International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

Fuzzy Logic Control Based Wind PV Cogeneration Using Back to Back Voltage Source Converters

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Abstract: This project establishes a new topology for performance of grid connected wind PV cogeneration system. The utility grid via btb (back to back) voltage source converter is interfaced to a synchronous generator based wind turbine. In this system a PV solar generator is connected to the dc link capacitor of VSC. The switching approach of the grid side converter is intended to pick up voltage drop caused by the fault in the grid while maximum obtainable active power of wind turbine system is injected to the grid and the DC link voltage in the converter is regulated. The efficiency of the system is improved as there is no requirement of dc to dc conversion. In this project the wind and photovoltaic generators uses independent maximum power point tracking to extract the maximum power and improve the efficiency the control of vsc uses FLC control scheme. The dynamic models of the system components were developed to explore the stability. The system is verified by using simulation results.

***Index Terms*--AC-DC power converters, DC-AC power converters, maximum power point trackers, permanent magnet machines, solar power generation, wind power generation.**

I. INTRODUCTION

Among the environmental benefits of renewable energies, the launch of new technologies in the management and control of renewable energy sources and the growing demand for high quality and constant supply lead to greater attention to this type of energy source. [1-4]. In addition to the optimal operation of a power system under normal conditions, checking the system under fault conditions is one of the most difficult concerns [5-7]. Energy quality is one of the most important issues in the use of distributed generation (DG) [8-9]. In addition to the frequency and active power, the voltage and reactive power should be limited and controlled in predefined intervals [10-11]. To achieve this, generators must be properly controlled to prevent voltage drop and voltage surge at maximum or low demand, respectively [12-15]. One of the most important advantages of the DGs, in addition to the injection of active power and the supply of local load, is the injection of reactive power at the common coupling point (PCC) [16-17]. By controlling the reactive power of a DG, the voltage profile and the quality of the power supply can be improved in different operating modes of the network, especially in the event of faults. Wind turbine generation is one of the most common sources used in distributed generation systems for this purpose. Constant speed wind turbines that were more popular and efficient than recent wind turbine systems where electronic power technology has helped to improve efficiency by implementing variable speed wind generators in power generation. Due to the periodic and unrestricted nature of wind and solar energy, electronic power converters are used as an interface with the load side or the public grid and therefore distributed generation units are produced. To maximize the benefits of available renewable resources, the combination of wind and solar energy in the same neighborhood was considered. The cogeneration of wind and solar energy has the following characteristics; 1) The availability of wind and solar energy is generally harmonizing, and therefore the combination of both forms of energy increases the overall efficiency provided. 2) The combination of wind and solar co generator optimizes the use of land resources and therefore improves capital investments. 3) Compared to static photovoltaic generators, solar-wind cogeneration systems are more dynamically able to support the public grid due to the moment of inertia available in the mechanical system of wind generators [8]. 4) Having two sources of energy increases the reliability of the generation. One of the most important of the significant investigations in the VSWT is the request for different control schemes for some purposes in the plant. Help is needed for some techniques with VSWT control. Due to the efficient and economic use of renewable energies, some of the renewable energy resources are integrated, such as the wind turbine and the solar array. Due to the dependence on wind speed and solar radiation in such systems, its reliability in meeting load demands decreases in all conditions. Therefore, some studies propose the combination of a diesel generator as a backup system and wind / solar power generation systems. The proposed system is designed to obtain the maximum energy captured by the wind generator / solar array and deliver it to the electricity grid

Table 1 MPPT Comparison for Photovoltaic System

S. no	mppt technique	PV array Dependent	True mppt	Convergence Speed	implementation complexity	Sensed parameters
1	P&O	No	Yes	Varies	Low	Voltage, current
2	IncCond	No	Yes	Varies	Medium	Voltage, current
3	Fractional Voc	Yes	No	Medium	Low	Voltage,
4	Fractional Isc	Yes	No	Medium	Medium	current
5	Fuzzy logic	Yes	Yes	Fast	High	Varies
6	Neural network	Yes	Yes	Fast	High	Varies
7	dP/dV control	No	Yes	Fast	Medium	Voltage, current

