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DISTRIBUTED GENERATION SYSTEM BASED ON RENEWABLE ENERGY SOURCES – CASE STUDY

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ABSTRACT

Distributed generation (DG) based on Renewable Energy Sources (RES) has been increased in the last decade and penetrated the energy generation markets due to the huge rising up in energy consumption, environmental issues as well as due to the predicted depletion of the conventional energy sources. DG system uses disbursed generators near load sites, while traditional centralized generation units normally located far away from the loads.

This paper defines and introduces various combinations of DG systems based on RES and storage devices. The suitable application of each combination is addressed.

A case study to electrify a typical household in Italy using standalone hybrid system based on wind energy conversion system (WECS), photovoltaic energy conversion system (PVECS) and battery energy storage system (BESS) is presented to contribute in further understanding of DG systems.

This paper discusses the general issues of the system and introducing the simulation results without going into specific details of modelling and control strategies. The case study depends on real winter weather data collected in CNR/ITAE-Italy/Messina and on a designed winter household profile for Italy.

The simulation results of the case study are discussed. It shows the effectiveness of the proposed DG system in which the power flow among the different energy sources, storage battery energy system and the load demand is balanced successfully.

Keywords: Distribution Generation (DG), wind energy conversion system (WECS), photovoltaic energy conversion system (PVECS), Battery Energy Storage System (BESS).

1 INTRODUCTION

Increasing the interest in DG sources based on green energies are considered one of the solutions to reduce the dilemma of the world energy problem and global warming. The DG can be defined as a generating units scaled from kW to MW located near the load sites.

Standalone PVECS and WECS don't produce usable energy for considerable portion of time during the year. This is mainly due to dependence on variable sunshine hours in case of PVECS, and on relatively high cut-in wind speeds, which ranges from 3.5 to 4.5 m/s, in case of WECS (Elhadidy and Shaahid, 2004).

The above reasons and motivations and others such as power system deregulation and the shortage of transmission capacities have led to increased interest in DG sources based on green energies.

Many combinations of clean and renewable DGs technologies and storage devices can be built to form a standalone or grid-connected hybrid system. The common combinations is shown in Figure 1.

[Figure 1 here]

Standalone WECS/PVECS/Storage System : A great concern should be given to storage system in this combination in order fill the energy deficiency gap in case of reduction in power generation as well as to store the surplus energy in case of the generation exceeds the load requirements. There are many types of storage systems that can be installed:

- BESS: The high round trip efficiency and the relatively lower cost, and it's faster response to the instantaneous load changing are the driving force for being the BESS is commonly used in standalone RES.

- Fuel cell (FC)/Electrolyzer Storage . The BESS is economically more feasible choice for energy storage because of the low efficiency of the FC/electrolyzer system (D.B. Nelson et al, 2006).

- FC/Electrolyzer and BESS. This combination of a long and short term storage systems like FC/Electrolyzer and BESS, respectively can significantly improve the performance of standalone RES (Agbossou et al, 2004).

WECS/PVECS/FC : The storage system is not included because the grid will fill the gap in power in case of deficiency in power generation, at the same time the hybrid system will provide the grid with the excess generated power. The H_2 fuel is supported to FC from an external source through a reformer.

PVECS/Storage system :

- PVECS/ BESS : The storage of energy generated from the PVECS for a standalone system is an important issue, in which 60% of installed PVECS all over the world use this configuration (Andreas J. et al, 2004).
- PVECS/FC/Electrolyzer : The electrolyzer can be used to generate H_2 during excess of power from PVECS, where the generated H_2 can be stored in a tank . The FC provide energy in case of lower insolation levels or at night utilizing the stored H_2 in tanks (El-shater et al, 2002).

WECS /Storage system: The wind turbine power is fluctuating as it depends on wind speed, this causes a negative impact on the system frequency. This requires a BESS to absorb the power from wind turbine generators, this method is not effective according to (T. Senjyu et al , 2005) who proposes to generate hydrogen to be a fuel of FC using aqua electrolyzer .

