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Short Communication

Performances analysis of WT-DFIG with PV and fuel cell hybrid power sources system associated with hydrogen storage hybrid energy system

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ABSTRACT

This paper highlights the modeling and the simulation of a micro-grid renewable power system. It comprises wind turbine (WT) doubly fed induction generators (DFIGs), photo-voltaic generator (PV), a proton exchange membrane (PEM) fuel cell (FC) generator, a water electrolyzer used for long-term storage, a Hydrogen tank, and a battery bank (BB) utilized for short-term storage. Based on the given configuration and the different characteristics of the main components in the micro-grid, an overall control and a power management strategy are proposed for this system. This strategy consists in charging the BBs and producing hydrogen from the water electrolyzer in the case of excess power from the WT-DFIGs and PV generators. Therefore, the FC and the BBs will be used as a backup generator to supply the demand required power, when the WT-DFIGs and the PV energy are deficient. The effectiveness of this contribution is verified through computer simulations, where very satisfactory results are obtained.

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Introduction

Nowadays, renewable energy sources (RESs) for micro-grid system applications are attracting more interest for environment considerations; non-polluting, free in their availability and continuous [1,2]. Many RESs including wind turbine (WT), photovoltaic panels (PV) and micro-turbines are reported in the literature for hybrid power source systems for micro-grid applications [2,3]. As known, the drawbacks of these structures are the seasonal and daily climatic variations (solar radiation, wind speed, temperature) and geographical conditions as well as the profiles of the required power; it is why, as solutions, other measures are needed. In this way, Energy Storage Systems (ESSs) seem to be an adequate solution to mitigate the effects of wind and/or solar fluctuations and to maintain the power and energy balance as well so as to improve the power quality. To face the fast power variations, the ESS must have a

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$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Nomenclature	P _{rAC} power transferred through DC/AC converter III
G _p , C _p - max power coefficient and its maximum value pair pole number Proc. P _{ax} electronogree respectively, W P Ac Condition value Proc. P _{ax} electronogree respectively, W K ₁₀ , K ₂₀ , K	A_v area swept by the rotor blades, m ²	respectively, W
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	C_{n}, C_{n-max} power coefficient and its maximum value	P_{Elect} , P_{Bat} electrolyzer and BBs powers respectively, W
 e. δ arror and its time-derivative respectively, Kar, K₁, K₂, K₁, K₂, K₂, K₃, K₄, Scaling factors of the fuzzy PI controller K₂, K₁, K₂, K₂, S₂, K₃, K₅, Scaling factors of the fuzzy PI controller T, T, T	P pair pole number	P_{FC} , P_{pv} generated FC and photovoltaic powers
K _{in} <t< td=""><td>e, Δe error and its time-derivative respectively</td><td>respectively, W</td></t<>	e, Δe error and its time-derivative respectively	respectively, W
Kan, Kuan, Kun, Scaling factors of the fuzzy PD controller T, turbine aerodynamic torque not its reference respectively, Nm R, R, stator, rotor resistneces respectively, Ω la, I, stator, rotor resistneces respectively, Ω la, I, stator, rotor roticages respectively, Ω la, I, two-phase stator voltages respectively, N M magnetizing inductance, H W, I, Var, Var, Var A, Var, Var Var, Var, Var Var, Var, Var Var, Var Var Var Var Var Var Var Var	K_{1e}, K_{1Ae}, K_{PI} scaling factors of the fuzzy PI controller	P_{AC} , P_g exchanged powers between the proposed system