On photovoltaic framework a front-end support converter will be by and large obliged towards the center about inverter will match the load prerequisites. Previously, such DC- AC alternately DC-DC AC energy converters, there will be An likelihood for concurrent exchanging from claiming switches (IGBTs/MOSFETs) of the same leg(s) from claiming inverter because of EMI effect, inappropriate terminating of switches, aggravation out breaking and nonattendance of cross conduction security inside the gate-drivers itself and so on. This prompts shorting from claiming wellspring alternately dc connection capacitor through the shorted leg(s) of inverter, causing a large current flow and damage to the system.

II PROPOSED SYSTEM DESCRIPTION

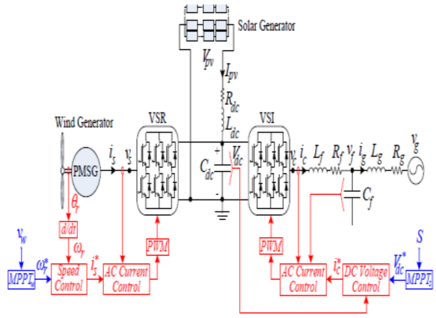

Fig.1 The proposed wind-PV cogeneration system.

The proposed hybrid power generation system is illustrated in Figure 1. This system consists of a horizontal axis and a variable speed wind turbine, a solar generator, a synchronous generator with permanent magnets.

1. Grid-Side Voltage source converter control:

Most inverters operate as a current source by injecting a sinusoidal current and in phase with the mains voltage, with a power factor equal to or very close to the unit. The inverter must be synchronized with the fundamental component of the grid voltage, even in cases where the grid voltage is distorted or unbalanced or when the grid frequency varies. Figure 1 shows an example of steady-state synchronization for a three-phase system, in which

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the three-phase wind photovoltaic cogeneration system with load

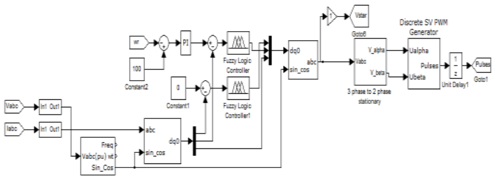

Fig. 2 VSI side converter control

As shown in Fig. 1, the ac-side of the VSI is terminated by an inductive filter ($\square_f$) with an internal resistance ($\square_f$) and a shunt capacitor ($\square_f$). The $\square_f$-$\square_f$ filter and the utility-grid impedance are modeled as following;

$$\bar{v}_c = \bar{v}_f + R_f\bar{\imath}_c + L_f\frac{d\bar{\imath}_c}{dt} + j\omega L_f\bar{\imath}_c$$

$$\bar{v}_f = \bar{v}_g + R_g\bar{\imath}_g + L_g\frac{d\bar{\imath}_g}{dt} + j\omega L_g\bar{\imath}_g$$

$$\bar{\imath}_c = C_f\frac{d\bar{v}_f}{dt} + \bar{\imath}_g + j\omega C_f\bar{v}_f$$

To avoid VSI over modulation, the design of a PV array should take into account the coordination between the MPPT voltage of the PV array and the actual voltage at the common coupling point (PCC), i.e. □o, at general levels of irradiation. In power converters, the pulse width modulation (PWM) and the switching model are dictated by the relationship between AC and DC voltage such that Vc = mVdc / 2 where where is the complex vector modulation signal. Since Vc is relatively constant and therefore in steady-state conditions, any significant variation in dc could induce modulated operation or improper use of the DC connection, which in turn degrades the quality of the energy injected into the public network.

