



Permanent Magnet Synchronous Generator Based Wind Energy Battery Storage System Using Nonlinear Multi Input Multi Output Controller

R.Geetha¹, G.Angalaparameswari¹,
K.Suresh Kumar³,A.Sangeetha⁴

¹Assistant professor, Velammal Engineering College, Chennai.

³Associate professor, Velammal Engineering College, Chennai.

⁴PG scholar, Velammal Engineering College, Chennai.

⁴sangeealan31@gmail.com

April 25, 2018

Abstract

The intend of nonlinear multi-input multi-output controller (MIMO) is to control different sort of loads. Here a solitary controller is used to manage the entire system. Controller equations are derived using Feedback linearization control design technique and be capable of operate in stand alone mode as well as grid connected mode. In this system battery stores back up power competently. The process is performed with diverse type of loads such as balanced three phase, unbalanced three-phase and non linear loads and the result is compared with as well as without MIMO controller.

Key Words:PMSG; MIMO controller; non linear control strategy; storage battery; feedback linearization technique.

1 INTRODUCTION

Wind power generation is developing hastily. Universal install wind power is about 486,790 MW on 2016. It indicates a promote development of additional 12.5% compare to prior year. Control objectives should be warily well thought-out in order to increase the renewable energy generation. The existing wind turbine system is not intended to run mutually in stand-alone and grid-connected modes. If there is any problem in wind generation system the grid will be disconnected from the system and these sorts of circumstances will lead to losses. For this kind of situations a PI regulator is used for the grid-side converter here the active and reactive power are regulated separately. Earlier work needs one or more controllers to regulate each module of the system. Islanding detection is one of the vital issues to be considered with in prior works.

The purpose of this manuscript is to design a non-linear controller for a wind energy system with battery storage. Switching actions are reduced by the usage of single controller. MIMO controller use response linearization design technique in this scheme. The operation of this proposed system is carried out for three different types of loads for stand-alone mode of operation and also supply to grid.

2 MODELLING OF SYSTEM

The fig.1 represents illustration of planned system. The wind energy system is driven by PMSG, here the battery is connected to dc-dc buck boost converter and it regulates the dc link voltage with respect to battery voltage. Switching action is applied to switch from one mode of operation to another. Generally, wind turbine converts the kinetic energy of the wind to mechanical energy and by the use of generator it is transformed into electrical energy. Output of the generator is not constant so a back to back converter synchronizes the output related to grid frequency rate. The mechanism of each component is represented as follows.

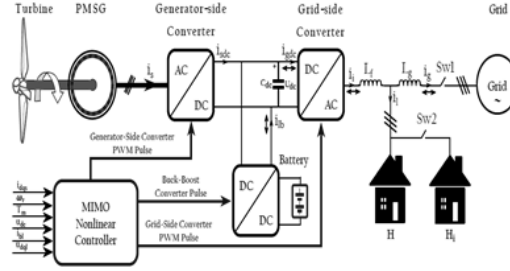


Fig.1. Wind energy conversion system with battery storage unit.

A. Turbine model

The region sweep via the blade, S_w ($S_w = R^2$), speed of wind, w , density of air, ρ , and coefficient of power, C_p , which characterize all turbine. The mechanical power of the turbine is calculated as,

$$P_m = \frac{1}{2} \pi \rho C_p(\lambda, \beta) R^2 v_w^2 \cdot \lambda = \frac{\omega_m}{v_w} \quad (1)$$

R - turbine radius; m -angular speed of the turbine. The wind turbine equation by eliminating the force of friction are derived as,

$$\frac{d\omega_m}{dt} = \frac{P}{J} (T_m - T_e) \quad (2)$$

where P -pole pair, J -generator inertia of momentum, T_m - mechanical torque, T_e - electromagnetic torque.

B. PMSG Configuration

The wind turbine mechanical energy is converted to electrical energy by permanent magnet synchronous generator. The mathematical calculation of the generator is carried out with reference of dq function,

$$u_{ds} = R_s i_{ds} + L_d \frac{di_{ds}}{dt} - \omega_r L_q i_{qs} \quad (3)$$

$$u_{qs} = R_s i_{qs} + L_q \frac{di_{qs}}{dt} + \omega_r L_d i_{ds} + \omega_r \lambda_r \quad (4)$$

where u_{ds} & i_{ds} - d-axis stator voltage and current, u_{qs} & i_{qs} - q-axis stator voltage and current, R_s winding resistance of stator (Ω), L_d and L_q - d-q-axis self-inductances of stator (H) where $L_d = L_q$, ω_r - electrical angular speed of rotor (rad/s), and λ_r flux linkage of rotor (Wb).

C. Design of Buck-Boost Converter

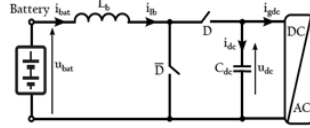


Fig.2. Converter design with battery

The converter is bi-directional, it act as boost converter when battery is in discharging mode and buck converter when it is in charging mode.

