Energy Management System of Wind and Photovoltaic based Hybrid Nanogrid

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Abstract— The hybrid photovoltaic (PV)- wind based power generation systems are installing on many rooftops of individual houses, apartments, institutions, hospitals and small scale industries worldwide. Even though it is connected to single phase utility grid, a battery is used for backup power supply during power cuts. The diesel generators also can be integrated to this system for supplying continuous power long term. This configuration can establish a nanogrid under low power systems. Many loads are operated under this nanogrid system, hence a proper control technique is required to maintain power quality as well as to compensate reactive power. Compensating reactive power demanded in nanogrid through the inverter can reduce the reactive power demand on the main utility grid. Individual maximum power point tracker (MPPT) circuits are employed for both PV and wind to harvest maximum power. The system is synchronized with single phase utility grid through the control of the inverter. The proposed control method can able to regulate the phase voltage t its reference signal for improving the power quality. MATLAB Simulink platform is used to present the results for testing the performance of the proposed method.

Keywords— Nanogrid, Power Quality, Wind, PV, Renewable Sources.

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1. INTRODUCTION

Establishment of renewable energy sources based rooftop power generation systems is increasing day to day due to its benefits and interesting of people in the society. Apart from many sources, solar and wind are the main resources on the earth which are daily available in major places [1-3]. Further there is a sufficient empty place available on rooftop of every building. Therefore, establishment of a nanogrid by using photovoltaic (PV) and wind generators can be a feasibly solution for both humans as well as societies [3-4].

However, the nanogrid should be integrated to the main utility grid to make the system more reliable and stable. Power cuts are common activities in the distribution system, hence a battery storage should be integrated to the nanogrid for achieving continuous supply. However, large size batteries are required where heavy loads and public loads are connected to nanogrid like for apartments and hospitals etc. Under this category, the diesel generators also can be maintaining as optional power backup for a long run applications [5].

A boost converter is necessary to capture maximum power from wind turbine under various wind speeds to work as a MPPT converter due to its high efficiency [3-5]. Similarly, the MPPT device such as boost converter should be integrated in between dc-link and PV to capture maximum available power [1]. These two power generators are connected in parallel to establish a common dc-link through their respective MPPT converters. Generally, the output from both PV and wind is not constant hence; the battery is integrated to dc-link through a bidirectional dc to dc converter which can capable to maintain charging and discharging current of the battery bank by proper control. The dc to dc bidirectional converter can maintain constant voltage at dc-link by maintaining power balance. Even the inverter can used to charge the battery from grid in case of no power from PV and wind for long time. The main requirement in nanogrid systems is to satisfy the customers by supplying the quality power irrespective of changes. Apart from this, the inverters can also working to compensate the reactive power demanded by the load in nanogrid. Most of the loads are nonlinear loads due to chargers in home; these can inject the harmonics to utility grid. Hence, these issues can be minimized by control of the inverter proposed in this paper. In order to make small power generation wind systems, a permanent magnet DC (PMDC) generator is directly coupled with wind turbine to avoid multiple converters.

2. MODELING OF THE COMPONENTS IN NANOGRID

The detailed modeling of major components is discussed in this section. This section is further presented by below parts:

A. Wind Turbine [3-4]

An attempt is made to model a typical wind turbine in this paper by using below equations.

$$P_t = 0.5\rho A C_p(\lambda, \beta) v^3 \tag{1}$$

Where, ρ indicates air density, A is blade's swept area, v denotes wind speed, and C_p used for coefficient of turbine-rotor power.

$$T_m = \frac{P_t}{\omega_t} \text{ And } \lambda = \frac{\omega_t}{v} \tag{2}$$

At maximum power point, $\lambda = \lambda_{opt} = \text{constant}$.

$$\frac{\omega_{t1}}{v_1} = \frac{\omega_{t2}}{v_2} \tag{3}$$

However, if considered MPPT, in steady state,
ρ , A are constant and $C_p = \text{contant} = 1\,\text{p.u.}$,

$\therefore T_m \,\alpha = \dfrac{v^3}{\omega_t}$ Therefore, finally, $\dfrac{T_{m1}}{T_{m2}} = \dfrac{v_1^2}{v_2^2}$

The generator should be coupled with wind turbine to produce electrify. Authors in [6-7] were used a DFIG and in [8-9] used a PMSG to produce electricity from mechanical power of wind turbine. However, usually these configurations mentioned in [6-9] are for the application of high power as well as not a nanogrid. In [8-9], the wind generator requires an extra diode rectifier which will inject the harmonics into the system as well as ripples will be more in dc-link voltage. However, for the rooftop applications, small generators are required where less cost and losses. Hence, a PMDC generator is used to generate the electrical power from wind turbine. The output of the PMDC generator can be easily connected to boost converter for working it at maximum power.

