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Conference paper

Application of Artificial Intelligent Techniques for Power Quality Improvement in Microgrid System

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ABSTRACT

This paper focuses on modeling, control and power quality improvement of a microgrid connected system. This last was designed as a multi-converter system with Wind Turbine driven Permanent Magnet Synchronous Generator, and lithium ion Battery Storage Energy System. These sources are connected by a continuous bus to a nonlinear load through a DC /AC converter and three-phases multi-functional voltage source inverter. Where, wind systems are considered as primary power resource, and the grid is used for the effect of consumption of the overage power available from sources, when the battery has been fully charged. Multi Functional Voltage Source Inverter is used to ameliorate the performance of the proposed system, guaranteeing both reactive power and harmonic compensation. Moreover an intelligent control by fuzzy logic control algorithm are managed In order to extract the maximum power from wind turbine, to guarantee an effective storage management, this about the DC side. For the AC side a direct power control strategy with fuzzy logic algorithm have been used. The simulation of the system solution is carried out in Matlab/Simulink. The obtained simulation results show that the technique of fuzzy logic furnish the best solution in term of robustness, optimization performance, low THD and fast dynamic response.

1. INTRODUCTION

The problem with fossil fuels lies mainly in their harmful environmental impact, particularly in terms of greenhouse gas emissions and air and water pollution. Fossil fuels such as oil, coal and natural gas are also non-renewable resources, meaning they become depleted over time (Gajewski & Pieńkowski,

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2021). To resolve this problem, many solutions rely on the development and the use of renewable energies (Das et al., 2022). These come from natural sources such as sun, wind, water, biomass and geothermal energy. Renewable energy sources are inexhaustible on a human scale, meaning they can be used continuously without depletion, emit little or no greenhouse gases or air pollutants during their use (Vlad, 2013).

Microgrids are electrical energy distribution systems that can operate independently or in parallel with the main electricity network. Microgrids are often equipped with energy storage systems, load management technologies and advanced controls that enable more efficient use of available resources and adaptation to variations in demand and production (Aissou et al., 2015) .

Furthermore, the topology of microgrid connected system with battery storage is divided in two parts (DC, AC). The DC part consists of DC/DC boost converter using Maximum power point tracking MPPT algorithm to extract maximum power from wind system ,and bidirectional DC/DC converter to manage the charging/discharging operations of the battery storage. The AC part consist of an MFVSI inverter in series with filtering device connected to differing nonlinear load and to the grid (Madaci et al., 2016).

The presence of non-linear loads such as inverters, variable speed drives, frequency converters, etc., also rapid load variations, such as those induced by electrical equipment can generate non-sinusoidal currents, thus introducing harmonics into the system (Adineh et al., 2021).

To mitigate harmonics, several solutions can be considered, the use of active and passive filters can help reduce harmonics by removing unwanted components from voltage and current waveforms.

Active power filtering proves to be a best solution (Feng et al., 2018). In the literature, there are a lot of strategies for the regulation and control of the shunt active power filter(SAPF), in our case we have concentrate on Direct Power Control Current Control (DPCCC) (Debdouche et al., 2022) wich is a variation of direct power control, That aims to assure control accuracy and stability by directly controlling the current in electrical power energy conversion systems. We have interested on the (DPCCC) cause it give more precise current control in power converters which is essential to assure optimal system performance, can provide faster response to load variations and system disturbances, reduce current harmonics, which helps to improve electrical power quality, and can also help to maintain better voltage regulation in the system.

The microgrid system is usually optimized for Maximum Power Point Tracking (MPPT) (Madaci et al., 2016) to extract the maximum power from the wind turbine energy source. There exist different MPPT techniques having different complexities, topologies and hardware. This study is focus to use fuzzy logic control(FLC) strategy to control and improve the power quality of microgrid connected system with battery storage.

FL provides significant flexibility and robustness in the modeling and control of complex systems, where operational conditions can be variable and unpredictable (Das et al. 2022). However, successful implementation of FL in microgrid system requires appropriate modeling of the system and judicious definition of fuzzy rules to meet the specific operational objectives of the microgrid.

By combining DPC with FLC in a microgrid-connected system, the control strategy can effectively regulate power flow and current, enhance system stability (Debdouche et al., 2022), and improve overall performance, especially under varying operating conditions and disturbances. This approach offers flexibility, adaptability, and robustness required for microgrid applications, contributing to the reliable and efficient operation of the microgrid system.