2 STANDALONE DG SYSTEM BASED ON WIND/PV/BESS – CASE STUDY

2.1 System Description

A technical case study was carried out in CNR/ITAE-Italy/Messina to design a standalone DG system based on WECS/PVECS/BESS for a typical home. The schematic diagram of the designed standalone hybrid system used in this case study is shown in Figure 2. A micro WECS TN1.5 (Tozzi Nord Wind,2009) of 1.5 kW capacity consists of a wind turbine driving a multi-pole permanent magnetic synchronous generator (PMSG) in which The WECS is connected to the DC bus through AC/DC rectifier. The PVECS SOLYNDRA™ (Alwita brochure,2009) of 1.88 kWp consists of 3 strings connected in parallel in which each string consists of 4 modules. The BESS is consisted of 4.6 kWh of lead acid type at terminal voltage of 96V. The DC bus collects the energy generated by the RES and supplies it through a DC/AC inverter.

[Figure 2 here]

2.2 System Modelling

The renewable wind and solar power are taken as the primary source while batteries are used as a backup and storage system. Each component in the system is modelled using MatLab SIMULINK™ and POWERSIMULINK™ environment.

Modelling of PVECS

The relationship between the current (I) and the terminal voltage (V) is given in equation (1) (H. S. Rauschenbach, 1980). This equation depends on one diode model with four parametes , in which the parallel resistance is assumed high.

$$I = I_L - I_o[exp(V + Rs\,I/V_t\,a) - 1] \qquad (1)$$

Where I_L(A) is the light current of array, I_0(A) is the diode reverse saturation current, $R_s(\Omega)$ is the equivalent series resistance of the array, V(V) is operation voltage of the array, I(A) is the operation current of the array, V_t(V) is the thermal voltage of the array : $V_t = N_s kT/q$ in which Ns is the number of cells in the panel connected in series, k is Boltzmann's constant, q is the charge of the electron, a is diode ideal constant , and T is the temperature at STC in Kelvin (K) .

Modelling of WECS : The power generated from the rotor turbine wind is given by equation (2)

$$P_t = \frac{1}{2} A_t V^3 C_p \rho a \quad (2)$$

Where P_t(W) is the wind turbine power, ρ_a(kg/m^3) is the air density, A_t(m^2) is the swept area of the turbine, V(m/s) is the wind velocity, and C_p is power coefficient. This coefficient is defined as the aerodynamic efficiency of the wind turbine as a function of tip speed ratio λ . The tip speed is defined as the ratio between the peripheral speed of the blades and the wind speed ($R\ \Omega/V$) in which Ω is the rotational speed of the blades, and R(m) is the turbine radius (D.B. Nelson et al, 2005).

The wind turbine torque on the shaft can be calculated from the wind power as in equation(3):

$$T_t = P_t/\Omega = (C_p\ \rho a\ R\quad V^2)/\lambda \quad (3)$$

The mechanical system is represented by the following equation(4):

$$\frac{d}{dt} w_r = \frac{1}{J}(T_e - F w_r - T_m) \quad (4)$$

Where ωr(rad.s^{-1}) is the angular velocity of the rotor $d\theta/dt$, θ (rad) is rotor angular position, J(kg.m^2) is the combined inertia of rotor and load, F(N.m.s.rad^{-1}) is combined viscous friction of rotor and load, T_m(N.m) is the shaft mechanical torque. The sinusoidal electrical model of PMSG in the synchronous reference frame (dq) is given in equations 5,6, and 7.

$$\frac{d}{dt} i_d = \frac{1}{L_d} v_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p w_r i_q \quad (5)$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} v_q - \frac{R}{L_q} i_q - \frac{L_d}{L_q} p w_r i_d - \frac{\lambda p w_r}{L_q} \quad (6)$$

$$T_e = 1.5\ p\ [\lambda i_q + (L_d - L_q) i_d i_q] \quad (7)$$

Where Lq, Ld (H) is q and d axis inductances, R(Ω) is the resistance of the stator windings, iq, id (A) is the q and d axis currents, Vq, Vd (V) are the q and d axis voltages, λ(Wb) is the amplitude of the flux induced by the permanent magnets of the rotor in the stator phases, p is the number of pole pairs, Te(N.m) is the electromagnetic torque.