B. Modeling of PMDC Generator[10-11]

The PMDC generator taken in this paper is like a simple separately excited DC machine with a constant flux by permanent magnets. When it is used as a PMDC generator, generally coupled with a mechanical power which is capable to drive it faster than their rated speed [10]. The PMDC generator is suitable for low power applications especially it can quickly respond to changes in wind speed due to strong and constant stator field as well as having a high efficiency [11]. The input of the PMDC generator is the shaft torque of the wind turbine as shown in Fig. 1. The modeling of the PMDC is attempted by considering resistive load with the help of below equations.

$$\frac{di_{ag}}{dt} = -\frac{r_{ag} + R_L}{L_{ag}} i_{ag} + \frac{k_{ag}}{L_{ag}} \omega_{rpm} \tag{4}$$

$$T_{epm} - \left(B_{mpm} + B_{mg}\right)\omega_{rpm} - T_{eg} = \left(J_{pm} + J_g\right)\frac{d\omega_{rpm}}{dt} \tag{5}$$

Where ω_{rpm} is used for the angular velocity of the shaft, i_{ag} is the generator armature current; r_{ag} and L_{ag} represents the armature resistance and inductance respectively; R_L represents the load resistance; B_{mpm} and B_{mg} are the viscous friction coefficients; k_{ag} is the back *EMF* (*torque*) constant of the generator; J_{pm} and J_g are used as moments of inertia of PMDC and prim over. The electromagnetic torque (T_{epm}) is developed by the generator.

$$T_{eg} = k_{ag} i_{ag} \tag{6}$$

Hence,

$$\frac{d\omega_{rpm}}{dt} = \frac{k_{apm}}{J_{pm} + J_g} i_{apm} - \frac{B_{mpm} + B_{mg}}{J_{pm} + J_g} \omega_{rpm} - \frac{k_{ag}}{J_{pm} + J_g} i_{ag} \tag{7}$$

The prime mover can be represented by below mathematical expression:

$$\frac{di_{apm}}{dt} = -\frac{r_{apm}}{L_{apm}} i_{apm} - \frac{k_{apm}}{L_{apm}} \omega_{rpm} + \frac{1}{L_{apm}} u_{apm} \qquad (8)$$

and , $$\frac{di_{ag}}{dt} = -\frac{r_{ag} + R_L}{L_{ag}} i_{ag} + \frac{k_{ag}}{L_{ag}} \omega_{rpm} \qquad (9)$$

where r_{apm} and L_{apm} used for armature resistance and inductance. u_{apm} is the armature voltage.

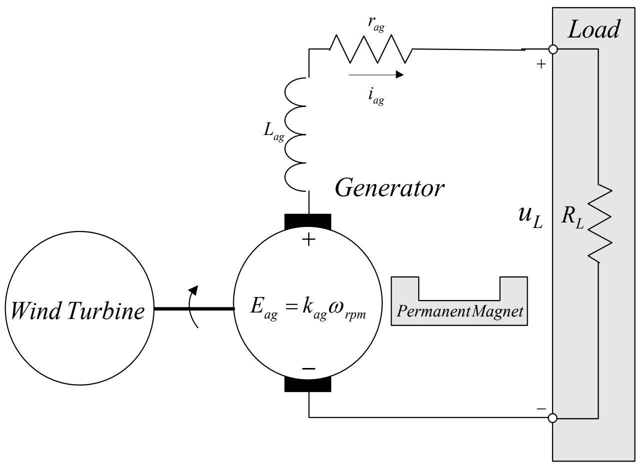

Fig. 1: Wind power conversion system.