D. Design of Battery

In this system a Nickel metal hydride model battery is used to store energy when generation is more and it is connected through buck boost converter.

2.0.1 DESIGN OF NONLINEAR CONTROLLER

A. Proposed Nonlinear Controller Design

Appropriate control signal for each converters can be calculated and generated using MIMO controller. feedback linearization method is used to find controller equation.

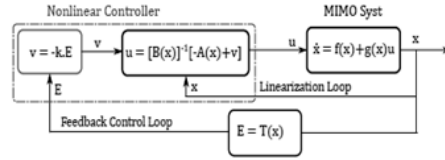


Fig.3. MIMO controller design

The system controls the wind turbine, PMSG, generator side and grid side converter, buck-boost converter and battery charging operation regardless the mode of operation. The variable state vector, control input vector and controlled outputs vector are expressed as,

$$\bar{x} = [i_{ds}, i_{qs}, \omega_r, i_{di}, i_{qi}, i_{bl}, E_{dc}]^T \quad (5)$$

$$\bar{u} = [u_{ds}, u_{qs}, u_{di}, u_{qi}, P_{bat}, D]^T \quad (6)$$

$$\bar{y} = [\tilde{i}_{ds}, \tilde{\omega}_r, \tilde{u}_{dl}, \tilde{u}_{ql}, \tilde{E}_{dc}, \tilde{i}_{lb}] \quad (7)$$

where the output variables symbolize the error of integrals among the variables to be controlled and their reference like $\tilde{i}_{ds} = \int (i_{ds} -$

$i_{ds}^*)d\delta$ and the other output variables are also calculated similarly. The designed closed loop arrangement employs integral action to make sure zero steady status fault.

$$\bar{U} = [B(\bar{X})]^{-1}[-A(\bar{X}) + \bar{v}] \quad (8)$$

Where $\bar{v}$ vector of controlled inputs. The matrix $B(\bar{X})$ is non zero at the stage of regular action. The output $y_d(\bar{X})$ and input $\bar{v}$ gives a steady rapport.

$$y_d(x) = \bar{v} \quad (9)$$

The equation of response characteristics is represent as,

$$v_p = -K_{pq}e_p \quad (10)$$

The response gain matrix k_{pq} where $p \in 1, 2, 3, 4, 5, 6$, and $q \in 1, 2, 3$ and e_p -error among the output variable & reference signal. v_p can be calculated using the following expression.

$$\begin{aligned} v_1 &= -k_{11}\tilde{i}_{ds} - k_{12}\tilde{i}_{ds} \\ v_2 &= -k_{21}\tilde{\omega}_{ds} - k_{22}\tilde{\omega}_{ds} - k_{23}\tilde{\omega}_r \\ v_3 &= -k_{31}\tilde{u}_{dl} - k_{32}\tilde{u}_{dl}; \quad v_4 = -k_{41}\tilde{u}_{ql} - k_{42}\tilde{u}_{ql} \\ v_5 &= -k_{51}\tilde{E}_{dc} - k_{52}\tilde{E}_{dc}; \quad v_6 = -k_{61}\tilde{i}_{lb} - k_{62}\tilde{i}_{lb} \end{aligned} \quad (11)$$

3 RESULT OF MALAB SIMULATION

The simulation are carried out in MATLAB software and the system is designed using the following parameters given table.1

Table 1. Parameters used

Variables	Values	Variables	Values
P_m	2.55 MW	u_g	4kv
ω_m	4.5 rd/s	u_{dc}	8kv
λ_r	26 wb	C_{dc}	1668 μF
p	8	L_f	16.88 mH
j	$4 \times 10^{-3} \text{ kg.m}^2$	L_g	1.688 mH
R_s	24.221 m Ω	F_{gen}	740 Hz
L_{ds}	9.82 mH	F_{grid}	2020 Hz
V_w	16 m/s	u_{ll}	4kv
r	28.18 m	P_l	2.3 MW
ρ	1.23	u_{bat}	4000V
λ_{opt}	8.1	P_{bat}	1.5 MW

Table 2. Contoller Gains k_{pq}

Controller Gains Description	Value
$\hat{i}_{d\pi}$ and $i_{d\pi}$ Gains	$[K_{11}K_{12}]=[500,1].10^3$
$\hat{\omega}_r$, $\hat{\omega}_r$ and $\hat{\omega}_r$ Gains	$[K_{21}K_{22}K_{23}]=[400,45,1.5].10^3$
$\hat{u}_{dl}$ and $\hat{u}_{dl}$ Gains	$[K_{31}K_{32}]=[800,600]$
$\hat{u}_{ql}$ and $\hat{u}_{ql}$ Gains	$[K_{41}K_{42}]=[30,300]$
$\hat{E}_{dc}$ and $\hat{E}_{dc}$ Gains	$[K_{51}K_{52}]=[300,0.3]$
$\hat{i}_{lb}$ and $\hat{i}_{lb}$ Gains	$[K_{61}K_{62}]=[4000,700]$

Two simulation is carried out case 1: The simulation circuit without MIMO controller for various load conditions and, case 2: The robustness of proposed MIMO controller for various load conditions are evaluated .