turbine aerodynamic torque, N.m Pase DC power in the DC-bus, W Tem. Tem_max electromagnetic torque and its reference respectively, N.m Pase Storage power, W Ray, Ray, stator, rotor leakage inductances respectively, Q Pase reactive power acchanged between the system and the AC grid and its reference respectively, Var M magnetizing inductance, H M Mode that the PC-bus, V Pase reactive power acchanged between the system and the AC grid and its reference respectively, V M magnetizing inductance, H Qa DE Gostor reactive power, VAR Qa acc act reactive power, VAR Main, two ophase rotor voltages respectively, V Cac -acc AC load reactive power, VAR Qa acc act meative power transferred through DC/AC converter III, Var Vest at terd wind speed, Ur/min reactive power transferred through DC/AC converter III, Var Var. Var. Var. Var	K_{2e} , K_{2Ae} , K_{PD} scaling factors of the fuzzy PD controller	and the AC grid respectively, W
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	T_t turbine aerodynamic torque, N.m	P _{Net} DC power in the DC-bus, W
respectively, N.m. R _s , R _s stator, rotor resistances respectively, H magnetizing inductance, H Y _{ad} , V _{at} V _{ad} v _{ad}	T_{em} , T_{em} – ref electromagnetic torque and its reference	P _{st} storage power, W
R_{g}, R_{r} stator, rotor resistances respectively, Ω Q_{cc}, Q_{cc-ref} reactive power, $Vardanged between thesystem and the AC grid and its referencerespectively, VarV_{cd}, V_{cd}, V_{cd}two-phase stator voltages respectively, VQ_{a}DFIG stator reactive power, VarV_{cd}, V_{cd}two-phase stator currents respectively, AQ_{a}AC load reactive power, VarV_{cd}, V_{cd}two-phase stator currents respectively, AQ_{a}AC load reactive power, VarV_{cdr}, V_{cd}two-phase stator currents respectively, AQ_{a}AC load reactive power, VarV_{cdr}, V_{cdr}two-phase stator currents respectively, AV_{arrand}PV_{cdr}, V_{dr}two-phase stator currents along a and \beta stator axes, AVP_{a}V_{cdr}, V_{dr}turbite rotor speed, T/minP_{a}\Phi_{r,ref}V_{bat}battery current, AP_{a}\Phi_{r,ref}V_{bat}battery current, AP_{a}\Phi_{r,ref}V_{bat}battery current, AP_{a}\Phi_{r,ref}V_{bat}battery current, AP_{a}\Phi_{r,ref}V_{bat}battery current, AP_{a}\Phi_{r,ref}V_{bat}battery current, A$	respectively, N.m	P _{wind} aerodynamic power, W
$ \begin{aligned} & _{L_{n}} \\ & \\ L_{n} \\ & \\ \\ \\ & \\$	R_s, R_r stator, rotor resistances respectively, Ω	Q_{AC} , Q_{AC-ref} reactive power exchanged between the
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	l _s , l _r stator, rotor leakage inductances respectively, H	system and the AC grid and its reference
v_{st}, v_{trd} v_{rd}, v_{rd} v_{rd}, v_{rd} v_{rd} v_{rd} v_{rd} v_{rd}, v_{rd} v_{rd} v_{rd}, v_{rd}, v_{rd} 	M magnetizing inductance, H	respectively, Var
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	v _{sd} , v _{sq} two-phase stator voltages respectively, V	Q_s DFIG stator reactive power, Var
$ \begin{aligned} & \begin{tabular}{lllllllllllllllllllllllllllllllllll$	v _{rd} , v _{rg} two-phase rotor voltages respectively, V	Q_{L-AC} AC load reactive power, VAR
$ \begin{split} & \begin{array}{lllllllllllllllllllllllllllllllllll$	i _{sd} , i _{sq} two-phase stator currents respectively, A	Q _{rg} reactive power transferred through DC/AC
