Modified Grid Connected Winds Photovoltaic Cogeneration Using Back To Back System

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Abstract- *In the modern era, grid connected cogeneration is considered as an alternative source for power generation. Especially, need of the time is to provide the three-phase power to grid with smooth sinusoidal voltages having fixed frequency in synchronization manner with the grid. In wind photovoltaic cogeneration system the integration of power electronics converters is a common for grid synchronization with improving current injected quality in terms of total harmonic distortions (THDs) This paper presents a new topology, yet simple and efficient, for a modified grid-connected wind-photovoltaic (PV) cogeneration system. A permanent magnet synchronous generator-based full-scale wind turbine is interfaced to the utility-grid via back-to-back voltage-source converters (VSCs).*

A PV solar generator is connected to the dc-link capacitor of VSCs through the boost dc to dc converter. The proposed topology features an independent maximum power point tracking for both the wind and the PV generators to maximize the extraction of the renewable energy. The proposed system control algorithm is developed and implemented, using soft tools in MATLAB software and perforce validated through the simulations results

Keywords- Frequency Control, Voltage Control, Voltage Source Inverter, Cogeneration system, Photovoltaic system, Wind energy system and MPPT

I. INTRODUCTION

Nowadays, energy demand is getting increased with the passage of time and co-generation power systems especially through wind, solar and fuel cells as well as their related power conversion systems are conferred immensely. Many problems like grid instability, low power factor and power outage etc. for power distribution have also been increased with increase in energy demand [1]. However, co-generation power systems are found to be a sensible solution for such problems as they have relatively robust stability and causes additional flexibility balance. Moreover, their utilization can also improve the distribution networks management and carbon release is also reduced. VSIs are extensively necessitated for the commercial purpose as well as for the industrial applications as they play a key role in converting the DC voltage and current, usually produced by various co-generation system applications, into AC before being discharged into the grid or consumed by the load. Several control systems are introduced, various schemes are proposed and numerous techniques are updated in order to facilitate the control of three-phase VSI. The objectives of these control schemes are to constrain the high and low-frequency electromagnetic pollution and to inject the active power with zero power factor into grid [2]. The smooth and steady sinusoidal waveform can be a good input to a load for getting the most suitable response, therefore, the output of the inverter, which normally enjoys special standards and characteristics, should be controlled for providing an aforementioned waveform to load and grid.

Generally, it is observed that several problems are caused in linking the co generation power system to a grid or grid to load in bidirectional inverters, i.e., grid instability, distortion in the waveform, attenuation as well as major and minor disturbances. Hence, in order to overcome these problems and to provide high-quality power, appropriate controllers with rapid response, compatible algorithm, ability to remove stable errors, less transit time, high tracking ability, less total harmonic distortion, THD value and smooth sinusoidal output should be designed. Various controllers are designed for achieving these qualities. The cascade technologies are introduced in the literature comprises of an inner current loop and outer voltage loop [3–9]. As the inner-loop current controller plays a fundamental role in closed-loop performance, various control approaches like PI [3], deadbeat [4] and hysteresis [5] are extensively applied. Outer voltage loop in the aforementioned cases refines the tracking ability and decreases the tracking error. In case of no input limitations, aforesaid PI controllers are the best choice for stabilizing the inner loop performance. However, input constraints restrict their performance and no optimization is usually observed by using PI controllers. The deadbeat control method is proposed in [4] to enhance the closed-loop performance but unfortunately, it was found highly sensitive to the disturbances, parameters mismatches and measurement noise. Later on, some observed based deadbeat controllers are introduced in order to provide compensation for these discrepancies, however, a trade-off was observed between phase margin and closed-loop performance [6-8].

Motivated by the promising benefits of the wind-PV generation systems, this paper present a new topology, yet simple and efficient to interface both the wind and PV generators into the utility-grid.

II. MODELING OF PROPOSED SYSTEM

As shown in Fig. 1, the proposed system consists of a voltage source rectifier (VSR) to interface the wind generator, and a voltage source inverter (VSI) to connect the cogeneration system into the utility-grid. The PV generator is connected with dc link through the boost dc-dc converter to extract maximum power. The VSR and VSI are two-level converters consisting of six cells; each comprises an insulated-gate-bipolar transistor (IGBT) in parallel with a diode. In the following subsections, the complete modeling of the proposed system is provided.