2. **Machine-Side Voltage Source Rectifier (VSR):** At any wind speed, there is an optimal mechanical rotor speed value which corresponds to the generation of maximum wind energy. The RSV in Fig. 3 obtains the extraction of the maximum wind energy. The MPPT algorithm for the wind generator uses the wind speed ($v1$) to generate the optimal value of the rotor speed based on the mechanical characteristics

III . FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator. The basic scheme of a fuzzy logic controller is shown in Fig.3 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

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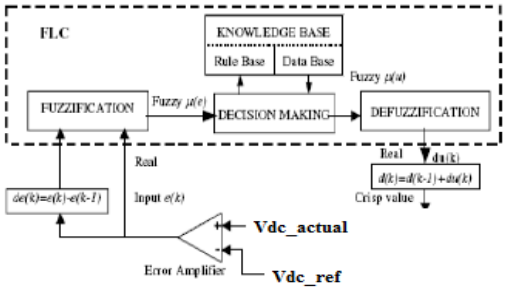

Fig.3. Block diagram of the Fuzzy Logic Controller (FLC).

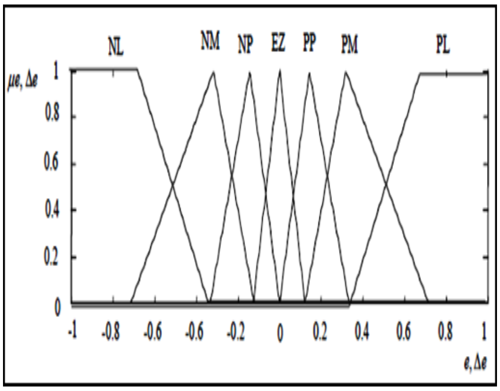

Fig.4 Membership functions for Input, Change in input, Output.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with „V_{dc}" and$V_{dc\text{-}ref}$ as inputs.

This sections presents a flexible control strategy to improve the performance of DSTATCOM in presence of the external inductor *L*ext. First, a dynamic reference load voltage based on the coordinated control of the load fundamental current, PCC voltage, and voltage across the external inductor is computed. Then, a proportional-integral (PI) controller is used to control the load angle, which helps in regulating the dc bus voltage at a reference value. Finally, three-phase reference load voltages are generated. The block diagram of the control strategy is shown in Fig. 6.

TABLE II:

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

IV. MATLAB/SIMULINK RESULTS

A time-domain simulation model for the hybrid system in Fig. 1 is developed under the Matlab/Simulink® environment to evaluate the validity and the performance of the system. The wind and PV generators are \ rated at 2.0 and 0.9 MVA, respectively. The complete model entities are built using the SimPowerSystem® toolbox. The VSCs are simulated using average-model-based blocks. The simulation type is discrete with a sample time of 50 µs. In the following subsections, the proposed wind-PV cogenerator is subjected to theoretical challenging operating conditions which might not occur in the realty, e.g., large step variations in the wind speed and the solar irradiance levels, and three-phase-to-ground (3PG) faults conditions. These worst-case scenarios are applied to challenge the system stability and show the effectiveness of the designed controllers.

A. Small-Signal Model Verification

The accuracy of the small-signal state-space model in (17)
is validated in Fig. 4 following a 5% step increase in *V*4j at
t = 1.0 s. In this particular scenario, a lightly damped response has been induced by increasing the bandwidth of the dc-link voltage controller of the VSI so that the model can be easily validated. For an eigenvalue $\lambda = -\sigma$ •} $j\omega$A, the frequency of oscillation is ωA [in rad/s] whereas the

envelope of the oscillatory response decays following the exponential function $A\exp(-\sigma t)$, where A is the amplitude of the oscillation and t is the time in seconds. The yielded dominant lightly-damped mode is λ = −73.03 •} j251.7. Referring to Fig. 4, the frequency of the oscillation of the lightly-damped response is 247.4 rad/s whereas the oscillatory response decays following a close match to $A\exp(-73.03t)$. This implies the accurate development of the small-signal model in (17).