v_{rated} rated wind speed, tr/minGreek letters $v_{cut-out}$ cut-out wind speed (limited), tr/min ρ air density, Kg/m^3 v_{rat} h_{in} current components along z and β stator axes, A λ , λ_{opt} tip speed ratio and its optimal value V_{bat} electromotive force corresponding to the open β blade pitch angle, $^{\circ}$ $cricuit battery voltage, V\betaturbine rotor speed, tr/minV_{bat}battery voltage, V\beta_{rat}V_{bat}battery voltage, V\phi_{ra}, \phi_{rp}, flux components along z and \beta stator axes, WbV_{bat}battery voltage, V\phi_{ra}, \phi_{ra}, for tor flux and its reference, WbV_{bat}battery current, A\phi_{ra}, \phi_{ra}, for tor flux and its reference, WbQ_dampere-hours stored in the battery, \Lambda/hPIG doubly fed induction generatorV_{cell}FC cell voltage, VDFIMP_{0}oxygen partial pressureDFIMP_0oxygen partial pressureDFIMP_{0}oxygen partial pressureDFIMP_{cen}fuel cell temperature, °CBBa, bFC constantsDFR_{cen}fuel cell temperature, °CHESSn_{bini}FC internal resistance, \OmegaMPTN_{catter}area of the electrical resistance, R_{ohm}, \OmegaA_{catter}area of the cell cell, R^{o}V_{cen}reversible cell voltage, VP_{catta}electrolyzer parameters for the ohmic resistanceO_{catta}rever$	i _{rd} , i _{rg} two-phase rotor currents respectively, A	converter III, var
$V_{eut-out}$ cut-out wind speed (limited), tr/min ρ air density, Kg/m³ $V_{eut-Vac_{ect-raf}}$ current components along z and β stator axes, A ν wind velocity, m/s $V_{der, Vac_{ect-raf}}$ direct voltage and its reference respectively, V β blade pitch angle, ° F_{bat} electromotive force corresponding to the open β blade pitch angle, ° C_{bat} internal battery capacity, F Ω_{1} turbine rotor speed, tr/min C_{bat} internal battery capacity, F Ω_{1} turbine rotor speed, tr/min V_{bat} battery voltage, V Ω_{ref} DFIG mechanical speed and its reference, tr/min V_{bat} battery voltage, V $\Phi_{r_1} \Phi_{r_2,ref}$ rotor flux and its reference, Wb V_{bat} battery voltage, V $\Phi_{r_1} \Phi_{r_2,ref}$ rotor flux and its reference, Wb V_{bat} pydrogen partial pressureDFIGdoubly fed induction generator P_{r_1} hydrogen partial pressureDFIGdoubly fed induction machine P_{0} oxygen partial pressureDFIGdoubly fed induction machine P_{0} electrolate drop, VBSbattery bank E_{otn} cut partial battery carent, A C<	v _{rated} rated wind speed, tr/min	Greek letters
$ \begin{aligned} i_{p,a} i_{r,\beta} & \text{current components along α and β stator axes, A y wind velocity, m/s \\ $\lambda_{a} \lambda_{opt}$ the spectration and its optimal value β_{batch} $\lambda_{a} \lambda_{opt}$ the spectration and its optimal value β_{batch} $\lambda_{a} \lambda_{opt}$ the spectration and its optimal value β_{batch} $\lambda_{a} \lambda_{opt}$ the spectration and its optimal value β_{batch} \bet	v _{cut-out} cut-out wind speed (limited), tr/min	ρ air density, Kg/m ³
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	$i_{r\alpha},i_{r\beta}$ current components along $lpha$ and eta stator axes, A	υ wind velocity, m/s
E_bat circuit battery voltage, Vβblade pitch angle, °C_bat circuit battery voltage, VΩturbine rotor speed, tr/minC_bat battery capacity, FΩ Ω, Ω_{res} Θ_{Fi} Rbat battery voltage, VΩ Ω, Ω_{res} Φ_{Fi} Vbatbattery voltage, V $\Phi_{ra}, \Phi_{r,ref}$ rotor speed, tr/minVbatbattery voltage, V $\Phi_{ra}, \Phi_{r,ref}$ rotor flux and its reference, tr/minMagnere-hours stored in the battery, A/h Ψ_{r-AC} local load phase shift, °N_cellFC cell voltage, VWTwind turbineVcellFC cell voltage, VWTwind turbinePH2hydrogen partial pressureDFIGdoubly fed induction generatorPM3nernst voltage, thermodynamic potential of the cell, VPECfuel cellEAct a citvation voltage drop, VBBbattery bankECon concentration voltage drop, VESSenergy storage systemRohmo part of the electrical resistance Rohm, ΩACalternative currentRohmo part of the electrical resistance Rohm, ΩACalternative currentRohmo part of the electrolyzer parameters for the ohmic resistanceP-Vpower and voltage characteristicP-Vvoltagevoltage characteristicP-VI_r, r2electrolyzer parameters for the ohmic resistanceP-VRohmopart of the ell electroly mark resistanceCRohmopart of the ell electroly mark resistanceP-VRohmopart of the ell electr	V_{dc} , $V_{dc - ref}$ direct voltage and its reference respectively, V	λ , λ_{opt} tip speed ratio and its optimal value