C. PV System [1, 12]

An electrical representation of a PV cell structure is shown in Fig. 2 which can be represented by below characteristic function:

$$I_{PV} = n_p I_{ph} - I_{rs}\left[\exp\left(\frac{q(V_{PV} + I_{PV}R_s)}{AKTn_s}\right) - 1\right] - \frac{V_{PV} + I_{PV}R_s}{R_{sh}} \quad (10)$$

where q=1.602·10^{-19} C , n_s and n_p represents the series and parallel combinations of cells, K=1.3806·10^{-23} J/K is Boltzmann's constant, T is the cell's temperature (K), A=2 is the p-n junction's idealistic factor, I_{ph} is the cell's photocurrent, $I_{ph} = I_{sc}\frac{G}{G^*}$, G is the solar irradiance and V_{PV} is cell voltage, I_{rs} is the cell's reverse saturation current.

The characteristics of power vs voltage of the PV system is depicted in Fig. 3. The maximum power can be exhibits at voltage corresponding to maximum power point (V_{mpp}). The simple and most used MPPT algorithm is P&O due to its high accuracy and efficiency as compared with other algorithms [1].

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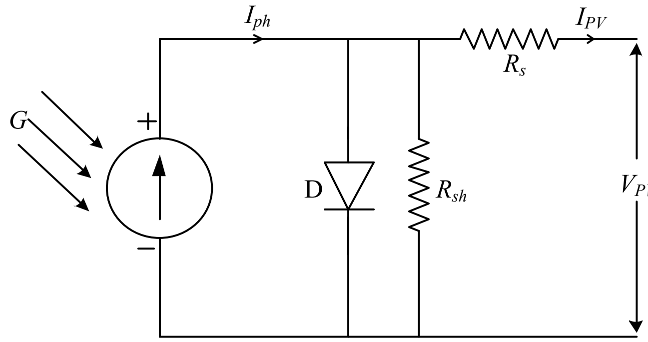

Fig. 2: Schematic Diagram of PV Cell.

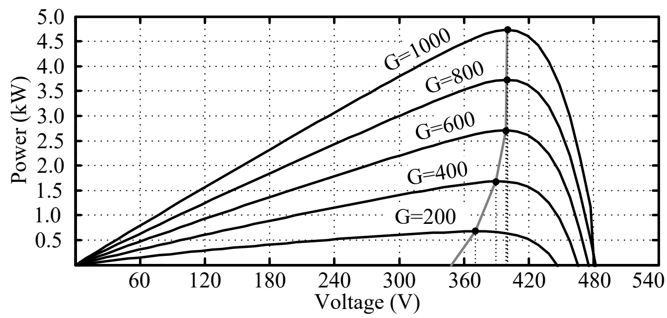

Fig. 3: Characteristic representation of a PV system of power vs voltage.

D. Modelling of a Battery

The modeling of a battery is attempted from [5, 13-15] by considering various parameters. For achieving realistic performance of the batter, temperature is also included in modeling. The modeling of the battery is attempted by considering below fundamental equations and the block diagram is shown in Fig. 4.

$$E_m = E_{m0} - K_E(273+\theta)(1-SOC) \tag{11}$$

$$Q_e(t) = Q_{e\_init} + \int_0^t -I_m(\tau)d\tau \tag{12}$$

$$I_p = V_{PN} G_{P0} \exp\left(\frac{V_{PN}}{V_{P0}(\tau_P s+1)} + A_P\left(1-\frac{\theta}{\theta_f}\right)\right) \tag{13}$$

$$C(I,\theta) = \frac{K_c C_{0*} K_t}{1+(K_c-1)(I/I^*)^{\delta}},\ K_t = LUT(\theta) \tag{14}$$

Where, $SOC = 1-\dfrac{Q_e}{C(0,\theta)}$, $DOC = 1-\dfrac{Q_e}{C(I_{avg},\theta)}$

$$\theta(t) = \theta_{init} + \int_0^t \frac{\left(Ps - \frac{(\theta-\theta_a)}{R_\theta}\right)}{C_\theta} d\tau .$$

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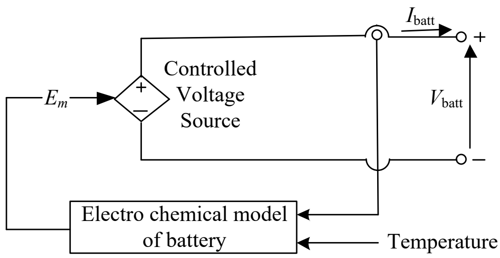


Fig. 4: Generic Battery Model

The nanogrid which consists of PV, wind, battery, diesel generator (optional), various loads, single phase inverter and grid is shown in Fig. 5. Other PV parameters are adopted from [16-18].