Modelling of BESS: The battery is modelled by a constant resistance connected in series with a controlled voltage source as shown in Figure 3. A constant resistance is assumed constant during the different modes of the battery. The controlled source is described in the following equation (Tremblay et al , 2007)

[Figure 3 here]

$$E_{batt} = E_0 - K\frac{Q}{Q - it} + A\exp(-B.it) \qquad (8)$$

Where E_{batt}(V) is the no load voltage, E_0(V) is the battery constant voltage, K(V) is polarisation voltage , Q(Ah) is the battery capacity, A(V) is exponential zone amplitude, B (Ah^{-1}) is exponential zone time constant inverse.

Modelling of power electronic: The system includes step up DC/DC convertor attached with PVECS to perform maximum power point tracking (MPPT), a three phase rectifier is attached with WECS, bidirectional DC/DC convertor is attached with BESS, and finally a DC/AC single phase inverter is attached with DC bus to have AC power at the load side.

2.3 System Control

The overall control strategy indirectly manages the energy exchanges between the power generation from RES and the storage system to ensure stable DC bus voltage.

The PVECS is controlled to obtain MPPT in case of the changing in weather conditions and load profile. The perturbation and observation (P&O) method is used in this study to perform this objective, It is a compromise between the accuracy, complexity and the cost of the control system.

The mechanical power extracted from the wind through the wind turbine is controlled to achieve MPPT through a lookup table provided from the manufacturer (Tozzi Nord Wind, 2009).

The BESS plays the main role in keeping the DC bus voltage stable through a bidirectional DC/DC converter which is controlled through a special battery control algorithm.

The DC bus collects the energy generated by the RES and supplies it through a DC/AC inverter. The inverter is controlled using the PWM technique to ensure voltage sine wave signal at the load side with the required amplitude and frequency after being filtered by LC filter.

2.4 Load profile and Weather Data

The Italian cold season hourly average demand of atypical household load profile is shown in Figure 4. The load profile used in this study is designed depending on European load profiles included in reference (H. Ribberink and I. knight,2007).

[Figure 4 here]

The weather data are measured in CNR/ITAE-Italy/Messina .The wind speed, solar irradiance and air temperature data at the same site on the same day are shown in Figures 5,6 and 7, respectively.

[Figure 5 here]
[Figure 6 here]
[Figure 7 here]

2.5 The Simulation Results

The system performance under the load demand profile given in Figure 4 and the weather data shown in Figures 5 to 7 is evaluated. The output power from the WECS, PVECS in the hybrid energy system over the simulation period is shown in Figure 8 and 9, respectively.

[Figure 8 here]
[Figure 9 here]

Figure10 shows the charged and discharged energy of the BESS. In fact, different states of the battery is a good indication to energy balance in the system. The state of the BESS is govern by the following relation:

[Figure 10 here]

$$P_{net} = P_{wind} + P_{pv} - P_{load} \qquad (9)$$

If $P_{net} > 0$, this means that generated power is more than the load demand and the surplus energy should be stored in BESS, while if $P_{net} < 0$, the BESS is asked to discharge power to system as generated power is less than the load demand.

Figure 11 shows the DC bus voltage signal, which is mostly constant within the designed range (390-410)V from the control strategy. Figure 12 shows the AC voltage signal in the load side, this figure shows a sinusoidal signal with 230Vrms and 50 Hz frequency. The total harmonic distortion (THD) of the output signal is less than 1.5% and the frequency deviation from standard frequency (50Hz) is within (-0.2-0.2)Hz throughout the day.

[Figure 11 here]
[Figure 12 here]

3 CONCLUSION

The integration of hybrid system based on WECS/PVECS/BESS as a distributed generation systems is not a new technology, but the details govern the operation of this system are the research issues that are the subject of this research .

Simulation study has been performed to verify the system performance using real weather data collected at CNR/ITAE-Italy/Messina and practical load profile designed by the author depending on different studies on the daily load profiles of different European countries.