The control and quality improvement performances are presented using MATLAB/simulink.

2. CONFIGURATION OF THE GLOBAL SYSTEM

Microgrid system are classified into three general architecture types (DC-coupled structure, AC-coupled structure and the mixed-structure MICROGRIDs) (Mezzai et al., 2014)**.** In this study we focus with the form of DC-coupled architecture wich is presented in Fig 1.

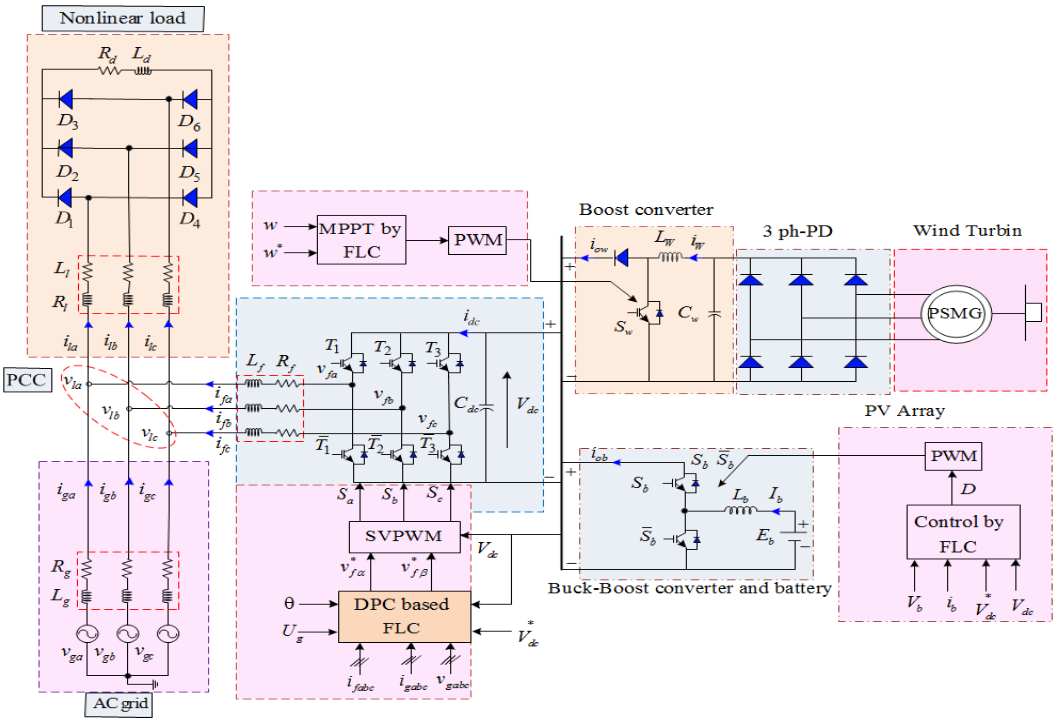

Fig. 1 Architecture of the proposed system

2.1 Model of Wind turbine

The power generated changes with various wind speeds, The mechanical power can be written as follows(Gajewski & Pieńkowski, 2021):

$$P_t = \frac{1}{2}\rho A C_p(\lambda,\beta) v_\omega^3 \tag{1}$$

where: $A = \pi R^2$ the area swept by the rotor blades and R is the radius of the turbine blades, ρ the air density, C_p the power coefficient of the wind turbine, $\lambda = \omega_m R / v_\omega$ the tip speed ratio and ω_m is the mechanical angular speed of the turbine rotor, β the blade pitch angle expressed in degrees, and v_ω the wind speed.

2.2 Model of Permanent Magnet Synchronous Generator(PMSG)

Mathematical equations of the PMSG are presented in the dq frame, revolving with the electrical angular velocity of the rotor. The final form of this equation can be described as follows(Gajewski & Pieńkowski, 2021):

$$\begin{cases} v_{sd} = R_s i_{sd} + L_d \dfrac{di_{sd}}{dt} - p\omega_m L_q i_{sd} \\ v_{sq} = R_s i_{sq} + L_q \dfrac{di_{sq}}{dt} + p\omega_m \left(L_q i_{sd} + \Phi_m\right) \end{cases} \quad \omega_e = n_p.\omega_m,\, T_e = 1.5 n_p \left(i_{sd} i_{sd} - i_{sd}\right) \tag{2}$$

where: R_s the stator phase resistance, L_d, L_q the direct and quadrature stator inductances, v_{sd}, v_{sq} , i_{sd}, i_{sq} the *dq* components of the stator voltage and current vectors ω_m, ω_e the electrical and mechanical angular speed of the PMSG rotor, ψ_{PM} the flux established by the permanent magnets, and n_p the number of pole pairs of PMSG.