3. CONTROL OF VOLTAGE AT DC-LINK

The dc-link is established by connecting the boost converters of PV and wind systems. However, both boost converters cannot operate at the same voltage. Hence, the dc to dc bidirectional converter which is associated with battery can regulate the dc-link voltage. So that, boost converters of the PMDC generator and PV are regulating only current. The controllers of boost converters for MPPT of wind and PV are shown in Fig. 6 and Fig. 7 respectively.

Second order harmonics will be imposed to dc-link voltage due to nonlinear load connected at AC bus. These harmonics can make oscillation on shaft of the wind turbine as well as increase the heat across PV panels. Hence, the controller of bidirectional dc to dc converter is implemented to minimize the effect of these harmonics. The control of a bidirectional dc to dc converter is shown in Fig. 8. The oscillating component (V_{dco}) is estimated from V_{dc} by using a low pass filter. The oscillating component is used to produce the extra reference current of the battery. The reference for the V_{dco} is considered as '0'. The required pulses of Q_1 & Q_2 of the dc-dc converter are produced through a hysteresis loop.

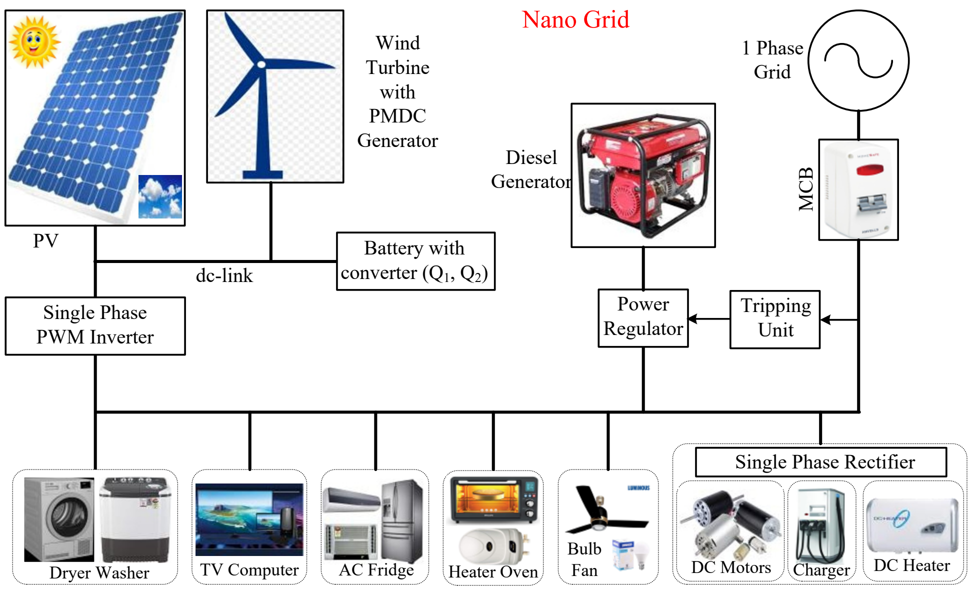


Fig. 5: Wind-PV powered Hybrid nanogrid

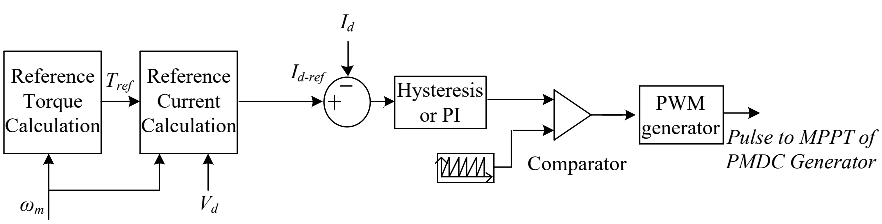


Fig. 6: MPPT of wind.

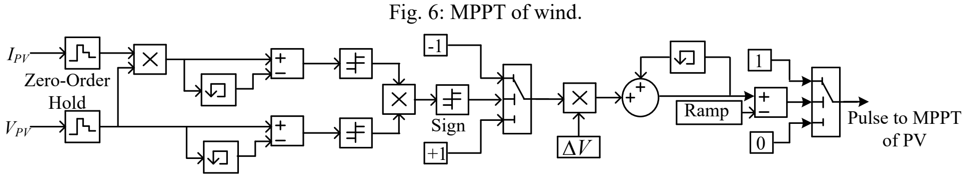


Fig. 7: MPPT of PV.