B. Wind-PV Cogeneration

The cogeneration of the wind and PV energy is investigated following different weather conditions. As shown in Fig. 5, the wind speed increases from 8.4 to 10.8, then drops to 7.2, and finally increases to 12m/s at t =2, 4, and 6s, respectively. The solar irradiance level decreases from 1 to 0.8, and then to 0.4, and finally increases to 0.6kW/m%, at t =3, 5, and 6s, respectively. Following Figs. 2-3, the MPPT1 and MPPTA generate the optimal ω* and V4js . The corresponding variables are then regulated using (4) and (12), as shown in Figs. 6(a)-(b), respectively. During the entire operating range, both ω? And V4j are highly damped which is reflected on the generated wind and PV power as depicted in Figs. 6(c)-(d), respectively, and the injected current to the utility-grid as in Fig. 6(e). For further investigation, the maximum wind power, i.e., 2MW, and a PV power of 0.568MW are generated at t = 6.0 s where the dc-link stability is preserved with a maximum overshoot of 0.06 p.u. as shown in Fig. 6(b). Under all conditions, a unity PCC voltage is maintained following (14), as shown in Fig. 6(f).

The designed vector controllers for the VSR and the VSI do not saturate the generated PWM, as shown in Figs. 6(g)-(h), respectively, where the variable frequency operation of the VSR is clearly noted.

C. Wind-Only Generation

During the night-time or at low-irradiance conditions, the PV generator provides a zero power to the utility-grid. Under this condition, the dc-link voltage is regulated to the minimum value. As shown in Fig. 7(a), the dc-link voltage drops to 0.858p.u. at t = 2.0 s as the PV power generation drops to 0, and is restored back to 1.0 p.u. at t = 3.0 s when the PV power is generated. The corresponding wind and PV power as well as the injected ac current to the utility-grid are shown in Figs. 7(b)-(c), respectively. Note that a blocking diode is usually connected in series with each PV string to prevent reverse current flow at the low irradiance levels.

D. PV-Only Generation

The wind speed is assumed to be less than the cut-off speed, and hence the majority of the generated wind power is consumed in the system losses. Therefore, the PMSG operates in the braking mode and the rotor is brought to a stand-still by mechanical means.

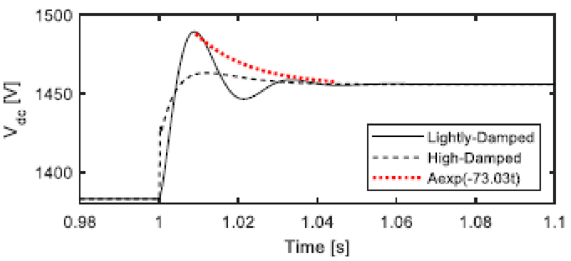

Fig .4. The step response of the dc-link voltage to verify the developed smallsignal model in (17).

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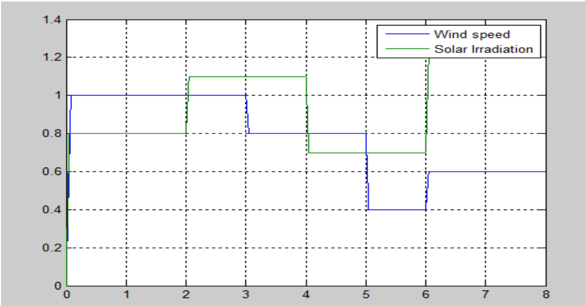
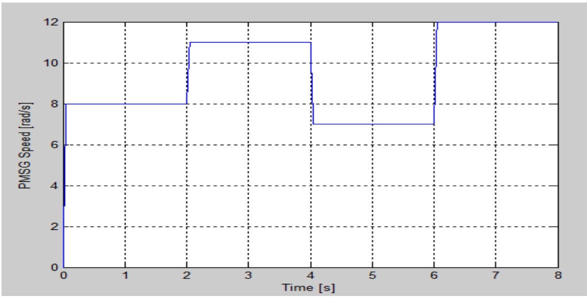