2.3 Battery Energy Storage (BES) Model

In the event of a grid failure, or wind turbine energy source operating with low efficiency or being out of service. The BES system can also provide power to the microgrid(Lee et al., 2021).

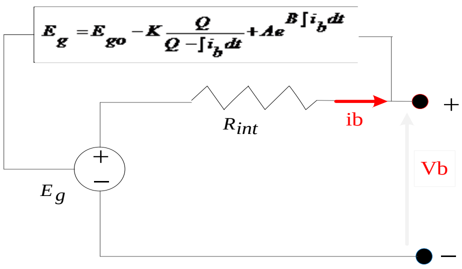

Fig.2 Equivalent model of the battery

Where: (Ego) battery constant voltage (V), (K) the polarization voltage (V), (Q) the maximum battery capacity (Ah), (A): exponential component amplitude (V), (B) the exponential component time constant inverse (Ah)-.

The equations of state-of-charge(SOC) is given by the following equation:

$$\frac{d(SOC)}{dt} = -\frac{\eta_b}{Q_b} i_b \tag{3}$$

Where: (ηb) the battery efficiency, and (Qb) is the battery capacity.

2.4 Shunt active power filter model

The simplified equation of the grid current in the rotating frame d-q is given by(Feng et al., 2018):

$$v_{gq} = U_g = \sqrt{\frac{3}{2}} U_{gm} \quad with \quad (v_{gd} = 0) \tag{4}$$

Where: (Ugm) is the amplitude of the phase grid voltage.

3. THE PROPOSED CONTROL OF MICROGRIDS CONVERTER

In this section, we concentrate in the application of fuzzy logic algorithm control wich is simple and convenient for nonlinear systems that present parameters variation.

Fuzzy Logic system consists of three stages (Fuzzification, Fuzzy inference rule base, and defuzzification) as shown in the figure 3.

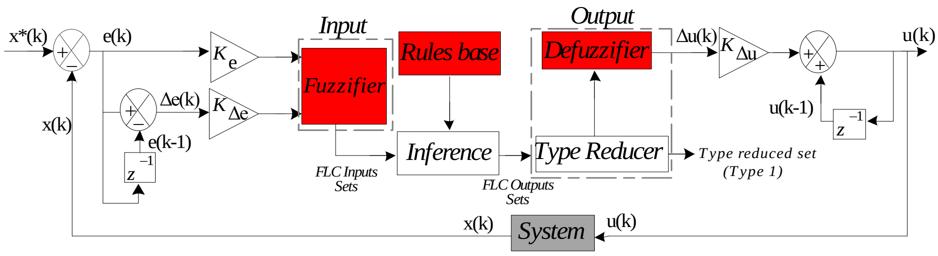

Fig.3 FLC diagramme bloc

The error (e) and there variation (Δe), are the inputs and the output is the change of control law (Δu_k).

$$\begin{cases} e(k) = K_e\left(x^*(k) - x(k-1)\right) \\ \Delta e(k) = K_{De}\left(e(k) - e(k-1)\right) \end{cases} \tag{6}$$

3.1 FLC Control (MPPT) For Wind Turbine System

The architecture of wind turbine controlled by FLC algorithm is shown in the figure bellow:

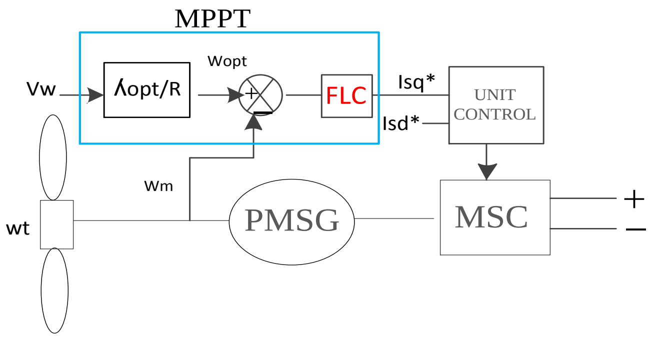

Fig.4 FLC control for wind turbine

The form of this control law is given by the equation follow:

$$u_{k+1} = u_k + K_{du}.\mathrm{du}_{k+1} \tag{7}$$

Where: Kdu the gain associated with the order uk+1, duk+1 the variation of the order.