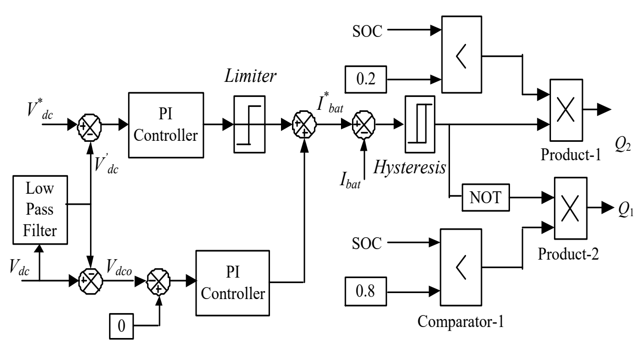


Fig.8: control of the bidirectional converter controller.

4. CONTROL OF INVERTER

The proposed control of the inverter is shown in Fig. 9. The control scheme is developed to supply reactive power demanded by the load as well as to maintain the constant voltage at AC bus. The reactive component of the phase current is obtained by comparing the reference RMS voltage to voltage at AC bus. This can also help to compensate the reactive power. The active power transferred to grid by regulating dc-link voltage. This can help to inject surplus power from renewable energy sources to utility grid. However, the standalone frequency is also considered to work the inverter during no supply from the utility grid.

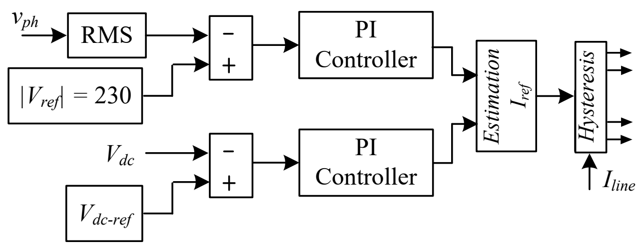
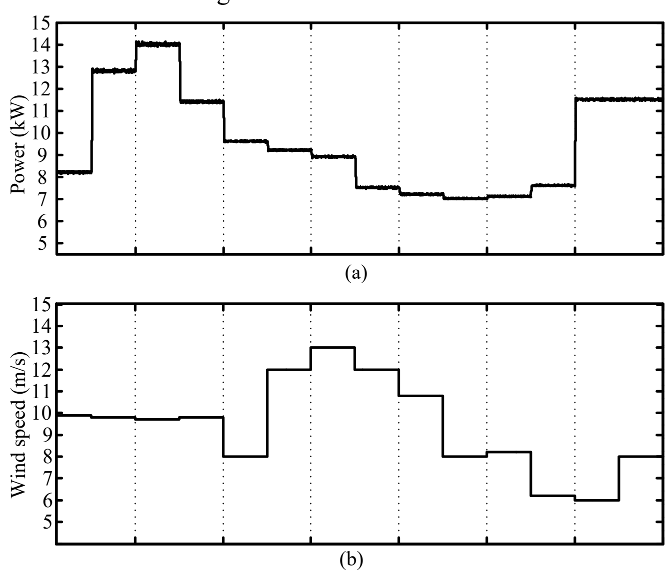


Fig.9: control of the inverter.

5. RESULTS

Considering meteorological changes

Usually the metrological changes will be effect on generated power from renewable energy sources. The nanogrid shown in Fig. 5 (without diesel generator) is tested under considerations of meteorological changes including wind power, load, solar irradiance and temperature which are shown in Fig. 10.



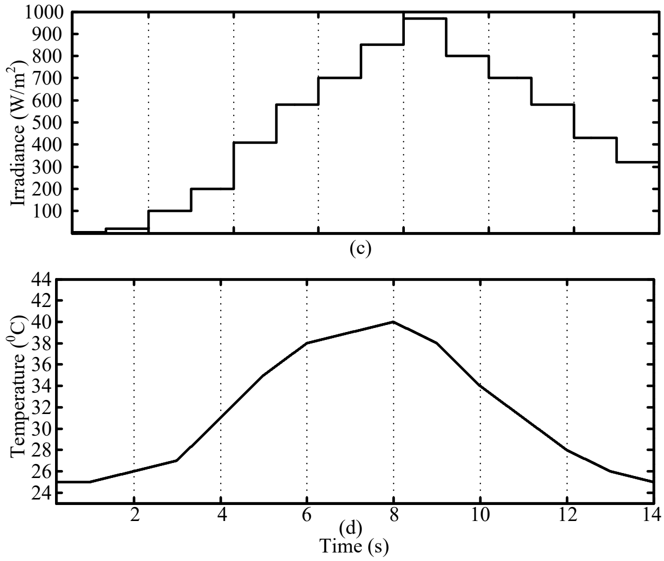


Fig. 10: (a) load, (b) speed, (c) Irradiance, (d) temperature.