Circuit battery voltage, VΩtturbine rotor speed, tr/minCbatinternal battery capacity, FΩ, ΩDFI mechanical speed and its reference, tr/minRbatinternal battery resistance, Ω Φ_{rac} , Φ_{rac} DFI mechanical speed and its reference, WbVatabattery voltage, V Φ_{rac} , Φ_{rac} rotor flux and its reference, WbLbatbattery voltage, V Φ_{rac} , Φ_{rac} rotor flux and its reference, WbPdatmere-hours stored in the battery, A/h Φ_{rac} local load phase shift, °Nrcnumber of FC cells in the stackDFIGdoubly fed induction generatorPdatFC cell voltage, VDFIGdoubly fed induction machinePdatremst voltage, thermodynamic potential of thePWphotovoltaic generatorPo:oncentration voltage drop, VBBbattery bankEconconcentration voltage drop, VRESrenewable energy sourceRohmipart of the electrical resistance Rohm, ΩACalternative currentRohmiFC internal resistance, ΩMPTmaximum power point trackingUrevreversible cell voltage, VBBCbuck-boost bidirectional converterI, rzelectrolyzer parameters for the ohmic resistanceI-Vcurrent and voltage characteristicRohmiFC internal resistance, ΩMPTmaximum power point trackingI = 0current and voltage characteristicI-Vcurrent and voltage characteristicRohmiFC internal resistance Rohm, ΩGCitercurrentRoh	E _{bat} electromotive force corresponding to the open	β blade pitch angle, °
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Rbatinternal battery resistance, Ω $\Phi_{rat} \Phi_{TP}$ flux components along α and β stator axes, WbVbatbattery voltage, V Φ_{r} , $\Phi_{r,ref}$ rotor flux and its reference, WbIbatbattery current, A Ψ_{P} Θ_{L-AC} local load phase shift, °Oddampere-hours stored in the battery, A/hAbbreviationsAbbreviationsNFCnumber of FC cells in the stackAbbreviationsVcellFC cell voltage, VDFIGdoubly fed induction generatorPh_3hydrogen partial pressureDFIMdoubly fed induction generatorPo, oxygen partial pressureDFIMdoubly fed induction machinePo, cell, VFCflux components along a and β stator axes, WbRhermatcell, VProtone exchange membraneCell, VFCflux components along a and β stator axes, WbEveration voltage drop, VBBbattery bankEconeconcentration voltage drop, VBBbattery bankConconcentration voltage drop, VRESenewable energy sourceA, bFC constantsDCdirect currentRohmoFC internal resistance, ΩMPPTmaximum power point trackingUcellcell terminal voltage, VBBDbuck-boost bidirectional converterUrevielectrolyzer parameters for the ohmic resistanceP-Vpower and voltage characteristicUrevielectrolyzer current, AACalternative currentRheretare of the cell electrode, m ² FCfuc direct torque control <td>C_{bat} internal battery capacity, F</td> <td>Ω, Ω_{ref} DFIG mechanical speed and its reference, tr/min</td>	C _{bat} internal battery capacity, F	Ω , Ω_{ref} DFIG mechanical speed and its reference, tr/min
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Qdampere-hours stored in the battery, A/hAbbreviationsPrcnumber of FC cells in the stackWTwind turbineVcellFC cell voltage, VDFIGdoubly fed induction generatorPhg.oxygen partial pressureDFIMdoubly fed induction machinePo.oxygen partial pressurePFMproton exchange membranecell, VPEMproton exchange membraneEnernstactivation voltage drop, VFCfuel cellFc.concentration voltage drop, VRESrenewable energy sourceFc.fuel cell temperature, °CSSenergy storage systema, bFC constantsDCdirect currentRohmopart of the electrical resistance Rohm. ΩACalternative currentRohmoreversible cell voltage, VBBDCbuck-boost