3.2 FLC Conrol For Storage System

The architecture of Storage system controlled by FLC algorithm is shown in the figure bellow;

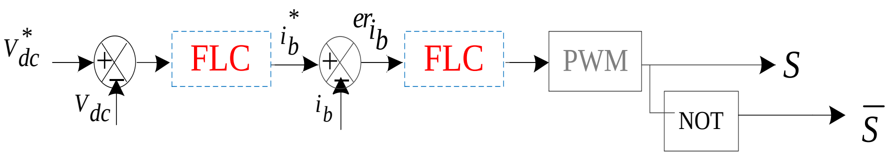

Fig.5 Storage system controlled by FLC

The battery current generator error ($e_{ib}(k)$), and the changes of this error ($\Delta e_{ib}(k)$) are The inputs variables.

$$\begin{cases} e_{i_b}(k) = K_{i_b}\left(i_b(k) - i_b(k-1)\right) \\ de_{i_b}(k) = K_{\Delta i_b}\left(e_{i_b}(k) - e_{i_b}(k-1)\right) \end{cases} \quad (8)$$

Where: K_{ib}, $G_{\Delta ib}$ are the normalization gains of errors and the change in the errors.

3.3 FLC And DPC Control For The Grid Side

A MFVSI controlled by FLC with DPC is a sophisticated control strategy employed in microgrid systems to manage power flow, voltage regulation, and other functionalities efficiently.

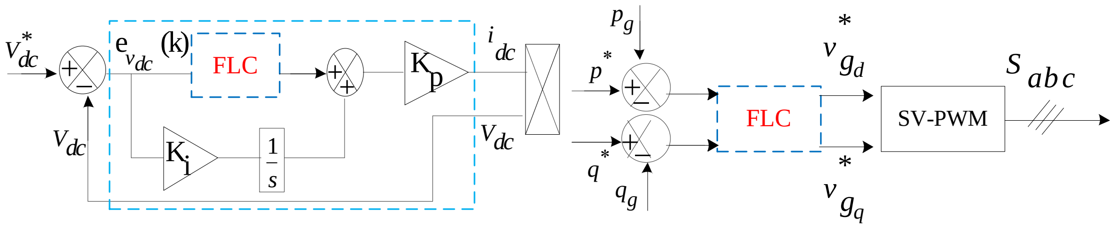

Fig.6 DPC-SVM Conrolled by FLC

4. SIMULATION RESULT

The microgrid operation connected system with storage is simulated using MATLAB/simulink under varying wind speed

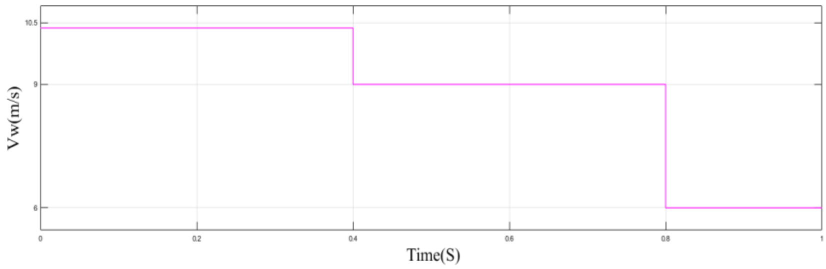

Fig. 7 wind speed profile

Fig.8 represents the power flow distribution in the proposed system

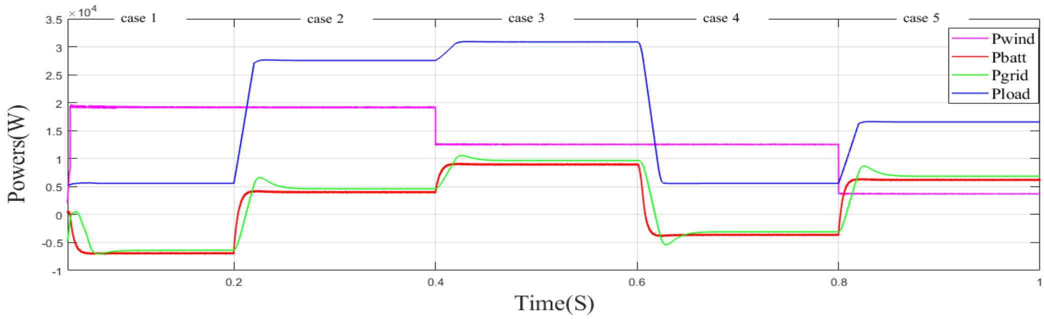

Fig.8 Power flow distribution

As shown in figure bellow, We can observe that the FLC algorithm controller increases the dc-link stability