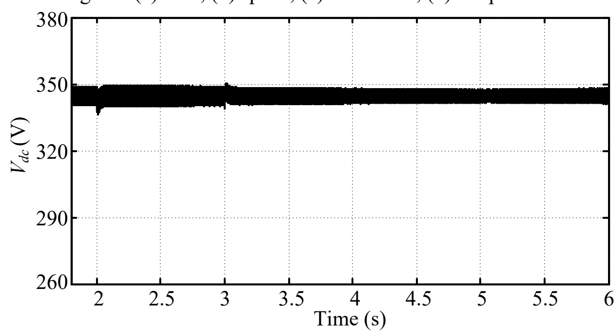


Fig. 11: DC-link voltage.

Ccorresponding response of voltage at dc-link and voltage at AC load are depicted in Fig. 11 and Fig. 12 respectively. From Fig. 11 and 12, the voltages on DC and AC side are quite satisfactory, which can be possible by only proposed controllers. However, for better visibility the instantaneous voltages at AC bus and line currents are depicted in Fig. 13 and Fig. 14 respectively.

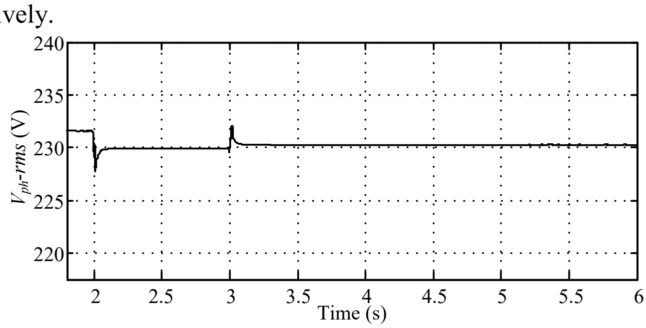


Fig. 12: Phase RMS voltage.

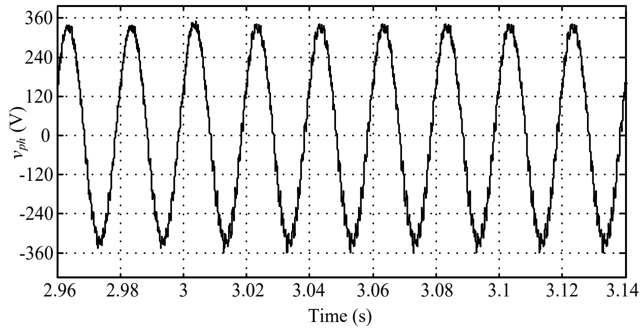


Fig. 13: Instantaneous voltage at AC bus.

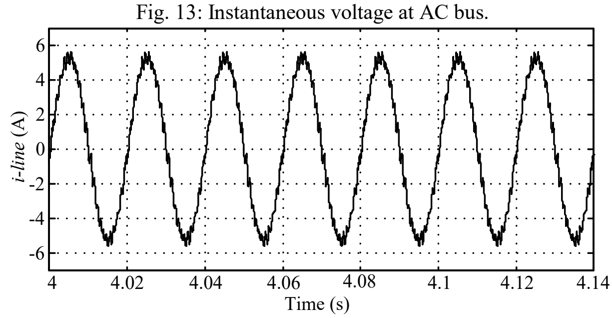


Fig. 14: Instantaneous output line current.

6. CONCLUSION

The nanogrid consists of wind, PV and battery is integrated with single phase utility grid presented in this paper. The PMDC generator based wind system is considered due to its merits for small power applications. MPPT converters are integrated along with controllers to achieve the maximum utilization. In order to supply reliable power, batteries also included via dc to dc bidirectional circuit. The novel control of an inverter is developed in such a fashion that, it can able to maintain constant voltage at AC bus. Various results along with valid analysis are incorporated by using MATLAB/Simulink.