bidirectional converterI, r_2electrolyzer parameters for the ohmic resistanceP-Vpower and voltage characteristicVrevreversible cell voltage, VBBDCbuck-boost bidirectional converterI, r_2electrolyzer parameters for the ohmic resistanceP-Vpower and voltage characteristicVrevreversible cell voltage, NFCfiect curque and reactive power controlKelee, kr_1, kr_2, kr_3electrolyzer parameters for the ohmic resistanceP-Vpower and voltage characteristicP-Vpower and voltage characteristicP-Vpower and voltage characteristicF_1, r_2electrolyzer current, AGCfiect torque controlKelee, kr_1, kr_2, k	I _{bat} battery current, A	ϕ_{L-AC} local load phase shift, $^{\circ}$
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p_{O_2} oxygen partial pressureDrivedubuity fet induction mathine P_{Nernst} nernst voltage, thermodynamic potential of the cell, Vphotovoltaic generator F_{Nernst} nernst voltage, thermodynamic potential of the cell, Vphotovoltaic generator F_{C} activation voltage drop, VBB E_{con} concentration voltage drop, VBB E_{cohm} ohmic voltage drop, VBB E_{ohm} ohmic voltage drop, VRES r_{FC} fuel cell temperature, °CESS a, b FC constantsDC R_{ohm0} part of the electrical resistance R_{ohm} , Ω AC R_{ohm1} FC internal resistance, Ω MPPT U_{cell} cell terminal voltage, VBBDC U_{rev} reversible cell voltage, VBBDC U_{rev} reversible cell voltage, VI-V r_{1, r_2} electrolyzer parameters for the ohmic resistances k_{Elec} , k_{T1} , k_{T2} , k_{T3} electrolyzer parameters for the ohmic resistancesP-V R_{elect} area of the cell electrode, m ² I_{elect} electrolyzer current, A T electrolyzer current, A T electrolyzer current, A T electrolyzer cell temperature, °C R_{s} , P_{L} R_{c} , P_{L-DC} variable AC and DC load powers respectively, W P_{I} proportional and integral controller P_{ID} proportional, integral and deviative controller	p _{H2} hydrogen partial pressure	DFIG doubly fed induction machine
$ \begin{array}{cccc} F_{Nernst} & nernst voltage, thermodynamic potential of the cell, V & PIN Protocontaic generator (Fig. C) & PEM proton exchange membrane (Fig. C) & Fig. C & fuel cell & PEM proton exchange membrane (Fig. C) & Fig. C & fuel cell & PEM proton exchange membrane (Fig. C) & Fig. C & fuel cell & PEM proton exchange membrane (Fig. C) & Fig. C & fuel cell (Fig. C) & Fig. C & fuel cell (Fig. C) & Fig. C & fuel cell temperature, °C & Fig. C & nergy storage system (Fig. C) & Fig. C & fuel cell temperature, °C & Fig. C & fuel cell temperature, °C & Fig. C & fuel cell terminal voltage, V & Fig. C & fuel cell terminal voltage, V & PI & maximum power point tracking (Fig. C) & Fig. C & fuel cell voltage, V & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell voltage (fig. C) & Fig. C & fuel cell (fig. C) & Fig. C & fuel (fig. C) & Fi$	p _{O2} oxygen partial pressure	Drim doubly lea induction inactime
cell, VFLMproton exchange memorane E_{Act} activation voltage drop, VFCfuel cell E_{Con} concentration voltage drop, VBBbattery bank E_{Ohm} ohmic voltage drop, VRESrenewable energy source E_{Ohm} ohmic voltage drop, VESSenergy storage system T_{FC} fuel cell temperature, °CHESShybrid energy storage systema, bFC constantsDCdirect current R_{ohm0} part of the electrical resistance R_{ohm} , Ω ACalternative current R_{ohm1} FC internal resistance, Ω MPPTmaximum power point tracking U_{cell} cell terminal voltage, VBBDCbuck-boost bidirectional converter I_{ry} reversible cell voltage, VBBDCbuck-boost bidirectional converter I_{ry} electrolyzer parameters for the ohmic resistances $P-V$ power and voltage characteristic k_{Eleck} area of the cell electrode, m ² DCdirect torque control I_{elect} electrolyzer current, ASOC, SOC_{max} , SOC_{min} battery state of charge with its $T_{electrolyzer current}$, ASOC, SOC_{max} , SOC_{min} battery state of charge with its $I_{electrolyzer current}$, Amaximum and minimum value P_{L-AC} , P_{L-DC} variable AC and DC load powers respectively, WPIDproportional, integral and derivative controller	E _{Nernst} nernst voltage, thermodynamic potential of the	PFM proton exchange membrane