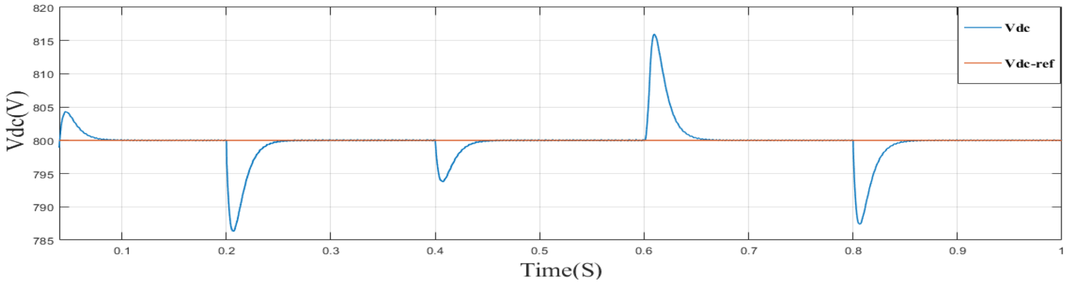

Fig.9 DC link voltage regulation.

The voltage and current curves and the THD obained after filtering, based on FLC regulation is shown in the following figures:

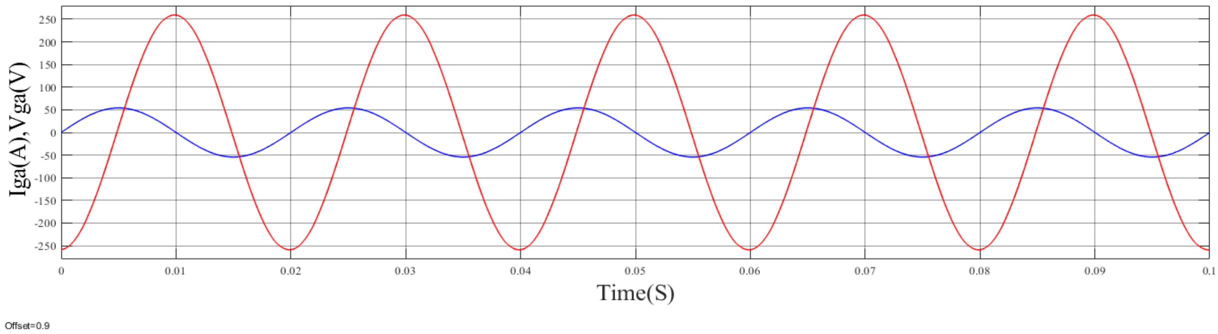

Fig.10 Grid source current and voltage

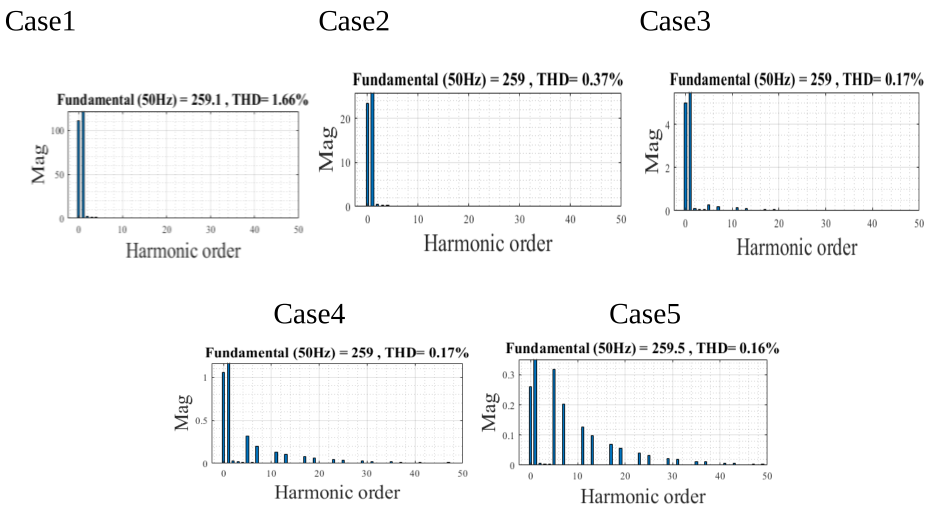

Fig.11 Harmonic spectrum

About Fig 11, we can see that, after filtering the THD over all cases is maintained less than 5% respecting healthy operation.