A. *Wind turbine modeling*

A full-scale wind turbine (FSWT) utilizing a permanent magnet synchronous generator (PMSG) is selected for its low maintenance and low operational cost [10]. In wind energy conversion system (WECS) wind potential energy is converted into electrical energy with the help of wind turbine and generator, in proposed paper permanent magnet synchronous generator is used to convert mechanical energy to electrical energy. In modeling of WECS following key equations are used,

Power contains in the undisturbed wind is in form of kinetic energy then the power is,

$$E = \frac{1}{2} m v^2 \tag{1}$$

Where *m* and *v* are rate of flow of wind and speed of undisturbed wind respectively, and the rate of flow of wind is the function of air density, area through wind is passing and speed of wind then the power contains in undisturbed wind can be also written as,

$$P = \frac{1}{2} r A v^3 \tag{2}$$

Where ρ and A are the density of wind and swept area of wind turbine respectively

Power output from the wind turbine is given as,

$$P = \frac{1}{2} r A v^3 C_p \tag{3}$$

$$P = \frac{1}{2} C_P(\beta, \lambda) \rho \Pi R^2 v_{wind}^3 \tag{4}$$

Where λ is tip speed ratio it is depends on wind speed length of blade and generator angular speed in the case of direct driven wind turbine. And C_p is the betz limit its optimums value is 0.49. Characteristic of wind turbine is shown in Fig. 1

B. *Modeling of Permanent Magnet Synchronous Generator (PMSG)*

To analysis equivalent circuit of PMSG normally modeled in synchronous reference frame. To model PMSG rotor circuit there is no field winding so it can be replaced with constant current source with fixed magnitude

The following mathematical manipulation can be done. The voltage equation of PMSG in synchronous reference frame is given by

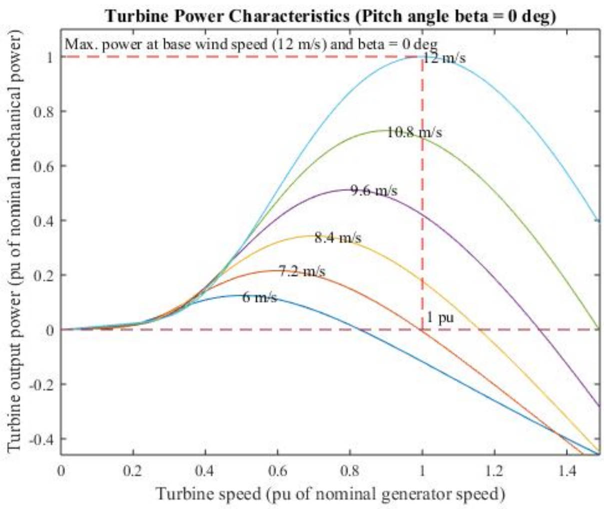


Fig. 1Wind turbine characteristic

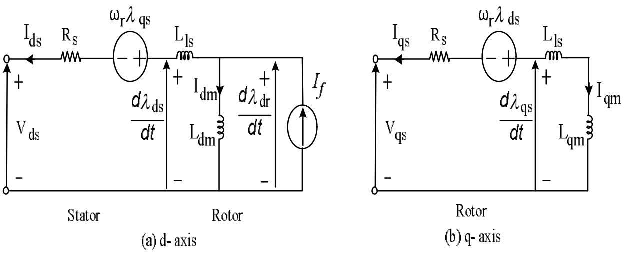


Fig.2 Equivalent circuit of PMSG in synchronous reference frame

$$V_{ds} = -(I_{ds}R_s + w_r l_{qs} - \frac{dl_{ds}}{dt}) \quad (5)$$

$$V_{qs} = -(I_{qs}R_s - w_r l_{ds} - \frac{dl_{qs}}{dt}) \quad (6)$$

C. Modeling of photovoltaic system

Photovoltaic system is manly depends on PV module which is consist with PV cell equivalent circuit of PV cell is given in Fig. 3

