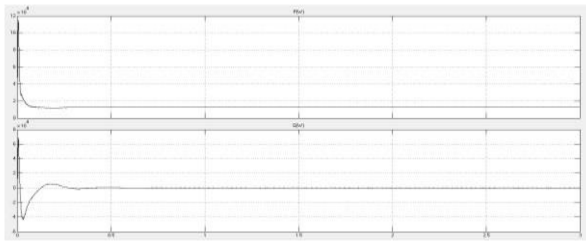


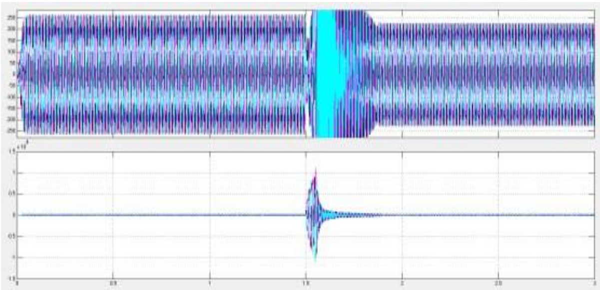
(b)

Fig 7. (a) grid voltage and grid current, (b) power delivered from grid.

4.2 Case 2: Transition from Islanded to Grid Connected Mode

When the system is operating normally the circuit breaker is closed and the sources are operating at rated voltage. When there is any disturbance in the system, the breaker is open. In this case, at start microsources will supply power to the load normally until 1.5s, at 1.501s theirs a disturbance in the system at the breaker is open. Then after 1.501s utility grid supplies power to the load. The total capacity of the load is

50kW. Fig 8 shows the power delivered to the load from microsources, voltage and current waveform. In fig 8a, the voltage waveform shows that until 1.5s the sources are suppling power and after 1.501s theirs is a dip in voltage. The transient is because of sudden switching of breaker, and microsources supply 45kW of power. Fig 9 shows the voltage, current and power delivered to the load from grid. In fig 9a upto 1.5s the current is zero and there is a increase in voltage. In fig 9b the power deliverd to the load of 5kW is shown after 1.5sec.



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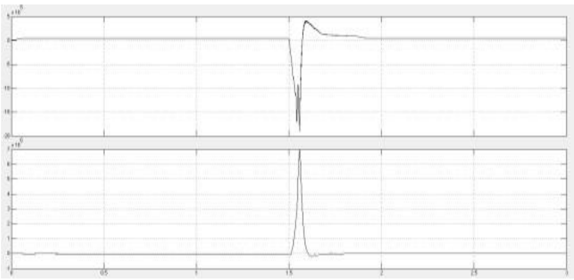
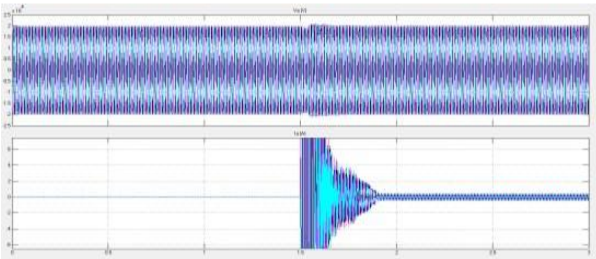


(b)

Fig 8.(a) voltage and current waveform, (b)Active and reactive power delivered from sources.



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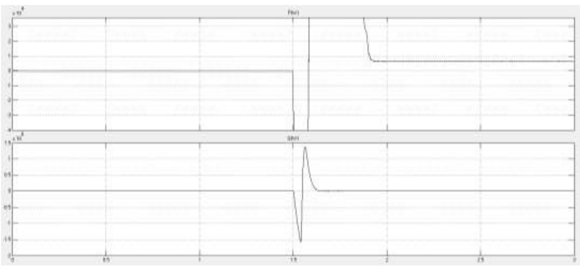

(b)

Fig 9. (a) grid voltage and grid current, (b)Active and reactive power delivered from grid.

5. CONCLUSION

In this paper control strategy for inverter has been implemented to maintain the system voltage and frequency, when microgrid is operating under grid connected mode. The selected AC microgrid consisting of wind module, PV module and fuel cell stack is simulated using MATLAB simulink environment. The simulation results shows that all the DER are sharing power as per their capacity. The power flow is continuous to the load even during the transition from islanded to grid connected mode. The switching transient appeared during transistion from islanded to grid connected mode has to be improved.

REFERENCES

[1]. Hartono B S, Budiyanto, Rudy Setiabudy, “Review of Microgrid Technology”, 2013 IEEE.

[2]. Robert H Lasseter, Paolo Paigi, “ Microgrid: A Conceptual solution”, 2004 35th Annual IEEE Power electronics Specialists Conference.

[3]. Ramon Zamora, Anurag K. Srivastava, "Controls for microgrids with storage: Review, challenges, and research needs", Renewable and Sustainable Energy Reviews, Volume 14, Issue 7, pp. 2009–2018 September 2010.

[4]. Ersan Kabalci, Eklas Hossain, Ramazan Bayindir, “Microgrid Test-bed Design with Renewable Energy Sources”, 2014 IEEE.

[5]. Mohammad S. Alotibe, Ruwan Chandrasena, and Sumedha Rajakaruna, “Simplified Voltage and Frequency Controller Based on Droop Control for the Dynamic Analysis of a Microgrid”, IEEE.

[6]. Liping Su, Guojie Li, Zhijian Jin, “Modeling, Control and Testing of a Voltage-Source-Inverter-Based Microgrid”, 2011 IEEE.

[7]. Yang chen, Jinbin Zhao, Jinlong Wang, Keqing Qu, Shuuichi Ushiki, Masaaki Ohshima, “A Decoupled PQ Control Strategy of Voltage Controlled Inverters”, 2015 9th International Conference on Power Electronics-ECCE Asia.

[8]. G. W. Chang, G. H. Zeng, H. J. Su, L. Y. Hsu, Y. R. Chang, Y. D. Lee, “Modelling and Simulation of INER AC Microgrid Control”, 2014 IEEE.