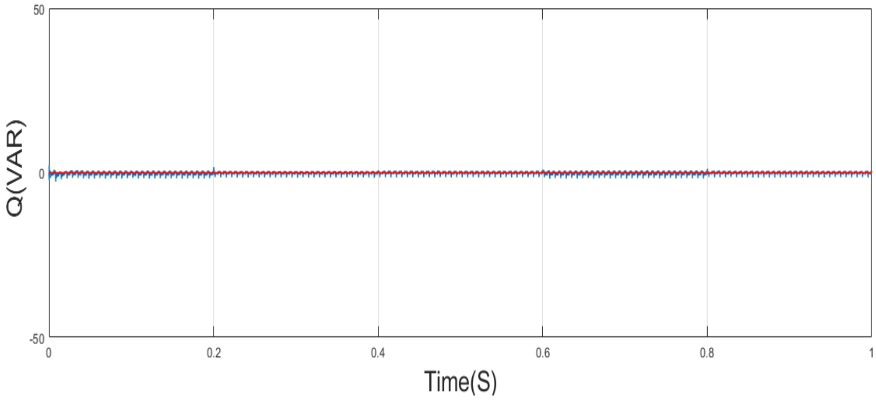

Fig.12 Reactive power on the grid side

Fig 12, represent the reactive power grid, we can see that the reactive power is kept At zero, so the proposed strategy assure a good compensation of reactive power.

5. CONCLUSION

The results of the executed simulations confirmed that the microgrid system is designed to test the power quality improvement of the system during different cases of operations under varying wind speed and load changes. Controlling power quality in a connected microgrid system using FLC offers an efficient and adaptable approach to ensuring optimal levels of voltage, frequency and power quality. The use of FLC makes it possible to effectively manage load fluctuations and variations, as well as external disturbances, thus ensuring stable and reliable system performance. The flexibility of FL allows it to adapt to different operating conditions and provide robust solutions in a dynamic environment such as a microgrid. By integrating FLC control, microgrid systems can improve energy efficiency, reduce losses and ensure high-quality power supply to users. Ultimately, fuzzy logic control represents a promising approach to address power quality control challenges in connected microgrid systems. Finally, the proposed study can be considered as an initial work in the microgrid power management field, which can be improved. The future work will aim to integrate advanced energy management optimization strategies.

NOMENCLATURE

WT: Wind Turbine
PMSG: Permanent Ma gnet Synchronous Generator
BSES: Battery Storage Energy System
DC: Direct Current
AC: Alternative Current
MFVSI: Multi-Functional Voltage Source Inverter
FLC: Fuzzy Logic Control
DPC: Direct Power Control
RE: renewable energies
MPPT: Maximum Power Point Tracking

APPENDIX

Table 1. Simulated system parameters.

	Parameter	Value
DC side hybride renewable energy		
[1]	Voltage source (Vg)	230V
[2]	Grid source Inductance (Lg)	2.5Mh
[3]	Grid source Resistance (Rg)	0.01Ω
[4]	Grid frequency (f)	50Hz
[5]	Reference voltage capaacitor (Vdc*)	800V
Wind turbine		
[6]	Rated power (PWt)	20kw
[7]	rotor radius (R)	4.4m
PMSG generator		
[8]	Rated power (Pe)	20kw
[9]	stator resistance (Rs)	0.1764w
[10]	stator dq-axis inductances (Ld, Lq)	4.48 mH
[11]	rated speed (ns)	211 rpm.
Li ion Battery storage		
[12]	Nominal voltage (Vn)	400V
[13]	Battery converter resistance	0.05Ω
[14]	Battery converte capacitance	4000ɥF
[15]	Battery converter inductance	1Mh
[16]	Rated capacitor	100Ah
Nonlinear load		
[17]	Resistance	51.64Ω
[18]	Inductance	83.2mH

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