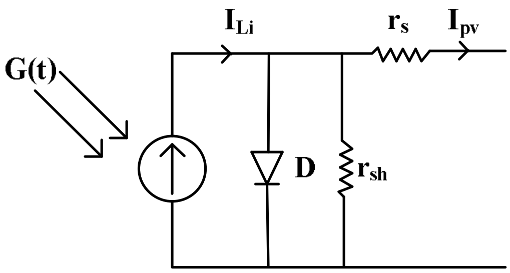


Fig. 3 The equivalent circuit of PV cell

Current equation of PV module are given as,

$$I_{PV} = I_{li} - I_0 e^{\frac{q(V_{PV}+r_s)-1}{nqA_i}} - \frac{V_{PV}+I_{PV}r_s}{r_{sh}} \quad (7)$$

Where Ipv output current of PV panel, I_{Li} light induced current, Io is the reverse saturation current q is the electron charge, Vpv is the voltage of PV, η is the Boltzmann constant, Ai is the semiconductor material ideality factor and ϴ is the cell temperature Light induced current is given as

$$I_{li} = G(t)\left[I_{sc} + b_i(q - q_r)\right] \quad (8)$$

Where *G(t)* solar irradiation in (w/m2) I_{sc} is short circuit current, β_i temperature coefficient in (per °C) and Θ_r is reference cell temperature and reverse saturation current is given as

$$I_o = I_{rs}\left(\frac{q}{q_r}\right)^3 e^{\left[\frac{E_b}{\eta A_i}\left(\frac{1}{q_r}-\frac{1}{q}\right)\right]} \quad (9)$$

Where I_{rs} reverse saturation current at standard testing condition and E_b is energy band gap. Power provided by PV array is written as

$$P_{pv} = N_s N_p P_{mod} h_{mppt} h_{oth} \quad (10)$$

Where Np and Ns are Number of PV module connected in parallel and series respectively, Pmodule power developed by single module, ηmppt and ηoth are efficiency at maximum power point and other existing losses. Characteristic of PV module is shown in Fig4.

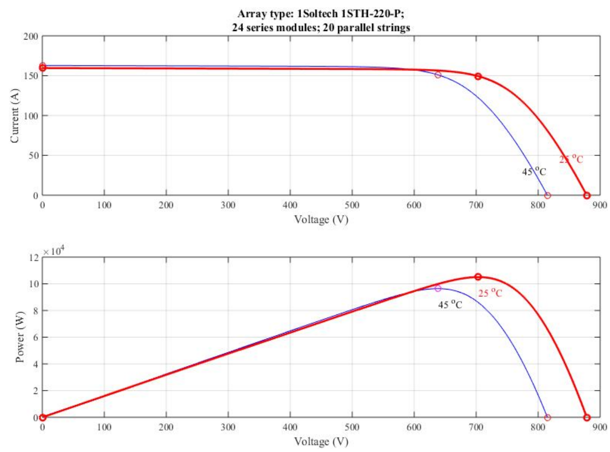


Fig. 4 characteristic of PV Module

III. CONTROL OF PROPOSED SYSTEM

To implement the control algorithm, the sensing of some Signals are required. These signals are three phase PMSG currents grid phase voltages (va, vb and vc), and grid line currents (ia, ib and ic). To implement optimum speed control to achieve maximum power from WECS generator speed is sensed The P&O based MPPT approach is used to optimize the PV array power. However, PV array voltage (Vpv) and current (Ipv) are needed to sense for proper estimation of MPPT under variable working conditions. And proposed system configuration is shown in Fig. 5

A. *Wind energy system control*

The generator controller must conform, the speed of the wind turbine. Therefore, that electrical torques of the generator must make controlled. Contingent upon the kind of the generator utilized within the wind turbine, the structure of the controller will be diverse. it quit offering on that one cam wood execute distinctive exchanging calculations for example, such that DTC, vector control et cetera for distinctive purposes. Fig. 6 indicates the square outline representational of a controller for that generator-side converter for recommended framework