References

[1] Siva Ganesh Malla, et al., "Coordinated power management and control of renewable energy sources based smart grid" International Journal of Emerging Electric Power Systems, vol. 23, no. 2, 2022, pp. 261-276. https://doi.org/10.1515/ijeeps-2021-0113.

[2] J. K. Singh, K. A. Jaafari, R. K. Behera, K. A. Hosani and U. R. Muduli, "Faster Convergence Controller With Distorted Grid Conditions for Photovoltaic Grid Following Inverter System," in IEEE Access, vol. 10, pp. 29834-29845, 2022, doi: 10.1109/ACCESS.2022.3159476.

[3] C N Bhende, S Mishra, SG Malla, "Permanent magnet synchronous generator-based standalone wind energy supply system", *IEEE Transactions on Sustainable Energy*, vol. 2, no. 4, pp. 361-373, 2011.

[4] S G Malla, C N Bhende, "Voltage control of stand-alone wind and solar energy system", Elsevier, International Journal of Electrical Power & Energy Systems, vol. 56, pp. 361-373, 2014.

[5] C. N. Bhende and S. G. Malla, "Voltage control of stand-alone "Photovoltaic-Diesel Generator-Battery" system," IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society, 2014, pp. 2292-2297, doi: 10.1109/IECON.2014.7048821.

[6]. Müller S., Deicke M., and De Doncker Rik W. "Doubly fed induction generator system for wind turbines", *IEEE Industry Applications Magazine*, May/June, 2002, pp. 26-33.

[7] H. Polinder, F. F. A. van der Pijl, G. J. de Vilder, P. J. Tavner, "Comparison of direct-drive and geared generator concepts for wind turbines", *IEEE Transactions on Energy Conversion,* vol., 21, no. 3, pp. 725-733, Sept. 2006.

[8]. T. F. Chan, L. L. Lai, "Permanent-magnet machines for distributed generation: a review", *Proc. 2007 IEEE power engineering annual meeting*, pp. 1-6.

[9]. Y. -K. Wu, S. -M. Yang and W. -C. Wu, "Design of a Large Commercial PMSG-based Wind Generator," 2019 IEEE 2nd International Conference on Knowledge Innovation and Invention (ICKII), 2019, pp. 5-8, doi: 10.1109/ICKII46306.2019.9042656.

[10] I.P. Kopylov, Mathematical Models of Electric Machines, Translated from the Russian by P.S. Ivanov, Revised from the Russian edition, 1980.

[11] Bose B.K, Power Electronics and Motor Drives, Academic Press, Imprint of Elsevier, 2006.

[12]. B. B. Rath et al., "Photovoltaic Partial Shading Performance Evaluation With a DSTATCOM Controller," in IEEE Access, vol. 10, pp. 69041-69052, 2022, doi: 10.1109/ACCESS.2022.3186906.

[13]. U. R. Muduli, K. A. Jaafari, K. A. Hosani, R. K. Behera, R. R. Khusnutdinov and A. R. Safin, "Cell Balancing of Li-ion Battery Pack with Adaptive Generalised Extended State Observers for Electric Vehicle Applications," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), 2021, pp. 143-147, doi: 10.1109/ECCE47101.2021.9595601.

[14]. M. I. Wahyuddin, P. S. Priambodo and H. Sudibyo, "State of Charge (SoC) Analysis and Modeling Battery Discharging Parameters," 2018 4th International Conference on Science and Technology (ICST), 2018, pp. 1-5, doi: 10.1109/ICSTC.2018.8528631.

[15]. A. S. Subburaj and S. B. Bayne, "Analysis of dual polarization battery model for grid applications," 2014 IEEE 36th International Telecommunications Energy Conference (INTELEC), 2014, pp. 1-7, doi: 10.1109/INTLEC.2014.6972132.

[16]. Sivachandran, P., Lakshmi, D., & Janani, R. (2015). Survey of maximum power point tracking techniques in solar PV system under partial shading conditions. ARPN Journal of Engineering and Applied Sciences, 10(1), 256-264.

[17]. S Baskaran, D Lakshmi, “Technical Study on Power Quality Issues and Their Mitigation Techniques”,Journal of Control System and its Recent Developments 1 (2), 1-5.

[18]. P Sivachandran, D Lakshmi ,R Janani “Performance Analysis of Stand-Alone PV System Under Partial Shading conditions”, International Journal of Applied Engineering Research 10 (42), 30785-30792.