Fig. 5. Wind speed and solar irradiance levels



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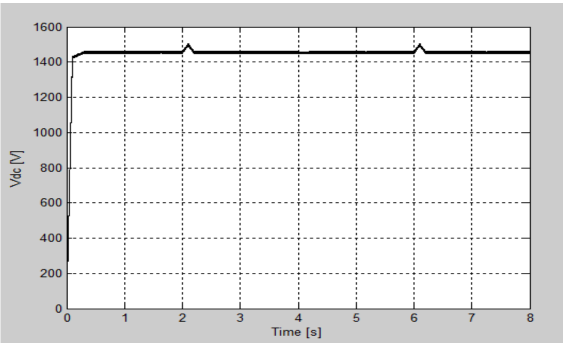

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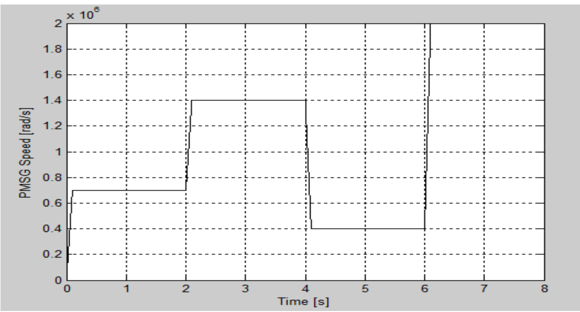

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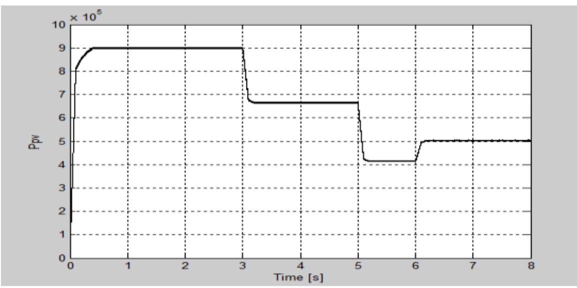

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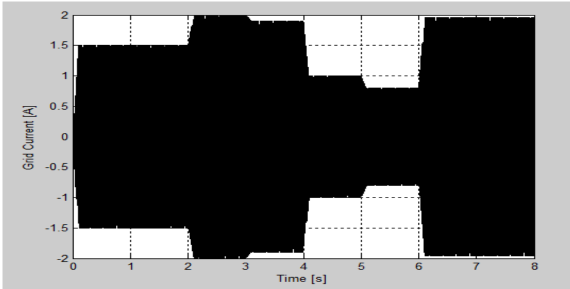

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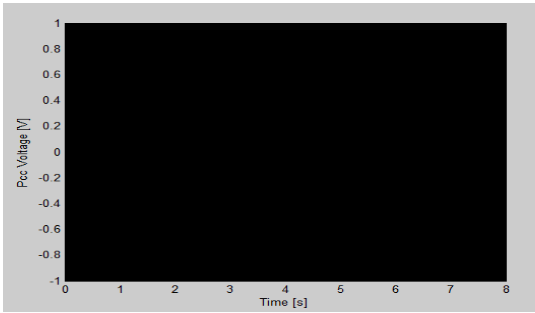

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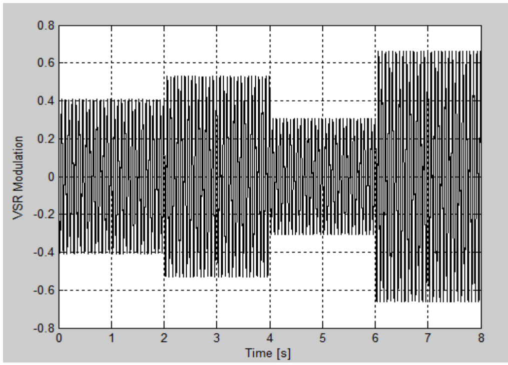