The simulation results show the effectiveness of the local and global control strategies in which the power flow among the different energy sources, storage battery energy system and the load demand is balanced successfully.

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Figures

Figure1: Common DGs combinations based on RES

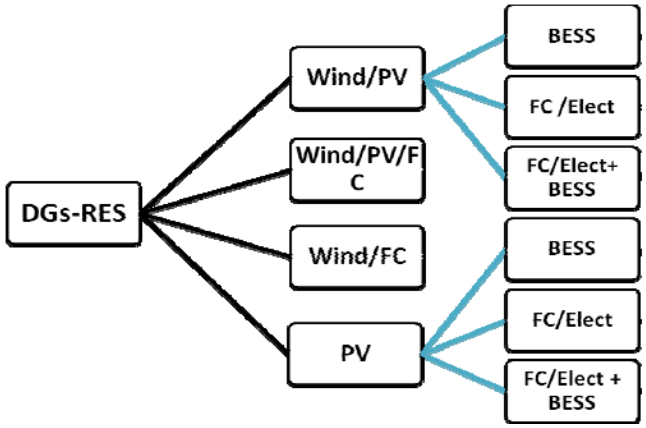


Figure 2: schematic diagram of standalone WECS/PVECS/BESS hybrid system

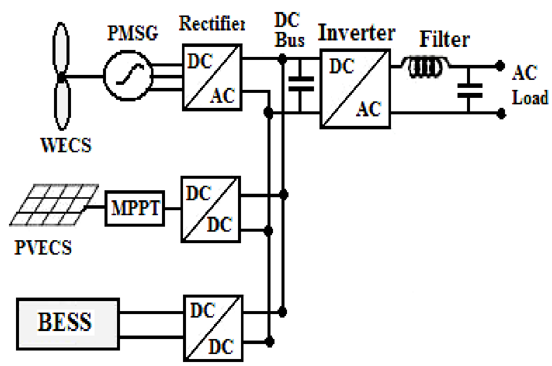
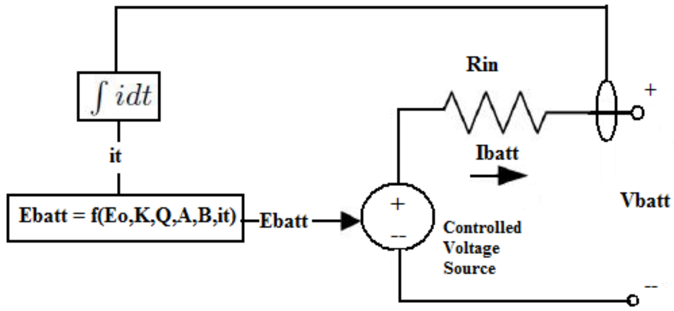