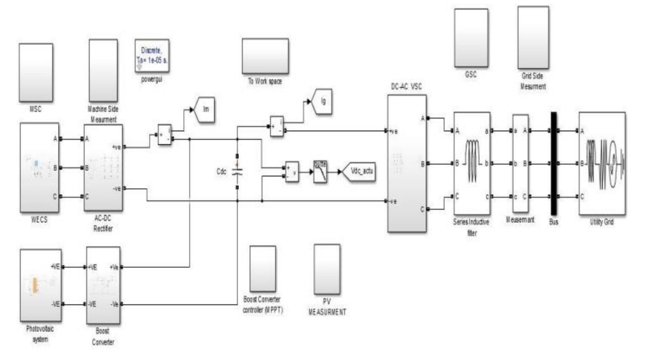


Fig. 5 Proposed System modeling

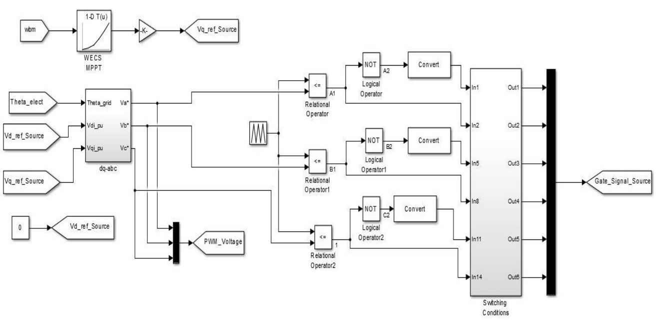


Fig. 6 Voltage source rectifier control

B. Photovoltaic system control

To enhancing the efficiency of the photovoltaic panel MPPT is utilized. According to the maximum power point theorem, the output power of any circuit will be maximum whenever source impedance equivalent to the load impedance, so the MPPT algorithm is utilized to the problem of impedance coordination. In this paper work, the Boost Converter is utilized as impedance coordination device between input and output by changing the duty cycle of the converter circuit. Favorable position of the Boost is that low to high voltage is acquired from the accessible voltage. Control algorithm, the PV voltage and current are sensed and then estimate the power, after that find the change in power and voltage by comparing the previous power and voltage; if change in power is zero then duty cycle will be same as previous otherwise duty cycle will change according to the fallowed condition which is shown in Fig. 7

C. Voltage source inverter control

Most inverters operate as current sources injecting a current that is sinusoidal and in phase with the grid voltage, with a power factor equal or very close to unity. It is required that the inverter synchronizes with the fundamental component of the grid voltage, even in the cases when the grid voltage is distorted or unbalanced or when the grid frequency varies. An example of synchronization in steady state for a three-phase system is shown in Fig. 8, in which three phase wind photovoltaic co generation system