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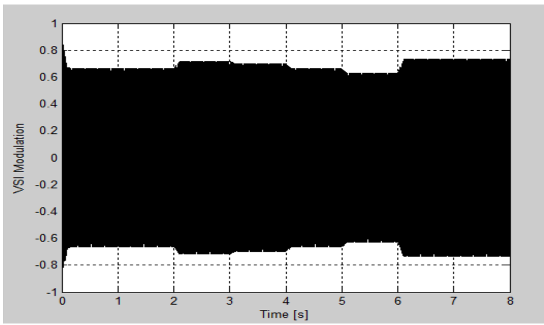

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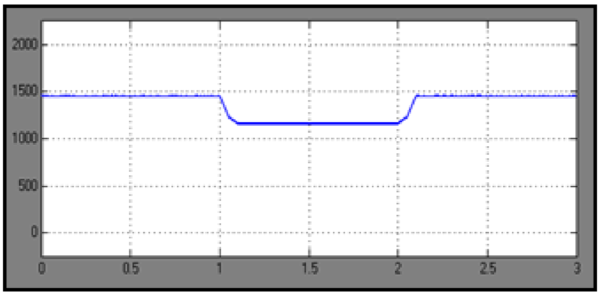
Fig .6. Performance of the wind PV cogeneration scenario.

As shown in Fig. 8(a), the rotor speed (wr) drops from 1 p.u. to 0, and then increases back to 1p.u. at t = 2 and 3s, respectively. This corresponds to a sudden change in the generated wind power and injected grid current as shown in Figs. 8(b)-(c), respectively. In spite of the challenging operating scenario, the system stability is maintained.

E. Wind-PV Cogeneration under Faults Conditions

Converter-based distributed generation units roughly contribute by the rated currents under the short circuit conditions. Therefore, and due to the increased penetration of the renewable energy resources to the electrical grids, some utilities have enforced the fault-ride through of power converters [33]. Accordingly, the distributed generation units must not disconnect during fault conditions with a voltage drop down to 0 p. u. that continues to less than or equal to 150 ms (9cycles for 60Hz systems). In this operational scenario, the proposed wind-PV cogeneration system is investigated for the fault-ride-through capabilities. The PCC in Fig. 1 has been subjected to a 3PG fault at t = 4 s for 4.0 cycles. Further, the VSCs have been implemented in the Simulink model using pulse-widthmodulated switching blocks. Fig. 9 shows the performance of the dc-link voltage and the utility-grid current under the 1.0 p.u. and 0.5 p.u wind power generation whereas the PV power generation is maintained at 1.0 p.u.



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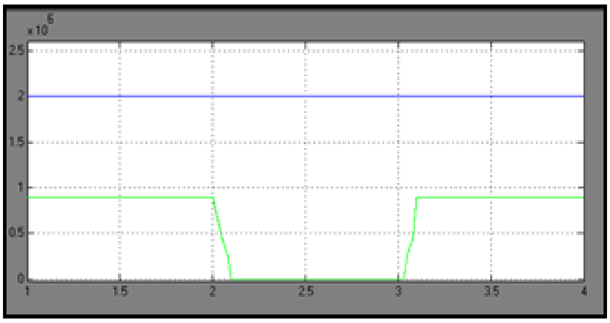

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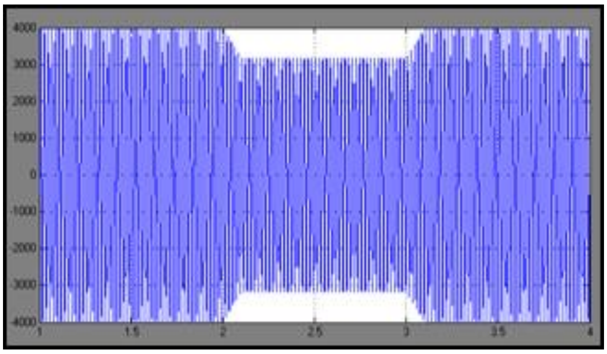
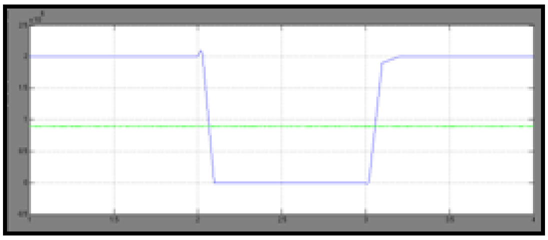


(c)

Fig .7. System performance at the wind-only generation scenario.