Table.3 represents the loads used in the simulation and their ratings.

Table 3. Type of Loads

Loads	H ₁	H ₂	H ₃
Type of Loads	three phase balanced series RL	three-phase unbalanced series RL	Nonlinear parallel RC
Value	R ₁ =16Ω L ₁ =16mΩ	R ₂₁ =10Ω L ₂₁ =11mΩ R ₂₂ =20Ω L ₂₂ =11mΩ R ₂₃ =30Ω L ₂₃ =11mΩ	R ₃ =50Ω C ₃ =20nF

The fig.4 show the generator voltage and the current and fig.5 is grid voltage and current.

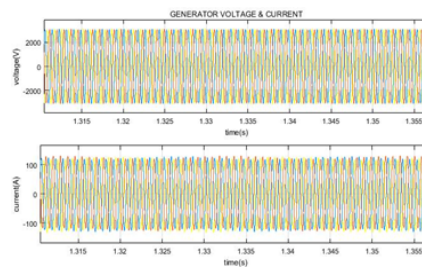


Fig.4 Generator voltage and current

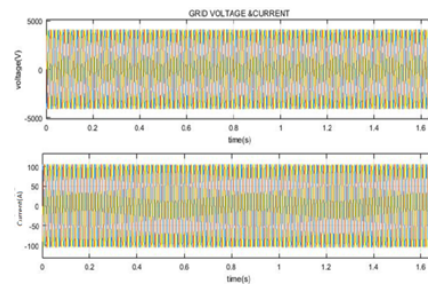


Fig.5 Grid voltage and current

The output for different load conditions without the use of MIMO regulator are as follows.

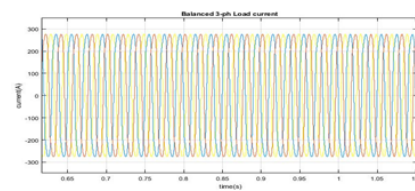


Fig.6 Balanced 3-ph Load current without MIMO controller

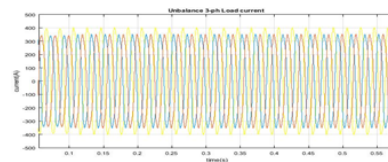


Fig.7 Unbalanced 3-ph Load current without MIMO controller

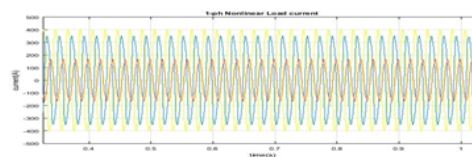


Fig.8 Non linear Load current without MIMO controller

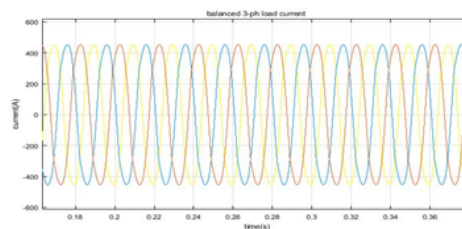


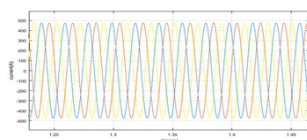
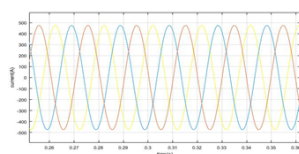
Fig.9 Balanced 3 Φ load current with MIMO controllerFig.10 Unbalanced 3 Φ load current with MIMO controller

Fig.11 Single phase nonlinear load current with MIMO controller

The result of different load conditions are simulated with and without MIMO controller and their THD values are compared to prove the efficacy of the projected controller.

Table 4. THD Comparision

	three phase balanced load THD	three phase unbalanced load THD	Non linear load THD
Without MIMO controller	25.46%	19.23%	19.25%
With MIMO controller	8.08%	3.46%	3.46%

Fig.10 Unbalanced 3 Φ load current with MIMO controller

4 Conclusion

In this paper a wind energy battery storage system is controlled by means of a non linear controller is projected . This scheme is capable of operating in both grid linked as well as stand alone modes. The designed method use only a solitary regulator. Islanding detection is not required in this scheme. This method is based upon MIMO feedback linearization control technique. The grid connected and stand alone mode for three diverse condition has been effectively evaluated. From the simulation results with

and without MIMO controller it is clear that the result for the system without controller has more harmonics than the system with the controller. A single controller plays a vital role in controlling each and every component of the system and also reduces harmonic content making the non linear output balanced.