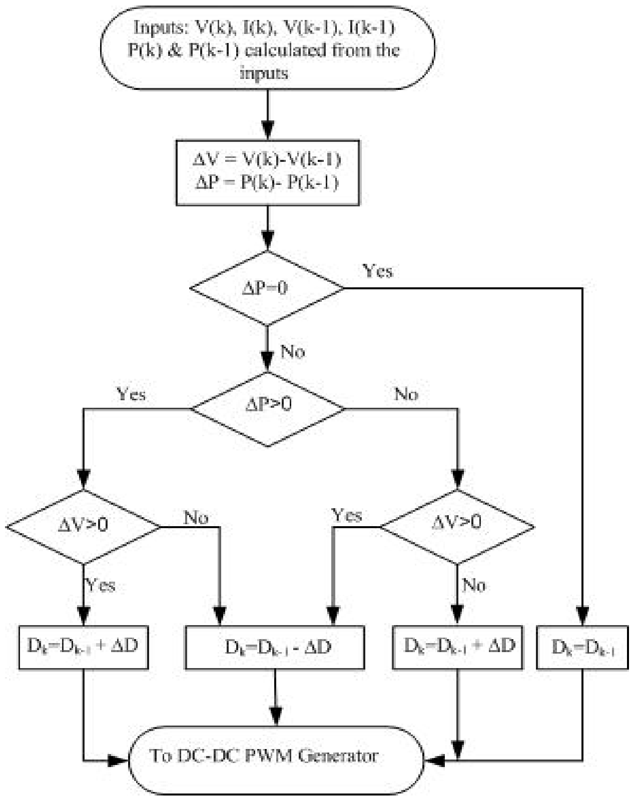


Fig. 7: Perturb and Observe control algorithm

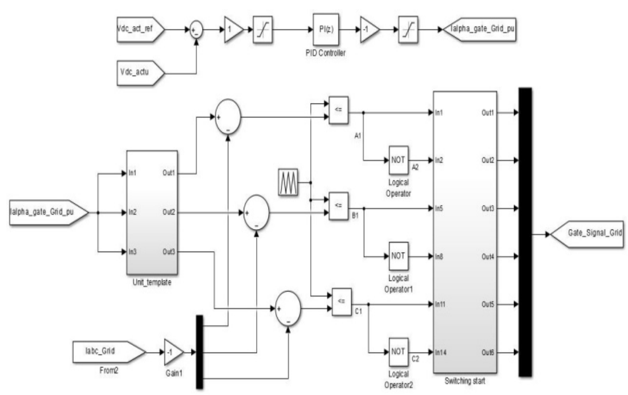


Fig. 8 voltage source inverter control

IV. RESULTS AND DISCUSSIONS

MATLAB Simulink™ 17a is used to evaluate the performance of the proposed co generation system and controllers. For the energy conversion system utilized in this paper, pitch angle is assumed zero and yaw control mechanism is not considered. It consists of an aerodynamic system based on wind speed model, wind power versus wind speed model and etc., permanent magnet synchronous generator (PMSG), a SPWM AC/DC converter, a DC/DC boost converter, a DC/AC inverter and AC filters, PID controllers

A. Performance of PV system sudden decreased in solar irradiation

Fig. 9 show the performance of PV system under varying in solar irradiation firstly solar irradiation varies from 1000w/m^2 to 800 w/m^2 at 2 second. Because of these solar radiations is varying current of PV panel will be varying so power is decreasing from 100kW to 80kW.

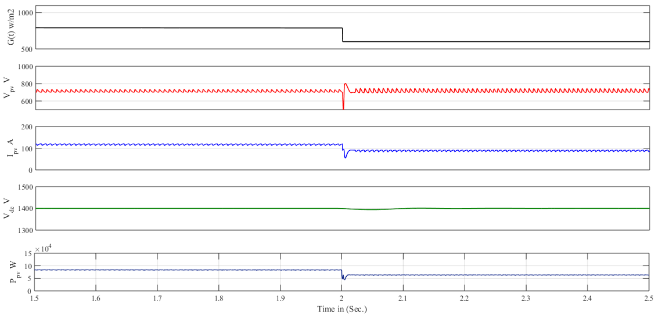


Fig. 9 Performance of PV system under sudden decreased in solar irradiation

B. Performance of PV system under sudden rise in solar irradiation

Fig. 10 shows the performance of PV system under sudden rise in solar irradiation from 600 w/m^2 to 1000 w/m^2.To extract the maximum power, power generation via PV system is from 60 kW to 100kW. Here also wave is sub divided into five parts.

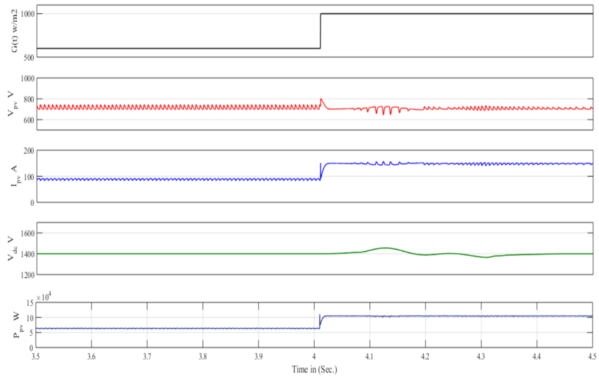


Fig. 10: Performance of PV system under sudden rise in solar irradiation

C. Performance of wind energy conversion system of co generation unit

Demonstrating the performance of proposed system under normal conditions when wind speed is fixed at 12 m / s with disturbance depicted in Fig. 11. When PMSG operated near rated speed at 2.72 rad/s, active power generated from wind turbine is 2 MW and electromagnetic torque of generator is -0.68 MN-m (negative sign indicate that machine operated as generator). Machine side converter maintained DC link voltage at 1400V, WECS system under varying wind speed firstly wind speed varies from 12m/s to 10m/s at 2 second. Because of these generated power is decreasing from 2MW to 1.2MW