$ \begin{array}{cccc} F_{Act} & \operatorname{activation voltage drop, V} & FC & \operatorname{Ider Cell} \\ F_{Con} & \operatorname{concentration voltage drop, V} & BB & \operatorname{battery bank} \\ F_{Conm} & \operatorname{ohmic voltage drop, V} & RES & \operatorname{renewable energy source} \\ F_{Ohm} & \operatorname{ohmic voltage drop, V} & RES & \operatorname{renewable energy source} \\ F_{C} & \operatorname{fuel cell temperature, °C} & FS & \operatorname{energy storage system} \\ F_{C} & \operatorname{fuel cell temperature, °C} & HESS & hybrid energy storage system \\ F_{Ohm0} & \operatorname{part of the electrical resistance R_{ohm}, \Omega} & DC & \operatorname{direct current} \\ R_{ohm0} & FC & \operatorname{internal resistance, \Omega} & DC & \operatorname{direct current} \\ R_{ohm1} & FC & \operatorname{internal resistance, \Omega} & MPPT & \operatorname{maximum power point tracking} \\ U_{cell} & \operatorname{cell terminal voltage, V} & BBDC & \operatorname{buck-boost bidirectional converter} \\ U_{rev} & \operatorname{reversible cell voltage, V} & BBDC & \operatorname{buck-boost bidirectional converter} \\ I_{1}, I_{2} & \operatorname{electrolyzer parameters for the ohmic resistances} \\ k_{Elec}, k_{T1}, k_{T2}, k_{T3} & \operatorname{electrolyzer parameters for the ohmic resistances} \\ V_{cell} & \operatorname{area of the cell electrode, m}^{2} & FLC & \operatorname{fuzzy logic control} \\ I_{Flect} & \operatorname{electrolyzer current, A} & DTRPC & \operatorname{direct torque and reactive power control} \\ I_{elect} & \operatorname{electrolyzer current, A} & DTRPC & \operatorname{direct torque and minimum value} \\ T_{1} & \operatorname{electrolyzer current, A} & DTRPC & \operatorname{direct torque and minimum value} \\ F_{1} & \operatorname{proportional and integral controller} \\ F_{1} & \operatorname{proportional and integral and derivative controller} \\ F_{1} & \operatorname{proportional and integral and derivative controller} \\ F_{2} & \operatorname{proportional and integral and derivative controller} \\ F_{2} & \operatorname{proportional and integral and derivative controller} \\ F_{2} & \operatorname{proportional and integral and derivative controller} \\ F_{2} & \operatorname{proportional and integral and derivative controller} \\ F_{2} & \operatorname{proportional and integral and derivative controller} \\ F_{3} & \operatorname{proportional and integral and derivative controller} \\ F_{3} & \operatorname{proportional and integral and derivative controller} \\ F_{3} & proportional and integral and derivative contr$	cell, V	FC fuel cell
$ \begin{array}{cccc} E_{Con} & \mbox{concentration voltage drop, V} & \mbox{RES} & \mbox{renewable energy source} \\ E_{Ohm,} & \mbox{ohmic voltage drop, V} & \mbox{RES} & \mbox{renewable energy source} \\ F_{Co} & \mbox{fuel cell temperature, °C} & \mbox{ESS} & \mbox{energy storage system} & \mbox{HESS} & \mbox{hybrid energy storage system} & \mbox{HESS} & \mbox{hybrid energy storage system} & \mbox{DC} & \mbox{direct current} & \mbox{HC} & \mbox{direct current} & \mbox{AC} & \mbox{alternative current} & \mbox{AC} & \mbox{alternative current} & \mbox{AC} & \mbox{alternative current} & \mbox{MPT} & \mbox{maximum power point tracking} & \mbox{HESS} & \mbox{hybrid energy storage system} & \mbox{direct current} & \mbox{AC} & \mbox{alternative current} & \mbox{MPT} & \mbox{maximum power point tracking} & \mbox{HE} & \mbox{directional converter} & \mbox{HE} & \mbox{HE} & \mbox{directional converter} & d$	E _{Act} activation voltage drop, V	BB battery bank