At 1.0 p.u. wind and PV power generation, and following the clearance of the 3PG fault, the dc-link voltage stability is violated whereas the quality of the injected ac current is degraded to a total-harmonic-distortion (THD) of 8.75%. On the contrary, the response with the 0.5 and 1.0 p.u. wind and PV power generation, respectively, reflects a stable dc-link voltage and a better current quality of a of 3.61%. This implies that the wind generator is associated with the system instabilities under the utility-grid faults conditions. The fault conditions are associated with a sudden drop in the PCC voltage that hinders the maximum power transfer from the dc-link to the grid. As the input wind power is driven by a relatively slow mechanical system, the wind generator keeps injecting the maximum wind power into the dc-link capacitor during the fault conditions. Therefore, the dc-link input power becomes significantly higher than the output power and so the dc-link voltage increases, as shown in Fig. 9(a) [at 1 p.u. wind power]. On the contrary, the PV generator does not contribute to the dc-link voltage instabilities under the fault conditions.The increased dc-link voltage pushes the operating point of the PV array beyond the maximum power point. As shown in Fig.3, as the PV array voltage exceeds the MPPT operating point, the generated PV power is naturally decreased, and so the PV array does not contribute to the fault currents. The PV generator has self-healing capabilities under the utility-grid faults conditions. In literature, the protection against the fault conditions in the wind generators is achieved by activating the following protection schemes [34]; 1) using a braking resistance in parallel to the dc-link capacitor of the BtB VSCs so that the generated wind power can be dissipated during the faults. 2) using the pitch angle control so that the wind turbine blades are twisted to reduce the amount of wind power extraction, and hence the mechanical torque input to the wind turbine is reduced.



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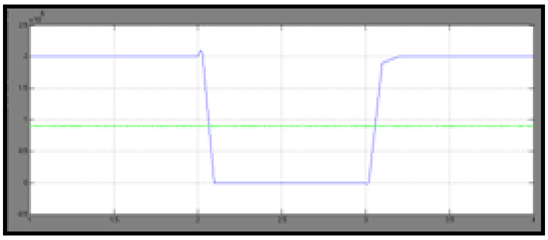

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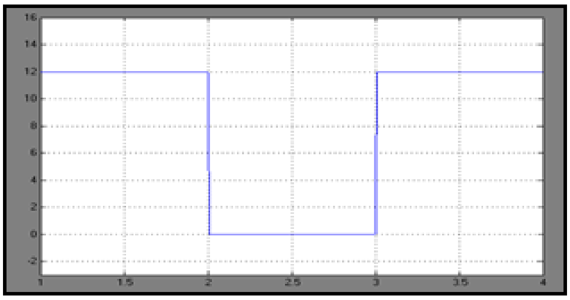

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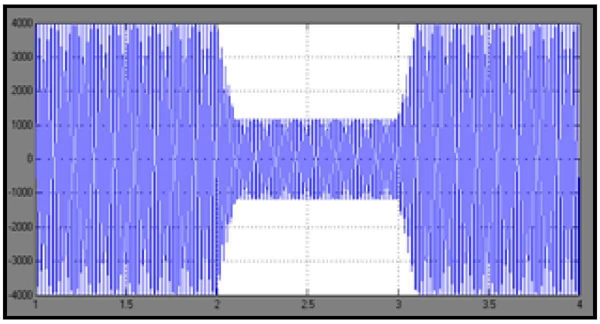
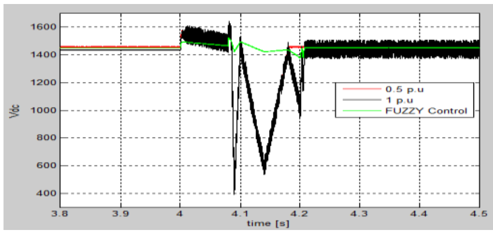


(e)

Fig .8. System performance at the PV-only generation scenario.