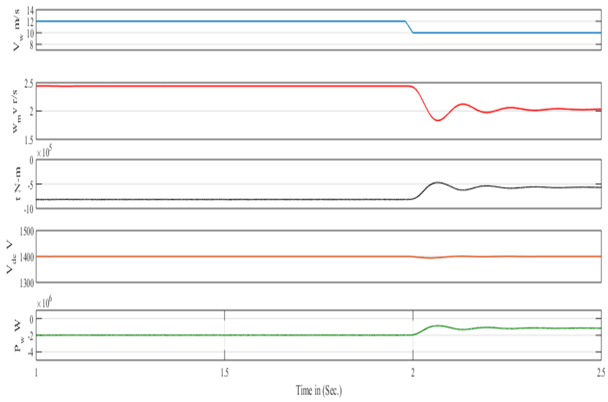


Fig. 11: Performance of wind energy conversion system under sudden fall in wind speed

D. Performance of wind energy conversion system under increasing in wind speed

Fig. 12 shows the performance of cogeneration unit under increasing in wind speed. Wind speed is decreases from 10m/s to 14 m/s. therefore power generation is decreases from

2MW to 3.9 MW. Because of this generator speed and torque is also a increase which is shown in fig.

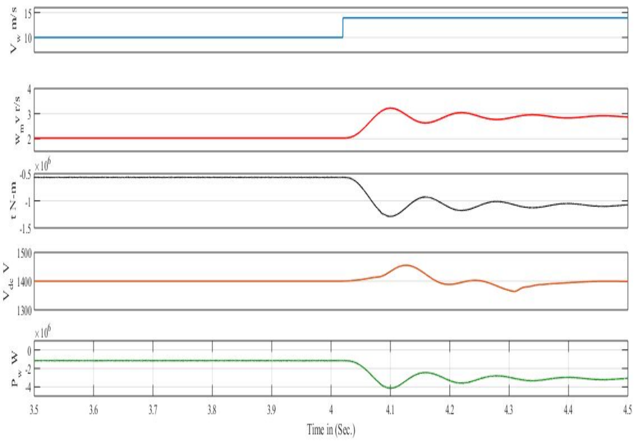
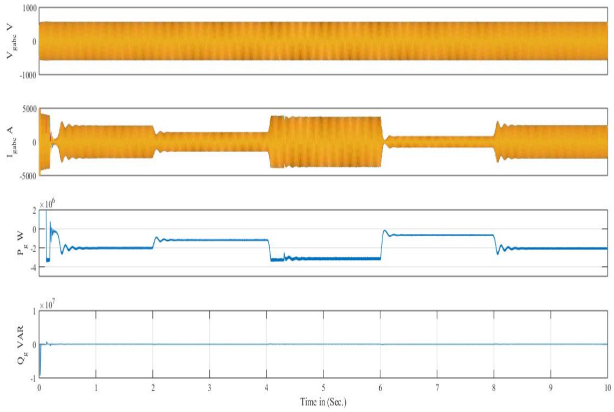


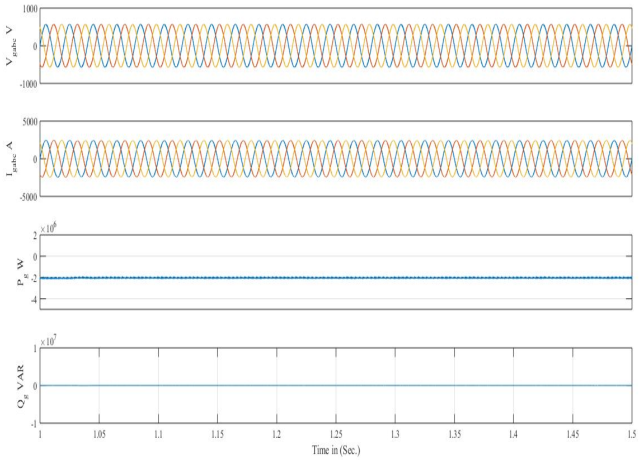
Fig. 12: Performance of hybrid power system under decreases in wind speed

E. Performance of grid of proposed cogeneration unit

Fig. 13 shows the performance of grid of cogeneration unit. Here performance of proposed system analyzed, in which first wave represents to grid voltage second one to grid injected current third one is grid injected active power while fourth one reactive power wave. It is observed that whenever power generation by wind and PV increases then grid injected current is increases and therefore active power is increases.