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	E _{Con} concentration voltage drop, V	RFS renewable energy source
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	E _{Ohm,} ohmic voltage drop, V	FSS energy storage system
a, bFC constantsIndex </td <td>T_{FC} fuel cell temperature, °C</td> <td>HESS hybrid energy storage system</td>	T _{FC} fuel cell temperature, °C	HESS hybrid energy storage system
Rohmopart of the electrical resistance Rohm, ΩDetermineRohm1FC internal resistance, ΩACalternative currentU_cellcell terminal voltage, VMPPTmaximum power point trackingU_revreversible cell voltage, VBBDCbuck-boost bidirectional converterI_r, r_2electrolyzer parameters for the ohmic resistancesF–Vpower and voltage characteristickElect, kT1, kT2, kT3electrolyzer parameters for the overvoltageDTCdirect torque controlAElectarea of the cell electrode, m²DTCdirect torque and reactive power controlIElectelectrolyzer current, ADTRPCdirect torque and reactive power controlTelectrolyzer cell temperature, °CSOC, SOC _{max} , SOC _{min} battery state of charge with its maximum and minimum valuePL _ AC, PL _ DCvariable AC and DC load powers respectively, WPI	a, b FC constants	DC direct current
R_{ohm1} FC internal resistance, Ω Internative current U_{cell} cell terminal voltage, VMPPTmaximum power point tracking U_{rev} reversible cell voltage, VBBDCbuck-boost bidirectional converter r_1, r_2 electrolyzer parameters for the ohmic resistances $BBDC$ buck-boost bidirectional converter $k_{Elec}, k_{T1}, k_{T2}, k_{T3}$ electrolyzer parameters for the ohmic resistances $P-V$ power and voltage characteristic k_{Elect} area of the cell electrode, m ² DTCdirect torque control I_{Elect} electrolyzer current, ADTRPCdirect torque and reactive power control T electrolyzer cell temperature, °CSOC, SOC _{max} , SOC _{min} battery state of charge with its maximum and minimum value $P_{L - AC}, P_{L - DC}$ variable AC and DC load powers respectively, WPIproportional and integral controller PID proportional, integral and derivative control	R_{ohm0} part of the electrical resistance R_{ohm} , Ω	AC alternative current
Ucellcell terminal voltage, VInternation power point detailingUrevreversible cell voltage, VBBDCbuck-boost bidirectional converterr1, r2electrolyzer parameters for the ohmic resistancesBBDCbuck-boost bidirectional converterkElec, kT1, kT2, kT3electrolyzer parameters for the ohmic resistancesI-Vcurrent and voltage characteristicAElectarea of the cell electrode, m²DTCdirect torque controlIElectelectrolyzer current, ADTRPCdirect torque and reactive power controlSOC, SOC <max, soc<="" soc<max,="" td="">maximum and minimum valuePL _ AG, PL _ DCvariable AC and DC load powers respectively, WPIproportional and integral controller</max,>	R_{ohm1} FC internal resistance, Ω	MPPT maximum power point tracking
U_{rev} reversible cell voltage, V DBC $Data transfer to our output to the total control to total control to to to the total control to total control total control total control total contr$	U _{cell} cell terminal voltage, V	BBDC buck-boost bidirectional converter
r1, r2electrolyzer parameters for the ohmic resistanceskElec, kT1, kT2, kT3electrolyzer parameters for the overvoltageAElectarea of the cell electrode, m2IElectelectrolyzer current, ATelectrolyzer cell temperature, °CPs, PrDFIG stator and rotor powers respectively, WPL - AG, PL - DCvariable AC and DC load powers respectively, W	U _{rev} reversible cell voltage, V	I–V current and voltage characteristic