References

- [1] Boubacar Housseini, Member, IEEE, Aime Francis Okou, Member, IEEE, and Rachid Beguenanesss, Member, IEEE Robust Nonlinear Controller Design for On-grid/Off-grid Wind Energy Battery-Storage System manuscript received March 10, 2017; revised April 1, 2017.
- [2] R.Walling, R.Saint, R.C.Dugan, J.Burke, and L.A.Kojovic, Summary of distributed resources impact on power delivery systems, IEEE Trans. on Power Delivery, vol. 23, no. 3, pp. 16361644, 2008.
- [3] S.Padron, M.Hernandez, and A.sFalcon, Reducing under-frequency load shedding in isolated power systems using neural networks. gran canaria: A case study, IEEE Trans. on Power Systems, vol. 31, no. 1, pp. 6371, 2016.
- [4] A. Gholami, F. Aminifar, and M. Shahidehpour, Front lines against the darkness: enhancing the resilience of the electricity grid through microgrid facilities, IEEE Electrification Magazine, vol. 4, no. 1, pp. 1824, 2016.
- [5] R. Teodorescu and F. Blaabjerg, Flexible control of small wind turbines with grid failure detection operating in stand-alone and grid-connected mode, IEEE Trans. on Power Electronics, vol. 19, no. 5, pp. 13231332, Sept. 2004.
- [6] M. N. Arafat, S. Palle, Y. Sozer, and I. Husain, Transition control strategy between standalone and grid-connected operations of voltage- source inverters, Industry Applications, IEEE Trans. on, vol. 48, no. 5, pp. 15161525, 2012.
- [7] M. Fatu, F. Blaabjerg, and I. Boldea, Grid to standalone transition motion-sensorless dual-inverter control of pmsg with

- asymmetrical grid voltage sags and harmonics filtering, IEEE Trans. on Power Electronics, vol. 29, no. 7, pp. 34633472, Jul. 2014.
- [8] M. Fatu, L. Tutelea, R. Teodorescu, F. Blaabjerg, and I. Boldea, Motion sensorless bidirectional pwm converter control with seamless switching from power grid to stand alone and back, in Power Electronics Specialists Conf., 2007. PESC 2007. IEEE. IEEE, 2007, pp. 1239 1244.
- [9] B. Mirafzal, M. Saghaleini, and A. K. Kaviani, An svpwm-based switching pattern for stand-alone and grid-connected three-phase single- stage boost inverters, Power Electronics, IEEE Trans. on, vol. 26, no. 4, pp. 11021111, 2011.
- [10] D. Gaonkar, R. Patel, and G. Pillai, Dynamic model of micro-turbine generation system for grid connected/islanding operation, in Industrial Technology, 2006. ICIT 2006. IEEE Inter. Conf. on. IEEE, 2006, pp. 305310.
- [11] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. de Vicuna, and M. Castilla, Hierarchical control of droop-controlled ac and dc microgridsa general approach toward standardization, Industrial Electronics, IEEE Trans. on, vol. 58, no. 1, pp. 158172, 2011.
- [12] Z. Yao, L. Xiao, and Y. Yan, Seamless transfer of single-phase grid- interactive inverters between grid-connected and stand-alone modes, Power Electronics, IEEE Trans. on, vol. 25, no. 6, pp. 15971603, 2010.
- [13] J. C. Vasquez, J. M. Guerrero, A. Luna, P. Rodrguez, and R. Teodorescu, Adaptive droop control applied to voltage-source inverters operating in grid-connected and islanded modes, Industrial Electronics, IEEE Trans. on, vol. 56, no. 10, pp. 40884096, 2009.
- [14] T. Chaiyatham and I. Ngamroo, Optimal fuzzy gain scheduling of pid controller of superconducting magnetic energy storage for power system stabilization, International Journal of Innovative Computing, Information and Control, vol. 9, no. 2, pp. 651666, 2013.

- [15] F. A. Okou, D. Nganga-Kouya, and M. Tarbouchi, A back-stepping approach for the design of a nonlinear controller for a two-wheeled autonomous vehicle, in Electrical and Computer Engineering, 2009. CCECE09. Canadian Conf. on. IEEE, 2009, pp. 641645.
- [16] K.-H. Kim, Y.-C. Jeung, D.-C. Lee, and H.-G. Kim, LVRT scheme of pmsg wind power systems based on feedback linearization, Power Electronics, IEEE Trans. on, vol. 27, no. 5, pp. 23762384, 2012.
- [17] L. Zhang and Y. Li, Optimal energy management of wind-battery hybrid power system with two-scale dynamic programming, Sustainable Energy, IEEE Trans. on, vol. 4, no. 3, pp. 765773, 2013.