(a)



(b)

Fig. 13: Performance of grid of cogeneration unit

F. Power quality analysis grid voltage

Fig 14 shows the voltage waves of grid voltage of phase A and its THDs analyzed and observed that THDs was 0.03%. It is under the IEEE standard. This is possible due to control strategy of inverter.

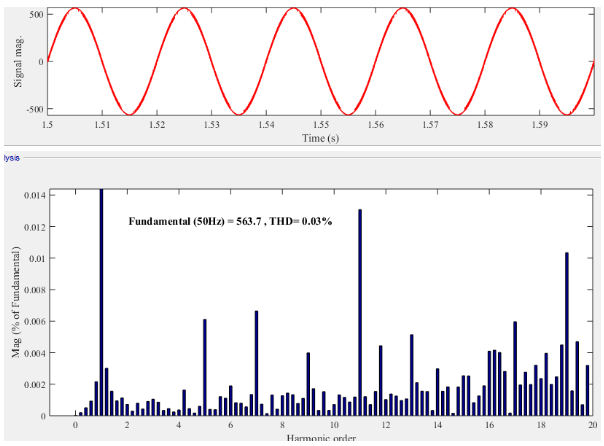


Fig. 14: Power quality analysis of grid voltage of co generation unit

G. Power quality analysis grid current

Fig 15 shows the voltage waves of grid current of phase A and its THDs analyzed and observed that THDs was 0.064%. it is under the IEEE standard. This is possible due to control strategy of inverter.

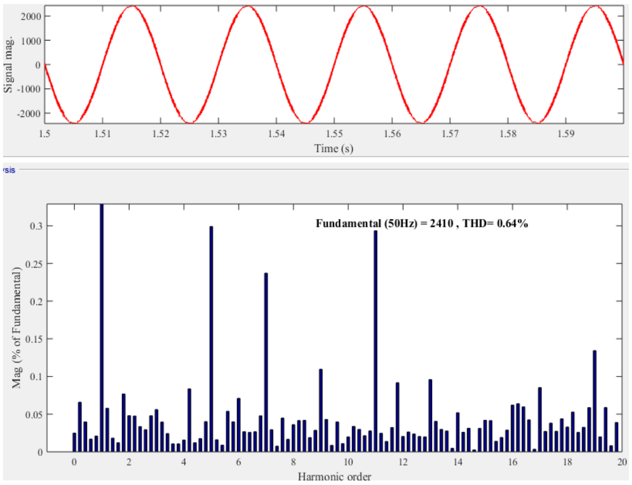


Fig. 15: Power quality analysis of grid current of co generation unit

V. COMPARISION OF PROPOSED MODIFIED SYSTEM WITH CONVERSIONAL

Modified, wind solar cogenerations using back to back system is which is modified with reference no. [12]

S. No.	Parameter and components	In ref [29]	In proposed
1.	MPPT achieve in Solar	Yes	Yes
2.	MPPT Achieve in Wind	Yes	Yes
3.	Solar irradiation measurement Required.	Yes	No
4.	Pyranometer Required	Yes	No
5	Wind measurement Required	Yes	No
6	Anemometer Required	Yes	No
7	Efficiency	Less due to voltage balancing in PV system.	Higher efficient than [29]
8	Harmonic Analysis	Not given	Very less V=0.03%(THD) I=0.064%(THD)

VI. CONCLUSION

This paper has presented the modified wind-PV cogeneration systems using current-controlled grid-connected VSIs. The VSR at the wind generator-side is responsible for extracting the maximum wind power following the wind speed variations. On the utility-grid side, the roles of the VSI are to extract the maximum PV power from the PV generator, achieve the maximum power by P&O techniques with the help of dc-dc boost converter and to maintain the dc link voltage VSI control is responsible a unity PCC voltage under different modes of operation. Different control techniques for proposed system such as PV mppt, WECS MPPT control. And Inverter control and it performance is validated through the MATLAB Simulink 2017a.

APPENDIX

Proposed system parameters are given in Table.