k _{Elec} , k _{T1} , k _{T2} , k _{T3} electrolyzer parameters for the overvoltageDTCdirect torque controlA _{Elect} area of the cell electrode, m²DTCdirect torque controlI _{Elect} electrolyzer current, ADTRPCdirect torque and reactive power controlTelectrolyzer cell temperature, °CSOC, SOC _{max} , SOC _{min} battery state of charge with its maximum and minimum valueP _s , P _r DFIG stator and rotor powers respectively, WPIproportional and integral controllerPL - AC, P _{L - DC} variable AC and DC load powers respectively, WPIproportional and integral controller	r_1, r_2 electrolyzer parameters for the ohmic resistances	P–V power and voltage characteristic
AElectarea of the cell electrode, m²FLCfuzzy logic controlIElectelectrolyzer current, ADTRPCdirect torque and reactive power controlTelectrolyzer cell temperature, °CSOC, SOC _{max} , SOC _{min} battery state of charge with its maximum and minimum valuePs, PrDFIG stator and rotor powers respectively, WPIproportional and integral controllerPL - AC, PL - DCvariable AC and DC load powers respectively, WPIproportional and integral controller	k_{Elec} , k_{T1} , k_{T2} , k_{T3} electrolyzer parameters for the	DTC direct torque control
A _{Elect} area of the cell electrode, m2DTRPCdirect torque and reactive power controlI _{Elect} electrolyzer current, ADTRPCdirect torque and reactive power controlTelectrolyzer cell temperature, °CSOC, SOC _{max} , SOC _{min} battery state of charge with its maximum and minimum valueP _s , P _r DFIG stator and rotor powers respectively, WPIproportional and integral controllerP _{L - AC} , P _{L - DC} variable AC and DC load powers respectively, WPIproportional and integral and derivative controller	overvoltage	FLC fuzzy logic control
IElectelectrolyzer current, ASOC, SOC <max, socmin<="" th="">battery state of charge with its maximum and minimum valueTelectrolyzer cell temperature, °CSOC, SOC<max, socmin<="" td="">battery state of charge with its maximum and minimum valuePs, PrDFIG stator and rotor powers respectively, WPL - AG, PL - DCvariable AC and DC load powers respectively, WPIPIDproportional and integral controller</max,></max,>	A_{Elect} area of the cell electrode, m ²	DTRPC direct torque and reactive power control
P Ps, Pr DFIG stator and rotor powers respectively, W PI proportional and integral controller PL - AG, PL - DC variable AC and DC load powers respectively, W PI proportional and integral and derivative controller	I _{Elect} electrolyzer current, A	SOC, SOC _{max} , SOC _{min} battery state of charge with its
Ps, PrDFIG stator and rotor powers respectively, WPIproportional and integral controllerPL - AC, PL - DCvariable AC and DC load powers respectively, WPIproportional and integral controller	1 electrolyzer cell temperature, °C	maximum and minimum value
PL - AC, PL - DC Variable AC and DC load powers PID proportional, integral and derivative controller respectively, W PID proportional, integral and derivative controller	P_s, P_r DFIG stator and rotor powers respectively, W	PI proportional and integral controller
respectively, W	$P_{L - AC}$, $P_{L - DC}$ variable AC and DC load powers	PID proportional, integral and derivative controller
	respectively, W	

high power density, and at the same time it must have a high energy density to give autonomy for micro-grid. For these reasons, it is necessary to associate more than one storage technology creating a Hybrid Energy Storage System (HESS) [4–6]. The ESS as BBs are very important for an efficient and economical utilization of these hybrid systems [3], but the charge and discharge cycles decrease the lifetime of batteries [6-8]. To improve the energy supply reliability of WT and PV

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