Note that both protection schemes can be used so that the braking resistance provides a quick damping till the mechanical pitch controller is activated. Fig. 10 shows the system performance when the preceding fault protections are implemented under 1.0 p.u. wind and PV power generation. The increase of the dc-link voltage has been limited whereas the injected ac current to the grid is maintained stable. The faultride through has been achieved by electrically dissipating the extra wind power into the braking resistance till the wind power input is mechanically suppressed using the pitch angle control. For further investigations, the system performance under the single-phase-to-ground (1PG) fault conditions is investigated in Fig. 11. It is clear that the 1PG fault is not detrimental to the system performance as compared to the 3PG faults in Fig. 9. However, the protected scheme reflects a more damped dc-link response as compared to the unprotected case.



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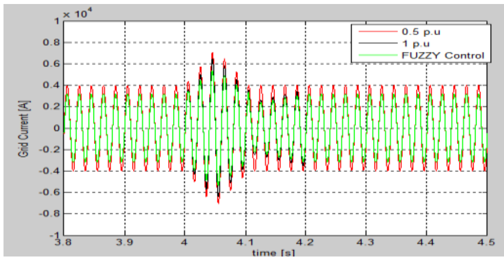

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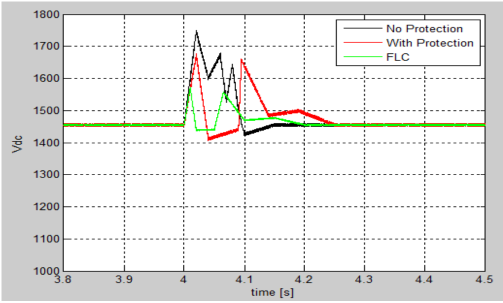

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Fig. 9. The system response to a 3PG fault at t = 4.0 s for 4.0 cycles – 1.0 and 0.5 p.u. wind power generation with 1.0 p.u. PV

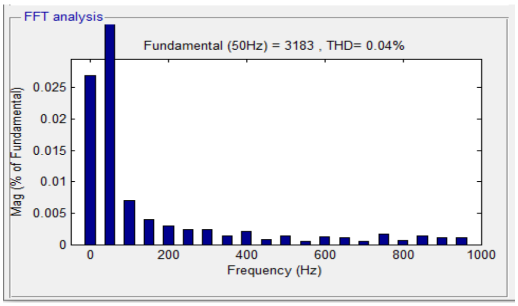

Fig. 10. The system response to a 3PG fault at t = 4.0 s for 4.0 cycles – 1.0 p.u. wind and solar power generation with the implemented fault protection schemes.

V. CONCLUSION

This project presented wind-photovoltaic cogeneration systems using VSC BtB connected to the vector-controlled network. The VSR on the side of the wind generator is responsible for extracting the maximum wind energy after changes in wind speed. On the utility side, the functions of the VSI are to extract the maximum PV power from the PV generator, to achieve a balance between the input and output powers through the intermediate circuit capacitor and to maintain a PCC voltage of the unit in different mode. of operation. The proposed system has the following advantages; 1) Maximum reliability and efficiency thanks to the combination of wind and photovoltaic generators. 2) Independent MPPT extraction since VSR and VSI are the only ones responsible for the extraction of wind and photovoltaic energy, respectively 3) simple system structure and controller design. 4) Bankruptcy can be achieved through existing protection systems. Optimal performance has been reported using time domain simulation results in the Matlab / Simulink environment.

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