Table 2 PV specifications

Variable	Description	Value
P_{PV}	Rated power	218W
V_{OC}	Open circuit voltage	36.6V
I_{SC}	Short circuit current	7.97A
V_{PVM}	MPPT voltage	29.3V
I_{PVM}	MPPT current	7.47A
N_s	Number of series module	20
N_p	Number of parallel module	24

Table 2 Boost converter Specification

Variable	Description	Value
L_C	Converter inductor	8.5mH
C_C	Converter capacitance	5000µF
f_C	Converter Switching frequency	10kHz

Table 3 Parameters of PMSG

Variable	Description	Value
P	Rated power	2MW
V_{LM}	Nominal voltage	690 V
f	Nominal frequency	9.75 Hz
R_s	Stator resistance	0.821 mΩ
L_d	d-Axis Armature Inductance	1.5731 mH
L_q	q-Axis Armature Inductance	5.839mH
j	Inertia	20000 Kg.m^2
Nr	Rated speed	22.5 rpm
p	Pole pair	26

REFERENCES

[1] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of Control and Grid Synchronization for Distributed Power Generation Systems," *Industrial Electronics, IEEE Transactions* on, vol. 53, pp. 1398-1409, 2006.

[2] G. H. Bode, L. Poh Chiang, M. J. Newman, and D. G. Holmes, "An improved robust predictive current regulation algorithm," Industry Applications, *IEEE Transactions on*, vol. 41, pp. 1720-1733, 2005.

[3] Rashid, N. Hasan, K. T. Parvez and M. N. I. Maruf, “Study and analysis of a small scale micro-grid using renewable energy resources,” *Proceedings of Inter. Conf. on Electrical Engineering and Information Communication Technology (ICEEICT)*, Dhaka, *2015*.

[4] M. Pichan, H. Rastegar and M. Monfared, “Deadbeat Control of the Stand-Alone Four-Leg Inverter Considering the Effect of the Neutral Line Inductor”, *IEEE Trans. Ind. Electron.,* vol. 64, no. 5, pp. 2592 - 2601, Nov. 2017

[5] P. Rodríguez, A. Luna, R. S. Muñoz-Aguilar, I. Etxeberria-Otadui, R. Teodorescu and F. Blaabjerg, “A stationary reference frame grid synchronization system for three-phase grid-connected power converters under adverse grid conditions,” *IEEE Trans. Power Electron.*, vol. 27, no. 1, pp. 99–112, Jan. 2012

[6] Fatih Cingoz, Ali Elrayyah, and Yilmaz Sozer, “Optimized Settings of Droop Parameters Using Stochastic Load Modeling for Effective DC Microgrids Operation,” *IEEE Trans. Industry Applications*, vol. 53, no. 2, pp. 1358 – 1371, 2017.

[7] M. Rezkallah, A. Chandra, B. Singh and S. Singh, “Microgrid Configurations, Control and Applications,” *IEEE Transactions on Smart Grid*, Early Acess, 2018.

[8] P. Roshanfekr, S. Lundmark, T. Thiringer, and M. Alatalo, “A synchronous reluctance generator for a wind application-compared with an interior mounted permanent magnet synchronous generator,” Proceedings in *7th IET Inter. Conference on Power Electronics, Machines and Drives (PEMD 2014* , Manchester, pp. 1-5, 2014.

[9] Z.M. Dalala, Z.U. Zahid, and Lai Jih-Sheng, “New Overall Control Strategy for Small-Scale WECS in MPPT and Stall Regions with Mode Transfer Control,” *IEEE Trans. Energy Conversion*, vol.28, no.4, pp.1082-1092, Dec. 2013.

[10] G. Pathak, B. Singh, and B. K. Panigrahi, “Back Propagation Algorithm Based Controller for Autonomous Wind-DG Microgrid,” *IEEE Trans. Industry Applications*, vol. 52, no. 5, pp. 4408-4415, Sept.-Oct. 2016.

[11] F. Blaabjerg, Z. Chen, and S. B. Kjaer, “Power electronics as efficien interface in dispersed power generation systems,” *IEEE Trans. Power Electron*., vol. 19, no. 5, pp. 1184-1194, 2004

[12] Radwan and Y. Mohamed, "Grid-Connected Wind-Solar Cogeneration Using Back-to-Back Voltage Source Converters," in IEEE Transactions on Sustainable Energy. 2019.