Figure 3 : Equivalent circuit of the Battery



Source: Tremblay et al , 2007

Figure 4: The hourly average demand of a typical household load in Italy

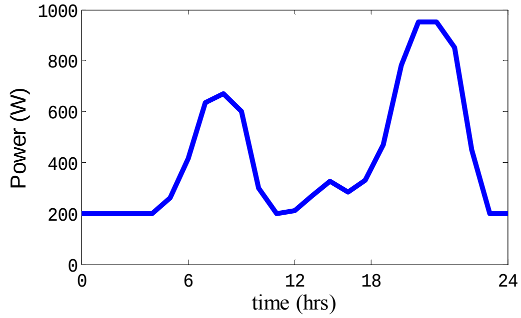


Figure 5: Wind data of winter day in December

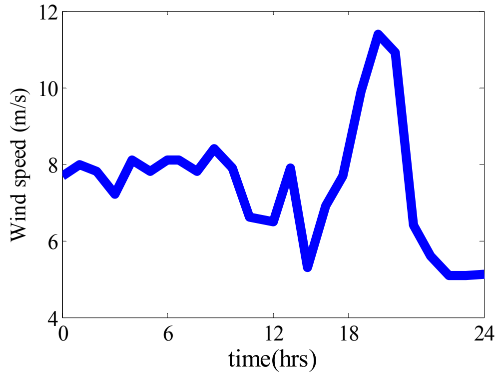


Figure 6: Irradiance data of winter day in December

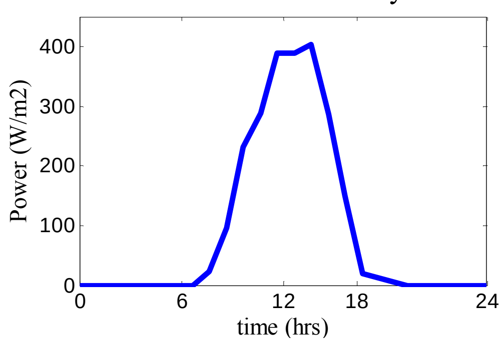


Figure 7: Temperature data of winter day in December

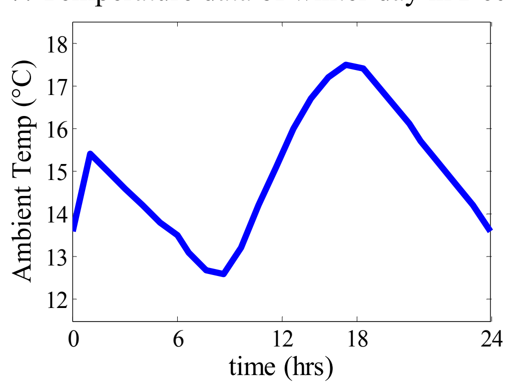


Figure 8: Output power from WECS

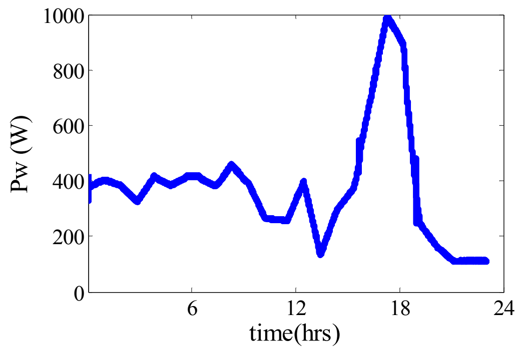


Figure 9: Output power from PVECS

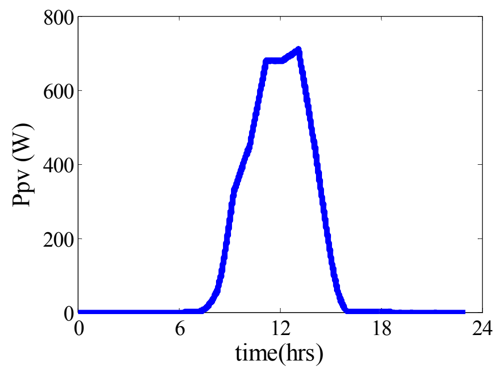


Figure 10: BESS charging and discharging modes

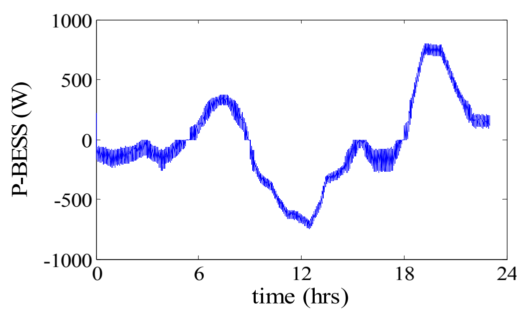


Figure 11: DC bus voltage

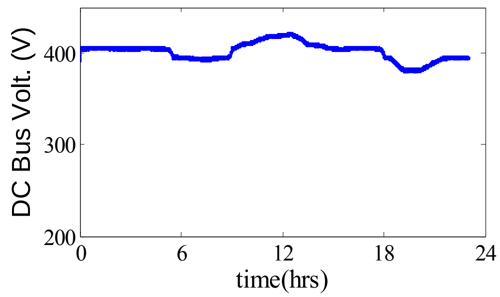


Figure 12: AC output power signal in the load side with power quality indications